Date: October 10, 2023

Memorandum

MIAMI-DADE COUNTY

To: Honorable Chairman Oliver G. Gilbert, III
and Members, Board of County Commissioners

From: Daniella Levine Cava
Mayor

Daniella Levine Cava

Subject: "Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida" Report, Resolution R-423-2022

Executive Summary

On May 3, 2022, the Board of County Commissioners (Board) adopted Resolution No. R-423-22 authorizing execution of an Interlocal Agreement (ILA) between Miami-Dade County and the University of Florida (UF) to conduct a study and prepare a report that:

- provides an overview of agriculture in Miami-Dade County;
- documents the importance of agriculture to Miami-Dade County and beyond;
- documents economic trends associated with major agriculture crops;
- identifies major factors affecting the profitability and sustainability of agriculture;
- identifies and evaluates emerging technological changes that may help or harm agriculture;
- provides recommendations to improve the economic sustainability of agriculture; and
- projects future agricultural land use needs in the years 2030, 2040, and 2050.

The attached report, "Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida" (The Study), finds that we are approaching a critical point with respect to the amount of agricultural land needed to sustain a viable industry.

Miami-Dade County is one of very few areas in the United States with year-round growing conditions enabling production of fruits and vegetables in the winter and production of certain ornamental plants and tropical crops. About 89 percent of the County's agricultural products are shipped out of the region to markets in the northeast and central U.S. and Canada, bringing new dollars into our economy that stimulate local economic activity. Our agricultural area is designated by the United States Department of Agriculture (USDA) as having soils of unique importance, meaning that they are capable of sustainably producing high value crops under appropriate management. Miami-Dade ranks first in the U.S. in production of ornamental plants and second in Florida in overall farm production value. In 2021, economic contributions of agriculture and related industries included 12,836 full-time and part-time jobs and $1.6 billion in industry output or sales revenues.

The Study estimates that a minimum of 64,800 acres will be needed in 2030, 60,900 acres will be needed in 2040, and 56,300 acres will be needed in 2050 to maintain an economically viable agricultural industry in Miami-Dade. The County had 58,606 acres Classified as agriculture for tax exemption purposes (Agriculture Classified) by the Property Appraiser in 2017 (the year of the most recent Census of Agriculture) then representing 74.6 percent of the total 78,543 acres identified as agriculture land in the Census, which also includes land not eligible for tax exemption and land where the owner did not request the exemption. As of September 2023, the County had a total of 52,630 acres of Agriculture Classified lands. Based on prior Census reports and available Property Appraiser data, approximately three-quarters (75%) of the Census of Agriculture-identified agriculture land area is Agriculture Classified by the Property Appraiser, which infers that about 69,844 acres of agricultural lands are in the County as of September 2023, based on the current 52,630 acres of agriculture classified lands.[1] **This represents a reduction of over 10% in total agricultural**

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[1] Within the Census of Agriculture-identified agricultural lands, non-commercial pastures, environmentally protected areas within farms, farm residences and farmworker housing, landscaped areas surrounding farms, etc. are examples of land uses that do not qualify for the Property Appraiser's Agriculture Classification, which substantially accounts for why Agriculture Classified lands

land (as defined by the Census) over the last 6 years. *If this trend continues over the next few years, the County will be below the projected minimum acreage estimate of 64,800 needed by the year 2030.*

For reference, the Comprehensive Master Development Plan (CDMP) adopted 2030 and 2040 Land Use Plan map designates a total roughly 69,072 acres for the future land use category of "Agriculture", including 1,183 acres inside the Urban Development Boundary (UDB) in "Horse Country" and 67,889 acres outside the UDB. This number does not include the approximate 400 acres pending removal from designation for the Aligned application. It is worthwhile to note that there are multiple existing farms and agricultural operations currently inside the UDB on lands that are not designated "Agriculture" by the CDMP but that are instead designated for urban development.

The Study further makes a series of recommendations to improve the viability and sustainability of agriculture, summarized below, including maintaining CDMP policies to protect farmland, limiting expansions of the UDB to Urban Expansion Areas when warranted after the year 2030 or to areas unsuitable for agriculture or environmental protection, and taking steps to support and promote agriculture through lobbying for state land policies, enabling urban farming in developed areas, carefully managing agritourism, and more.

Methodology

The Study examined available data as well as information about emerging technologies with the intention to help shape policy needed to maintain the County's viable agriculture and help the agricultural industry to prosper. The Study also made extensive use of industry-leading modeling techniques to forecast future conditions. Additional research included interviews with 74 industry stakeholders and four focus groups.

Relationship to the Comprehensive Development Master Plan (CDMP)

Miami-Dade County has long supported agriculture as a viable economic use of suitable lands through the CDMP. Specifically, CDMP Policy LU-1R states, in part, that the County shall take steps to reserve the amount of land necessary to maintain an economically viable agricultural industry. Policy LU-1S lists protection of viable agriculture and environmentally sensitive land as a key outcome for the Miami-Dade County Strategic Plan. Furthermore, Policy LU-8C states: "through its planning, capital improvements, cooperative extension, economic development, regulatory and intergovernmental coordination activities, Miami-Dade County shall continue to protect and promote agriculture as a viable economic use of land in Miami-Dade."

The CDMP Interpretive Text for Agriculture (page I-70 of the Land Use Element) explains that the area of the County designated as "Agriculture" contains the best agricultural land remaining in Miami-Dade County while providing that land uses incompatible with agriculture and uses and facilities that support or encourage urban development are not allowed in the agricultural area.

Study Findings and Recommendations

The study describes the agriculture industry, forecasts its future conditions, and makes recommendations towards maintaining a viable agricultural industry. Highlights of the forecasts and recommendations are outlined below.

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historically represent 75% of the total agriculture lands. To obtain the Agriculture Classification, a property owner needs to voluntarily apply and provide evidence that the property in question, or a portion of that property, is specifically engaged in commercial agricultural production.

Needed Agriculture Land Area Forecasts

The Study used a combination of statistical and economic models to project the future land area that is needed to ensure adequate amounts of farmland for a viable agriculture industry. This resulted in a consensus estimate that 64,800 acres will be needed in 2030, 60,900 acres will be needed in 2040, and 56,300 acres will be needed in 2050. These projections represent the minimum acreage required to meet demand for agricultural production, including farmland and uses directly supportive of agriculture, without compromising the viability of the industry.

According to the 2017 USDA Census of Agriculture, The County had 78,543 acres (both inside and outside the UDB), including cropland for vegetables (38%), nursery-floriculture (35%), and fruit orchards (27%), as well as farm buildings and other supporting service areas. From 1997 through 2017, total farmland area decreased by 6.2 percent – but 10% over just the last 6 years. Agriculture land has declined throughout the County's history, from 120,00 acres across Miami-Dade in 1959.

Loss of farmland is a national and a local issue. From 2001 to 2016 over 11 million acres of farm and ranchland throughout the United States were lost to development, including 299,000 acres in Florida, representing 3.4 percent of the State's total farmland. Significantly, Miami-Dade County has had the lowest percentage of agricultural land loss among the ten largest metropolitan counties in the nation, except for Kings County/Brooklyn, NY, which has no discernable agriculture. Between 1997 and 2017, while the County lost 6.2% of its farmland, other large metropolitan counties had losses of 29.7 to 71.8 percent. This finding indicates that the County's land use policies, including the Urban Development Boundary (UDB), have been effective in limiting the loss of agricultural land as compared with peer counties around the nation.

When farmland is converted to development, it is nearly impossible to return it back to agriculture. Loss of the agriculture area's soils of unique importance would negatively impact agricultural industry viability. The forecasted amounts needed for agriculture for the years 2030, 2040, and 2050 are necessary for a viable agricultural industry in Miami-Dade County and to maintain one of the few tropical farming areas within the United States. The Study provides guidance for various policies that can be developed to ensure that agriculture remains viable and that tropical agriculture continues to exist in the continental United States.

Recommendations to Improve the Economic Sustainability of Agriculture

The Study recommends that the County maintain the CDMP policies to protect farmland, and that future expansions of the UDB be limited to Urban Expansion Areas or to areas unsuitable for agriculture or environmental protection because of soil types or environmental factors. It also recommends that the County focus agricultural lobbying efforts on the promotion of state land policies, national trade policies, and immigration and guest worker policies to support reduced production costs, agriculture trade, and a viable workforce. The County is also encouraged to continue to work with agriculture-related local institutions to support education, technology development, marketing, succession planning, and risk management for the industry. Coordination with environmental agencies is also important to protect farmland from sea level rise and saltwater intrusion. The Study also recommends further enabling urban farming in developed areas, promotion and marketing of local agriculture products in the County, and carefully managing agritourism. Land use policies to further facilitate development of agricultural worker housing would improve workforce availability.

In accordance with Ordinance No. 14-65, this report will be placed on the next available Board meeting agenda. If additional information is needed, please contact Lourdes Gomez, Director, Department of Regulatory & Economic Resources.

Attachment

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Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida

Final Report

Prepared for Miami-Dade County Board of County Commissioners and Department of Regulatory and Economic Resources

Prepared by University of Florida-Institute of Food and Agricultural Sciences (UF/IFAS)
Food and Resource Economics Department, Gainesville, FL
Tropical Research and Education Center, Homestead, FL
Southwest Florida Research and Education Center, Immokalee, FL
September 29, 2023

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Executive Summary of Final Report: Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida

Prepared for Miami-Dade County Board of County Commissioners and Department of Regulatory and Economic Resources

By The University of Florida-Institute of Food and Agricultural Sciences, Food and Resource Economics Department, Tropical Research and Education Center, and Southwest Florida Research and Education Center

September 29, 2023

Study Scope and Methods. This study assessed the current situation, trends, threats, and the long-term economic outlook for agriculture in Miami-Dade County, Florida. It also projected future agricultural land needs to maintain a viable industry in years 2030, 2040 and 2050. Investigators used a wide variety of published data sources, individual and group interviews with local stakeholders, and economic and physical models. The study updates a previous economic and land use assessment conducted in 2001-2002. Information was compiled on County population and demographics; the local economy; number of farms, farm sales, employment, and worker earnings; farm operating income, expenses, net income, and return on assets; regional economic contributions; agricultural land use and farmland loss; the emerging aquaculture industry; local and direct marketing and agritourism. A previous study that surveyed County residents regarding willingness to pay for protection of agricultural lands was also summarized. Potential threats confronting the agricultural industry addressed in the report include climate change and sea level rise, import competition, increasing production costs, invasive pests and diseases, water supply, workforce availability, urban development, weather hazards, market disruptions, financial risk, and government policies. Climate, sea level and groundwater models were used to predict the effects of sea level rise on groundwater levels and quality. The profitability and risk of representative agricultural commodities were evaluated with budget data. Emerging agricultural technologies for specialty crop production were considered for their potential to reduce labor, increase efficiency, and improve management and profitability. A regional economic model (IMPLAN) for the County was used to estimate the current economic contributions of agriculture arising from interactions with other industry sectors and employee households. A separate economic model (REMI) was used to forecast the economic impacts of projected population growth to the year 2050 and assess the effects of various positive and negative scenarios for the agricultural industry in the future. Agricultural land use in the County was projected for the years 2030, 2040, and 2050 using various statistical and economic models.


Aerial view of farmland in Miami-Dade County, showing the patchwork of different types of nurseries, tropical fruit orchards, and field crops. Source: Miami-Dade County.

Description of the County. Miami-Dade County is very diverse, with over 50 percent of the population being foreign-born, 75 percent speaking languages other than English at home, and nearly 70 percent identifying as Hispanic/Latinx, with a strong social and cultural identity around immigrant communities from Latin America and the Caribbean. The local economy is a mix of basic and service industries, including agriculture, construction, real estate, transportation, and travel/tourism. The County is a major commercial center for global trade and a destination for domestic and international tourism. The economy continues to grow significantly faster than the rest of the United States in terms of population, employment, and Gross Domestic Product (GDP). Population is projected to grow from around 2.66 million currently to 3.29 million in 2050.

The County has strong land use planning policies to manage urban development and conserve farmland and open space through the Urban Development Boundary and other planning policies, which concentrate housing and non-agricultural commercial activity in urban areas. These policies have resulted in the lowest percentage of farmland loss among the ten largest U.S. metropolitan counties during 1997-2017.

Topic 1 -- Overview of Agriculture. Miami-Dade County has a long history of agriculture dating back to the late 1800s. It is one of only a few areas in the United States with an extremely mild subtropical winter climate and year-round growing conditions for production of fruits and vegetables for the wintertime market, along with production of ornamental plants and tropical crops not otherwise domestically available. About 89 percent of County agricultural products are shipped out of the region to markets in the northeast and central U.S. and Canada, bringing new dollars into the local economy that stimulate additional economic activity. A large area of the County is designated as having soils of unique importance for agriculture in the state, meaning that they are capable of sustainably producing high value crops under appropriate management.

Historic photo of papaya grove in Miami-Dade County. Source: University of Florida-IFAS, Smathers Archives.

According to the 2017 USDA Census of Agriculture, the County had 2,752 farms, total farm sales of $830 million, 78,543 acres of farmland, and $3.25 billion in farm assets. Farmland acreage has slowly declined from over 120,00 acres in 1959. The primary agricultural products are nursery/floriculture plants (83% of total value), vegetables (11%), and tropical fruits (5%). The County is ranked first in the U.S. in production of ornamental plants, and second in the State of Florida in terms of overall farm production value. The agricultural industry is increasingly concentrated in the nursery/floriculture sector. Nursery/floriculture is closely allied with the landscape services industry to maintain the lush, tropical appearance of the area that attracts visitors to the County. Livestock and animal products are a relatively small part of agriculture currently, but development of a large salmon aquaculture facility could be a significant economic contributor in the future. Intensive recirculating aquaculture systems land area requirements would not materially affect the overall demand for land.

In 2021, farm income in the County from product sales, inventory growth, government payments, and other non-operating income sources was $950 million, with production expenses of $905 million, and net farm income of $45.6 million, representing an operating margin of 4.8 percent (U.S. Department of Commerce, Bureau of Economic Analysis). Farm operating margins historically averaged around 30 percent, but reduced profits in 2021 were due to lower revenues and significantly higher production expenses, associated with the Covid-19 pandemic. The rate of return on farm assets calculated from various sources was 7.7 percent in 2017. In 2021, employment in agriculture and related sectors averaged 8,872 full-time and part-time jobs, representing an increase of 6.6 percent since 2001. Total salaries and wages paid to agriculture workers was $302 million in 2021, an increase of 47 percent since 2001 in inflation-adjusted terms (U.S. Bureau of Labor Statistics).

Topic 2 -- Importance of Agriculture. Total economic contributions of agriculture and related natural resource industries in the County in 2021 were 12,836 full-time and part-time jobs, $1.555 billion in industry output or sales revenues, $902 million in value added (GDP), and $183 million in local, state, and federal government tax revenues. Economic contributions included activity generated in other sectors through supply chain spending (indirect multiplier effects) and employee household spending (induced multiplier effects) estimated by the IMPLAN regional economic model. GDP contributions of agriculture increased 14 percent during 1998-2021. Agricultural sales have increased in inflation-adjusted terms, but the industry now represents a smaller share of employment and GDP in the local economy than in 2001 due to rapid growth in other sectors and urbanization of the County.

Topic 3 -- Trends in the Agricultural Industry. Nursery/floriculture production in the County has expanded rapidly over the past 20 years, while tropical fruits have increased slightly, and vegetables have declined significantly. Agricultural industry production and investment in the County is expected to continue increasing in the future, although at rates less than historically seen, due to market forces and other factors. Agricultural land use intensity will also continue increasing due to adoption of improved technology, improved management and production practices, and changes in crop mix, leading to higher value per acre and lower land requirements per unit of production. Profitability of agriculture is highly volatile and appears to be slowly declining due to increasing production costs and stable or declining product prices in inflation-adjusted terms.

Photo of ornamental bromeliad plants growing in a nursery shade house in Miami-Dade County. Source: University of Florida-IFAS.

Agritourism in the County has rapidly grown, capitalizing on the unique agricultural systems and large numbers of domestic and international visitors seeking nature-based experiences; however, no documented data is available on overall value. Additionally, local food systems can be significantly more developed to take advantage of the abundance of fresh produce and support regional food security.

Interviews and focus groups with over 70 stakeholders revealed optimism about the future of the nursery/floriculture industry which has shown robust growth, but pessimism about the fruit and vegetable industries that are threatened by import competition, rising production costs, and labor issues. Stakeholders foresee a future with many smaller farm operations producing more specialized crops. Many stakeholders expressed frustration that there is a lack of awareness and support for agriculture in the County, and indicated that myriad overlapping local, state, and federal regulations hamper profitability and competitiveness.

Topic 4 -- Factors Affecting Profitability and Sustainability of Agriculture. Among threats to agriculture in the County, specialty crop industries are challenged by pests and diseases, import competition, increasing production costs, and high debt loads that present financial risk from changes in market interest rates and macroeconomic conditions. Imported agricultural products, particularly from Mexico, reduce domestic prices and pose a dire threat to the U.S. fruit and vegetable industries. Phytosanitary regulations prohibiting import of live plants in soil media effectively protect domestic nursery producers from foreign competition, which is one reason that this industry has thrived.

Agricultural production costs in the County increased 42 percent during 2001-2021 in inflation-adjusted terms, exceeding overall growth in the U.S. economy. The combined effect of rising costs and declining farmland acreage increased the average expense per acre by 63 percent between 2012 and 2017. Increasing costs for agriculture in the County are comparable to U.S. agriculture generally.

Public groundwater withdrawals in the County are declining in total quantity and per capita, and water demand for agricultural irrigation is projected to decline in the future due to improvements in water use efficiency. Saltwater intrusion into the Biscayne Aquifer will accelerate due to rising sea levels, especially in coastal areas of the County.

Workforce availability for agriculture is complicated by low compensation rates, difficult working conditions, high cost of living, and lack of affordable housing. Nearly one half of agricultural workers in the U.S. are undocumented immigrants, according to farm worker surveys. Use of foreign workers under the H-2A Temporary Agricultural Workers visa program has remained relatively low in the County due to higher wage rates and requirements to provide worker housing and transportation; however, it is likely that agricultural producers will increase their use of H-2A workers to meet needs in the future. Labor markets in Florida are very uncertain because of recent state policy changes to enforce federal immigration law.

The County frequently experiences hurricanes, tropical storms, and other severe weather events that can disrupt the agricultural industry, in some cases for years. Hurricane Andrew in 1992 caused significant losses of agricultural products and infrastructure, and led to massive recovery, reinvestment, and rebuilding in the County. Projections show that even higher losses would occur today if a Category 5 hurricane struck the County, because of the more intensive production systems and structures at risk.

Global climate models downscaled to 35 local weather stations predict that average temperatures in the County will increase 1.5 to 1.8 degrees Celsius (2.7 to 3.2 degrees Fahrenheit) by the year 2050, and precipitation will be more variable, with more frequent droughts and flooding, although there is no discernable trend in overall annual amounts. The increase in temperatures could lead to loss of the County's comparative advantage for production of subtropical crops as other areas of Florida and the U.S. become suitable for these crops; however, the County may become more suitable for other truly tropical crops. Sea level rise will elevate groundwater levels and cause more seasonal flooding of agricultural lands, leading to increased losses of field crops and perennial orchards; however, nursery plants in above-ground benches and containers may not be as affected. In addition, seawater intrusion into the Biscayne aquifer may render groundwater unusable for irrigation in areas near the coast, although it is not expected to impact the agricultural areas located farther from the coast until after the year 2100.

Photo of unmanned aerial vehicle equipped with multispectral camera for assessing crop conditions, pests and diseases. (Source: Ioannis Ampitzidis, University of Florida).

Topic 5 -- Agricultural Technology. Emerging agricultural technologies – such as artificial intelligence, smart sensors, robotics, mechanical harvesters, and whole farm information systems – may help reduce product losses, reduce labor and chemical requirements, and control input costs; however, capital costs, efficiency improvements, and farmer adoption rates over the next 5 to 30 years are uncertain, especially for the numerous small farms with limited capital. Greenhouse hydroponic and vertical growing systems have potential to dramatically increase production per unit area and avoid pest pressures, but production and capital costs are high and the potential for increasing capacity is unknown.

Topic 6 -- Estimate Minimum Acreage Required to Maintain a Viable Agricultural Industry. A combination of various statistical and economic models was used to project the future agricultural land area needed in the County, resulting in a consensus estimate of 64,800 acres in 2030, 60,900 acres in 2040, and 56,300 acres in 2050. These projections represent the minimum acreage required to meet demand for farmland without compromising the viability of the industry under current or future land use policies. A forecast for the County using the REMI regional economic model and projected population growth indicates strong growth for the overall economy and the agricultural sector through the year 2050. A "most-likely scenario" for agriculture indicates that import competition, loss of farmland to the urban area, and climate change/sea level rise will reduce agricultural production about 24 percent compared to the baseline forecast in 2050.

Topic 7 -- Recommendations to Maintain a Strong Agricultural Industry. A variety of recommendations were made to support continued growth and development of the agricultural industry in the County. Some of the key recommendations are:

Photo of for-sale signs for residential development in Miami-Dade County. Source: William Messina, UF-IFAS.

- Maintain the current land use plan in the County with the Urban Development Boundary to control urban development, limit low density rural residential development, maintain open space for agriculture and natural resources, and avoid urban sprawl.
- Lobby State and Federal elected leaders to seek more favorable international trade agreements that safeguard domestic agriculture from international competition.
- Work with State and Federal leaders to address labor shortages by developing an agricultural guest worker program that is less burdensome as an alternative to the H-2A Temporary Agricultural Workers visa program.
- Maintain strong County support for existing agricultural programs and partnerships, including the County Agricultural Manager's Office, Agricultural Practices Advisory Board, University of Florida-Tropical Research and Education Center, and County Cooperative Extension Service, as well as vocational agriculture and post-secondary educational programs.
- Coordinate with the U.S. Army Corps of Engineers, South Florida Water Management District, and Florida Department of Environmental Protection to consider changes in water management regulations to avoid flooding associated with extreme rainfall events and elevated groundwater levels due to sea level rise.

The future viability of the agricultural industry in Miami-Dade County depends on maintaining profitability, securing resources to support the capacity to produce, and being resilient in adapting to change. Wise policy choices regarding land use, regulations, labor, and other issues affecting agriculture are critical to meet this need over the next three decades and beyond.

Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida

Final Report

Prepared for Miami-Dade County Board of County Commissioners and Department of Regulatory and Economic Resources

Prepared by University of Florida-Institute of Food and Agricultural Sciences (UF/IFAS)
Food and Resource Economics Department, Gainesville, FL
Tropical Research and Education Center, Homestead, FL
Southwest Florida Research and Education Center, Immokalee, FL
September 29, 2023

Acknowledgements

This study report was prepared for the Miami-Dade County Board of County Commissioners and the Department of Regulatory and Economic Resources, Planning Division, under Interlocal Agreement RE-R-423-22 (June 2022) with the University of Florida-Institute of Food and Agricultural Sciences (UF/IFAS) initiated by Resolution R-423-22 adopted by the Miami-Dade County Board of County Commissioners on May 3, 2022.

Personnel from UF/IFAS who contributed to this study and their roles in the project are as follows:

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- Ioannis Ampatzidis, Ph.D., Associate Professor, Southwest Florida Research and Education Center, Immokalee: agricultural technology
- Young Gu Her, Ph.D., Associate Professor, Tropical Research and Education Center, Homestead: climate and hydrology modeling
- Trent Blare, Ph.D., Assistant Professor, Tropical Research and Education Center, Homestead: stakeholder interviews and focus groups
- Andrew Ropicki, Ph.D., Assistant Professor, Food and Resource Economics Department, Gainesville: aquaculture industry
- William Messina, M.S., Economic Analyst, Food and Resource Economics Department, Gainesville: stakeholder interviews and focus groups
- Freddy Ballen, M.S., Economic Analysis Coordinator II, Tropical Research and Education Center, Homestead: agricultural commodity budget and profitability analysis
- Nathan Palardy, Ph.D., Assistant Professor, Food and Resource Economics Department, Gainesville: policy analysis
- Joao Ferreira, Ph.D., Research Associate, Food and Resource Economics Department, Gainesville (now University of Virginia): regional economic analysis and market disruptions
- Fei He, Ph.D., Research Associate, Food and Resource Economics Department, Gainesville: financial risk
- Xiaohui (Sherry) Qiao, Ph.D., Research Associate, Food and Resource Economics Department, Gainesville: weather hazards and hurricane impact assessment, land use mapping
- Kelsey McDaid, B.S., Research Coordinator, Food and Resource Economics Department, Gainesville: report review and editing
- Billie Maciunas, Ph.D., Editor, Food and Resource Economics Department, Gainesville: report editing
- Monique I. Scoggin, M.Ed., Marketing and Communications Specialist, Tropical Research and Education Center, Homestead: project team communications

- Susan B. Marynowski, M.S., Freelance editor: final report editing

Assistance to the project was provided by the following personnel from Miami-Dade County, Department of Regulatory and Economic Resources:

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- Manuel Armada, Chief, Planning Research and Economic Analysis Section
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- Zhijun (Jeannie) Tan, Analyst: REMI model analysis
- Glenn Amoruso, Planning Development Manager, Planning Division
- Robert Hesler, Supervisor, Planning Research and Economic Analysis Section
- Kimberly Brown, Director of Resilience Planning and Implementation, Office of Resilience

Technical assistance to the project on agricultural land and water use data and maps from *the Florida Statewide Agricultural Irrigation Demand* program was provided by:

- Daniel Duarte, Balmoral Group
- Yesenia Escribano, Florida Department of Agriculture and Consumer Services, Office of Water Policy
- Joann Dixon, U.S. Geological Survey
- Kyle Christesson, U.S. Geological Survey

Technical assistance to the project on the REMI regional economic modeling and forecasting system was provided by:

- Peter Evangelikas, Ph.D., Senior Vice President, REMI
- Chris Judson, Manager of Business Development, REMI

Industry stakeholder input to the study was provided by 74 people in Miami-Dade County agricultural and allied industries who participated in interviews and focus groups to provide personal observations and insights to inform the findings and conclusions.

Cover photo credit: Miami-Dade County, Department of Regulatory and Economic Resources.

Table of Contents

Summary

Introduction

This study report updates a previous economic and land use assessment of agriculture in Miami-Dade County ("the County") conducted in 2001-2002 by the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS). The present study in 2022-2023 assessed current conditions and trends from a wide variety of published data sources, conducted interviews and focus groups with stakeholders, evaluated threats confronting the industry, assessed the profitability of representative agricultural commodities using budgeted costs and returns, and used a regional economic model to forecast County growth and the effects of agricultural scenarios. A selected suite of statistical and economic models were used to project future agricultural land use in years 2030, 2040, and 2050. Another part of the study used models to predict the effects of climate change, sea level rise, and groundwater levels and quality on the agricultural industry in the County. In addition, an assessment of emerging agricultural technologies was compiled. Headings in this summary correspond to titles of topical sections in the body of the report. Click on the heading to jump to the pertinent section of the body of the report. References cited in the report, usually given in parenthesis, are available in alphabetical order at the end of the report.

Description of the County

Miami-Dade County is a unique area in the United States, located at the southern end of the Florida peninsula, with a warm-humid subtropical environment that supports an extremely diverse mix of plant and wildlife species and agricultural crops. The County is an important commercial center for trade in goods and services with Latin America and the Caribbean, and is a major tourism destination, with 24.2 million domestic and international visitors, and visitor spending of $19.22 billion in 2021. The County features Everglades National Park, a UNESCO World Heritage Site, and Biscayne Bay National Park.

Population in the County grew rapidly and steadily over the past 50-plus years, until recently during 2017-2021, following a national trend toward lower growth or loss of population in many major metropolitan areas. In spite of the recent deviation from growth patterns, the County population is projected to continue growing from around 2.71 million in 2021 to 3.29 million in the year 2050, representing a 21 percent increase.

The County has an extremely diverse social, racial, and ethnic makeup influenced by immigration from Latin America and rest of the world, with foreign-born people representing 54 percent of the population, nearly 70 percent identifying as Hispanic/Latino, and 75 percent speaking languages other than English at home.

The County has a long history of agriculture. It is one of the few areas in the United States with an extremely mild winter climate, which enables production of fruits and vegetables for the wintertime market and tropical crops not domestically available. It also has excellent access to seaport and airport facilities for exporting and distributing products. Agriculture in the County also has an important social and cultural identity. The County has over 146,000 acres of land with soils of unique importance for agriculture, representing 22 percent of the total area evaluated. This USDA designation is for farmland used for production of specific high-value crops, such as fruits and vegetables, that has physical characteristics, growing season, and water supply needed to economically produce sustainable yields, and with access to markets.

The County economy is a diverse mix of basic and service industries. The largest industry sectors in terms of value added are real estate/rental, finance/insurance, and health care/social services, while the largest industries for employment are health care/social assistance, professional/technical services, other services, retail trade, and transportation/warehousing. Travel and tourism are an important industry cluster (subsets of several industry sectors) catering to domestic and international visitors. County Gross Domestic Product (GDP) has grown slightly faster than for the U.S., but slower than for the State of Florida over the past two decades, while County employment has grown much faster than for the U.S. The County and its residents are challenged by income inequality, with median household incomes below state and national averages, high poverty rates, high cost of living and very low housing affordability.

The County is one of few in the United States with an Urban Development Boundary (UDB), an urban service boundary depicted and described within the County's Comprehensive Development Master Plan (CDMP). The CDMP determines allowable land uses throughout the County's jurisdiction and sets the policy framework for zoning regulations including for commercial and residential development, both inside and outside the UDB. CDMP policies for lands located outside the UDB are primarily oriented towards maintaining land for agriculture and natural and natural/environmental resources, with urban development to occur inside the UDB, encouraging infill countywide and higher densities within a network of mass-transit-supported urban centers and along transit corridors. Because of this policy, the County has avoided conversion of farmland to other uses more effectively than other major metropolitan counties in the U.S. over the past two decades. The policy has created a divided property market, with agricultural land prices inside the UDB more than four times higher than outside the UDB, and assessed land values of non-agricultural property outside the UDB in some cases more than 100 times higher than agricultural property. This effectively preserves land affordability for agriculture production outside the UDB.

Current Situation for Agriculture in the County

The County had 2,752 farms in 2017, with 73 percent of farms under 10 acres, and 93 percent under 50 acres (USDA-NASS Census of Agriculture). Agriculture in the County is dominated by specialty crops including nursery/floriculture, vegetables, and tropical fruits. Total farm sales in 2017 were $838 million. Nursery/floriculture sales ($697 million) were ranked first among all counties in the U.S. Average sales per acre were significantly higher for nursery/floriculture ($39,902) than for fruits ($3,266) or vegetables ($4,663). Sales of livestock and animal products are relatively small, with aquaculture being the largest and fastest growing segment, including a new facility for salmon farming that is among the largest in the world.

Local sales of agricultural products directly to consumers, sales of regionally branded products to retail markets, institutions, and foods hubs, and sales of processed or value-added products were reported by the Census of Agriculture at $31 million in 2017, representing 3.7 percent of total farm sales. The County has 21 regularly operating farmers markets. Agritourism revenues in the County appear to be growing, although there is no credible source of information on the scope of this emerging industry. There appears to be significant potential for expansion of agritourism, given the large number of visitors who visit the southern part of the County.

Employment in the County by agriculture, forestry, fishing, and hunting sectors fluctuated between 7,600 and 9,000 full-time and part-time jobs over the past decade. In 2021 there was an average of 8,872 agricultural workers, an increase of about 6.6 percent from 2001, while the total County workforce increased by 13 percent (U.S. Department of Labor, Bureau of Labor Statistics). Total salaries and wages paid in agriculture have steadily grown since 2015, reaching $302 million in 2021, an increase of 47 percent since 2001 in inflation-adjusted terms.

Total farm income in the County, including cash receipts from sales and other income, was $950 million in 2021, while production expenses were $905 million, and net farm income was $45.6 million, representing an operating margin (ratio of net income to total income) of 4.8 percent, according to data from U.S. Department of Commerce, Bureau of Economic Analysis. Farm income increased by 11 percent during the period 2001-2021 in inflation-adjusted terms; however, production expenses increased by 42 percent, resulting in a 79 percent decrease in net income. Between 2001 and 2021, farm operating margin averaged 22 percent. Value added, equivalent to GDP, including farm proprietor and corporate farm earnings, plus employee wages, salaries and benefits, increased about 9 percent during this 20-year period and agricultural employment increased by 1.6 percent (IMPLAN). Note that in 2020-2021 farm income was reduced and production expenses were significantly increased, possibly due to market disruptions and costs associated with the COVID-19 pandemic, which may not be representative of conditions going forward.

The value of fixed farm assets in land, buildings, machinery, and equipment was $3.25 billion in 2017, representing an average of $41,475 per acre (USDA-NASS). Fixed assets increased nearly three-fold during 1997-2017 in inflation-adjusted constant dollar terms. The rate of return on assets, calculated from asset values and net income less interest costs, declined from 21.2 percent in 1997 to 7.7 percent in 2017.

Agricultural land in the County in 2017 comprised 78,543 acres (both inside and outside the UDB), including cropland for vegetables (38%), nursery-floriculture (35%), and fruit orchards (27%), as well as farm buildings and other supporting service areas (USDA-NASS). During 1997-2017, total farmland area decreased by 6.2 percent, including decreased areas for fruits and vegetables, while nursery-floriculture area increased significantly. Historically, farmland in the County declined from over 120,000 acres in the late 1950s. The Florida Department of Agriculture and Consumer Services, Florida Statewide Agricultural Irrigation Demand program estimated around 63,000 acres in agricultural production in the County in 2020, based on field surveys and water use permits, which do not apply to many farms, and thus underestimated agricultural land.

The County Property Appraiser's office reported about 7,300 parcels classified under agricultural use, with total area of about 61,200 acres in 2022, including 6,329 properties (86%) and 55,700 acres (91%) outside of the Urban Development Boundary (UDB). Agricultural properties had a bare land value of $4.329 billion, or an average of $70,760 per acre. There is a significant difference in property values per acre attributable to land (excluding improvements) with respect to the UDB: $54,200 for land outside vs. $239,200 for land inside the boundary.

Production agriculture accounted for about 8,900 direct jobs in 2021, representing 0.54 percent of total County employment, and value added (personal income and business net income) of $586 million, representing 0.31 percent of County GDP. The agricultural sector in the County has grown despite reduced land area, with value added increasing by 8.9 percent during 2002-21, however, growth has not been as rapid as overall County GDP (55.1%), so the share of County GDP by agriculture declined from 0.44 percent to 0.31 percent during this time.

Total economic contributions of agriculture and related natural resource industries in the County in 2021, including multiplier effects in other sectors estimated by the IMPLAN regional economic model, showed 12,836 full-time and part-time jobs, industry output or sales revenues of $1.555 billion, and value added or GDP of $902 million, including employee compensation ($494 million) and proprietor income ($148 million). Contributions to government tax revenues totaled $183 million, including federal taxes ($129 million), state taxes ($24 million), and County taxes ($30 million) for property and sales taxes and local districts (police, fire services, schools, libraries), plus Water Management district assessments. Agriculture generated significant economic contributions in other sectors through supply chain activity (indirect multiplier effects) and employee household spending (induced effects), such as health care-social assistance, real estate-rentals, transportation-warehousing, retail trade, wholesale trade, accommodation-food services, finance-insurance, administrative-waste services, and professional-technical services.

Economic contributions of agriculture in the County increased between 1997-98 and 2021 for all indicators, including employment (15.6%), output (11.3%), value added (14.1%), labor income/earnings (25.6%), and government taxes (108.5%), based on similar models used to reanalyze agriculture sales information reported in the previous agricultural lands study in 2002.

In addition, agriculture is closely linked to food manufacturing, distribution and service industries that serve the resident population and visitors, generating very large economic contributions in the County and state.

A non-market valuation study of agricultural and rural lands in the County in 2002 found that a large majority of residents supported retaining agricultural and other undeveloped land uses as a source of locally grown food, wildlife habitat, protection of environmental quality, scenic views, recreational opportunities, and quality of life. A survey of County residents found that almost 70 percent of study respondents believed the County should consider purchasing land or development rights to retain undeveloped land, and a majority would consider financially supporting such a program in the form of voluntary contributions to a nonprofit conservation organization. In aggregate, the willingness-to-pay for land conservation programs by County residents was estimated at $125 to $300 million in 2022 dollars. These findings supported the adoption of County policies for Transferrable Development Rights and Severable Use Rights.

Threats to Agriculture

The project study team evaluated a number of different threats or stressors facing the agricultural industry in the County that may affect the outlook for the next 30 years. Stressor topics examined included commodity imports, increasing production costs, invasive pests and diseases, water resources, workforce availability, urban development, hurricanes and weather hazards, market disruptions, financial risks, government policies and regulations, and climate change-sea level rise-groundwater salinization. This was a task required in the project contract, and is not meant to be an overwhelmingly negative assessment of the outlook for agriculture in the County, but rather is intended to identify possible challenges in the future so that industry can be better prepared to prosper.

Import Competition

There is a high level of import competition for many specialty crop commodities in the U.S., Florida, and Miami-Dade County. Imports of fruits, vegetables, and other specialty crops to the U.S. market have significantly increased, particularly from Mexico under the 1994 North American Free Trade Agreement (NAFTA), and the subsequent 2020 United States-Mexico-Canada Agreement (USMCA), as well as the Central America Free Trade Agreement (CAFTA). Much of Mexico has growing conditions similar to South Florida, enabling it to compete directly with Florida producers during the winter season market. Imports of specialty crops to the Florida market doubled during 2008-2021 in constant dollar terms. Competing imports have reduced market share and depressed commodity prices received by domestic producers. Note that nursery/floriculture crops are protected from foreign competition by U.S. laws prohibiting the import of live plants in rooting media to prevent introduction of pests and diseases. Consolidation of retail supermarket chains has also exerted downward pressure on domestic prices for specialty crops.

Increasing Production Costs

Farm production expenses in Miami-Dade County in 2021 reached $905 million, including hired farm labor (33.7%), miscellaneous other (39.0%), seeds (15.4%), fertilizer/chemicals (8.4%), petroleum products (3.0%), and livestock/feed (<1%) (USDOC-BEA). Production expenses in the County increased by 42 percent overall during 2001-2021 in inflation-adjusted terms, with especially large increases for petroleum products (118%) and miscellaneous other items (80%). These increases exceeded the general rate of inflation in the U.S.

economy as measured by the GDP Implicit Price Deflator index (USDOC-BEA). Due to the joint effect of increasing costs and declining farmland acreage, the average inflation-adjusted production expense per acre increased from about $7,745 in 2012 to $12,609 in 2017, an increase of 63 percent or 12.6 percent per year. The increases in production costs are not unique to agriculture in the County. Continued escalation of farm operating costs will put further downward pressure on profitability and increase the risk of business failures.

Pests and Diseases

Invasive pests and diseases are an important risk to the agricultural industry in Miami-Dade County--the tropical climate and year-round growing conditions create ideal conditions for spread of invasive pests and diseases. The Port of Miami is a major gateway for imports of food and agricultural products to the U.S., especially from Latin America and other trading regions, with the potential for inadvertent introduction of pests and diseases. Two case studies of invasive pests and diseases in Miami-Dade County were reviewed: the Oriental Fruit Fly outbreak in 2015 (Alvarez et al., 2016), and Laurel Wilt Disease, which affects avocado trees (Evans et al., 2010). These two major pest outbreaks within the past 15 years are examples of the potential for ongoing disruption of the agricultural industry in the County. Damages may result from direct product losses, increased costs for controls, and grower decisions to avoid planting due to the presence of disease. The Oriental Fruit Fly outbreak was estimated to have caused over $3 million in annual grower losses, and a regional economic impact of over $10 million. Laurel Wilt Disease was estimated to result in loss of $22.5 million in annual avocado sales, and regional impacts of 273 jobs and $9.84 million in labor income lost, as well as increased management costs and reduced property values.

Water Resources

Water is an increasingly scarce resource around the world that shapes human development and settlement patterns, especially in arid regions. Miami-Dade County's water is supplied mainly from wells in the Biscayne Aquifer underlying southeast Florida. Total water withdrawals in the County from all sources (fresh and saline, ground and surface) were 468 million gallons per day (MGD) in 2015, including public supply (75%), mining (8.9%), irrigation (8.5%), and thermoelectric power plants (6.1%), while withdrawals of fresh groundwater were 409 MGD for public supply (83%), irrigation (8.4%), and mining (7.0%). Due to greater water use efficiency, total water withdrawals from all sources declined 22 percent, and self-supplied groundwater withdrawals declined 24 percent during 2005-2015 (USGS), even though County population increased significantly. Public-supplied water use per capita decreased by 20 percent during this period. Water use for agricultural irrigation in the County was projected to decrease 19 percent between 2019 and 2045 in average years, based on trends in land and water use, irrigation technology, commodity markets, and input costs; and irrigated crop acreage in the County was projected to decline to around 30,600 acres by 2045 (FDACS-FSAID). Declining water use per capita may offset population growth in the County, stabilizing overall water demand,

and reducing water constraints for agriculture; however, climate change and sea level rise could threaten groundwater quality from saltwater intrusion.

Workforce Availability

Specialty crop agriculture in Miami-Dade County is highly labor intensive and requires a large workforce for planting, harvesting, and crop care. Workforce availability reflects a variety of factors, including compensation rates, population growth, migration, living standards, housing affordability, education, and training. Work in agriculture is physically demanding, with long hours, irregular schedules, and relatively low pay compared to other occupations. The workforce is generally young and unskilled, with low to moderate educational attainment. About 44 percent of agricultural workers in the U.S. were unlawful or undocumented immigrants according to the National Agricultural Worker Survey in 2019-20. Foreign workers under the H-2A Temporary Agricultural Workers visa program are increasingly being used in agriculture for harvesting work, representing about 27 percent of the overall agricultural workforce in Florida; however, the program has not been used as much in Miami-Dade County because farm operators must guarantee employment for the contracted period, provide housing and transportation, and pay a minimum wage (Adverse Effect Wage Rate) of $14.33 per hour in Florida in 2023. Overall annual wages for agriculture, forestry, and fisheries doubled (100% increase) during 2001-2021 in constant dollar terms, compared to a 30 percent increase for the entire County workforce; however, the average annual compensation per worker in agriculture in 2021 ($26,534) was still far below average for the County workforce ($66,685). This represents a challenge to recruit and retain employees in agriculture. This report discusses other social and economic indicators that affect availability of agricultural workers in Miami-Dade County, such as unemployment, poverty, cost of living, and net migration. Unemployment rates in the County have been above the U.S. average for long periods since 1990 but were lower during the recent period of 2018-2022. The poverty rate in Miami-Dade County averaged 19 percent during 2012-2020, which was higher than the U.S. average of 14 percent, although poverty rates have generally declined since 2014 at both the national and County levels. The cost of living measured by the Consumer Price Index (CPI) for the Miami metropolitan area has been higher than the U.S. average since 2005, especially under the very high inflation during 2021-2022, resulting in lower consumer purchasing power. Net out-migration from Miami-Dade County to other U.S. counties has increased in recent years, suggesting that the appeal of the County may be declining to some residents.

Urban Development

Miami-Dade County has been rapidly growing, with a resident population of 2.662 million in 2021 projected to grow to 3.286 million in the year 2050, a 23 percent increase (MDC-RER). The County has planned for population growth within the land area designated for urban development with a variety of housing types and commercial and industrial development areas. The County Comprehensive Development Master Plan has long maintained a policy of concentrating urban development inside the Urban Development Boundary (UDB) encompassing urban Miami and a corridor along U.S. Highway 1 to Homestead and Florida City, enabling preservation of agricultural lands outside the boundary. The policy is intended to encourage infill of existing vacant properties, accommodate quality urban development, limit urban sprawl, provide urban services more efficiently, and maintain space for agriculture. Population density inside the UDB is over 6,000 people per square mile, or roughly four times greater than outside the UDB. During 2021-2022, about 3,600 acres of agricultural property throughout the County were sold at an average price of $80,151 per acre, while over 20,000 acres of non-agricultural property were sold at an average price of $3.97 million per acre (County Property Appraiser). The bare land value (excluding improvements) of property sales averaged $11,167 per acre for agricultural land and $1.29 million per acre (115 times higher) for non-agricultural land.

Rental rates for farmland are another indicator of the agricultural land market in the County. About 35,600 acres of farmland were rented in 2017, at an average price of $560 per acre (USDA-NASS Census of Agriculture). Farmland rents more than doubled between 1997 and 2017 in inflation adjusted terms, however, land rent represented less than 3 percent of total farm production expenses in 2017. More recent survey data for 2017-2022 suggest that rents have stabilized in the County, although rents for irrigated cropland were 14 percent higher than for the broader south Florida region (USDA-NASS).

A more recent land use threat is the introduction of truck and commercial vehicle parking operations in the agricultural area. Although not permitted in this area, except in designated places, truck parking operators have established operations in violation of policy, and aggressively lobbied for policy and zoning changes. Such parking facilities would likely result in permanent loss of farmland.

Hurricanes and Other Weather Hazards

Miami-Dade County frequently experiences hurricanes, tropical storms, and other severe weather events that can cause losses of agricultural products, destruction of farm assets and infrastructure, and disruption of operations. Since 1951 there have been 37 hurricanes or tropical storms with the central path crossing Miami-Dade County. The southeast Florida coast has an average return period of 17 years between major hurricanes. In addition, Miami-Dade County had a total of 942 severe weather events since 2000 that caused loss of life, injuries, property damage, or business disruption, including thunderstorm winds (204 events), hail (178), and floods (173) according to NOAA. These weather hazards can cause significant economic losses to agricultural crops and infrastructure, and cause spread of invasive species. Moreover, it is accepted within the scientific community that climate change causes more extreme weather events due to greater energy in the atmosphere and oceans.

Hurricane Andrew was a Category 5 hurricane that impacted Miami-Dade County in August, 1992 as one of the most destructive hurricanes ever in the United States. The strongest hurricane winds were in the agricultural areas around Homestead and Redlands, thus providing an example of the impacts that a major hurricane can have on agriculture in the County. A scenario analysis was conducted to estimate the agricultural production losses that would occur if another hurricane of this magnitude struck the County with the current mix of agricultural systems, using geospatial data on winds (NOAA), average values per acre for various crops, loss rates by windspeed zone, and production stage of annual crops in relation to the peak hurricane season in August-September. Results showed that 98 percent of agricultural lands would experience major hurricane force winds (Category 3-5), with total annual losses estimated at $555 million. Additional losses would be experienced for one or two more years from damages to trees and other perennial crops.

Market Disruptions

Market disruptions are events or circumstances that interrupt the normal functioning of a market and cause a shift in supply or demand, which may lead to fluctuations in prices and economic activity. Market disruptions may be caused by natural disasters, technological advancements, changes in consumer behavior, economic changes, and political instability. Such disruptions can be caused by various factors that affect a specific product itself, disruption of input supplies, or downstream events such as shortages in warehousing or transportation services. Market disruptions can lead to significant losses for businesses involved in a specific commodity and may ultimately benefit competitors or substitute goods. Examples of disruptive events in agriculture include weather, pest infestations, labor shortages, and global pandemics. The negative impacts associated with disruptions depend on the severity and duration of the event, exposure to competitors, access to alternative suppliers, and resilience of the logistic networks.

Labor is a major input for specialty crop production. Labor shortages tend to occur more frequently in industries such as agriculture where work may be seasonal or where farms rely on workers living abroad. Because much of agriculture relies on migrant or visiting workers, more restrictive migration policies could create labor shortages that affect production in Miami-Dade County. The COVID-19 pandemic caused temporary labor shortages affecting the agricultural supply chain. Seeds, starter plants, pesticides, and fertilizers are critical to all types of crop farming. Fertilizer prices in Florida have dramatically increased over the past two years, with acute shortages reported in some areas. In the face of persistent shortages of agricultural chemicals, U.S. farmers have reduced usage, changed production practices, and sought substitute products, which may increase the risk of pests, weeds and diseases.

Market disruptions associated with hazardous weather events include hurricanes, storms, drought, extreme heat, and excessive rainfall/flooding, which is discussed in depth elsewhere in the report. Production of perennial tree crops and large nursery plants may be affected for multiple years.

Disruptions in other regions can also affect Florida producers through changes in national or global market conditions. Transportation networks and logistic chains were disrupted during the COVID-19 pandemic, with trade restrictions that delayed transactions, increased prices, and caused shortages for nursery plastics. For domestic trade, most commodities from Miami-Dade County are transported by truck, using three specific roads: I-75, I-95, and the Florida Turnpike. The U.S. Department of Transportation (2019) classified Florida interstate traffic as the third busiest across all fifty states in the U.S.; accidents and construction can generate delays and increase transportation costs.

Financial Risk

Farming in the U.S. relies on debt financing, which is an important source of risk in any business. Risk-averse operators tend to have lower debt but may not have sufficient resources to expand their businesses or make needed capital improvements and they typically have lower rates of return on equity. When producers borrow money to purchase assets or finance farm operations, they face risk due to uncertain interest rates, changes in lending relationships, and changes in asset values. For example, following the mortgage/real estate crisis in 2008, many farms had their lines of credit cut significantly, or were required to pay down debt immediately due to asset devaluation.

Specific information was not available on financial risk for agricultural businesses in Miami-Dade County; however, information for the relevant specialty crop industries at the U.S. level was compiled from *IBISWorld* industry research reports for plant-and-flower growing, fruit/nut farming, and vegetable farming (Rose, 2022; Madigan, 2022; Curtis, 2022). During 2017-2020 these industries had a return on equity (ROE) of 30 to 45 percent and a return on assets (ROA) of 10 to 20 percent, which is considered competitive with most other agricultural industries. The profitability of these industries was projected to increase slightly over the next 3 to 10 years compared to 2020.

Specialty crop industries in the U.S. typically are highly financially leveraged, with a ratio of total assets to net worth generally exceeding 4:1 and as high as 7:1 during 2017-2020, whereas a leverage ratio of 2:1 is generally considered a safe financial position. Specialty crop growers in Miami-Dade County may have a similarly highly leveraged financial position due to higher costs of land, higher operating costs, and smaller operation scale. The leveraged financial position of specialty crop growers in Miami-Dade County may reflect the difficulty of obtaining financing or attracting investment because lenders and investors view the industry as riskier or less profitable than in the past.

Specialty crop farms in the U.S. also have issues with short-term financial risk, as indicated by low debt service coverage ratios that represent the ability to meet regularly scheduled debt payments through cash flow of the business. During 2017-2020, the ratios for specialty crop growers in the U.S. have been consistently very low, suggesting vulnerability for short-term debt repayment.

Interest rates have a significant impact on farms and other businesses, affecting the cost of loans, investment decisions and farmland values. Farms generally purchase machinery, land, and buildings with debt, so high interest rates lead to greater expenses. A change in interest rates directly affects the profitability of farming and indirectly impacts competitiveness in global markets. During 1982-2022, the average real (inflation-adjusted) interest rate in the U.S. decreased significantly, from around 7 percent to under one percent.

Changes in interest rates are partly driven by the Federal Funds Rate set by the Federal Reserve, along with markets for loans, mortgages, and treasury bonds.

Government Policies and Regulations

Local, state, and federal government policies and regulations can affect the viability of agriculture in Miami-Dade County. Some of the major policies identified that affect agriculture in the County are discussed as follows.

At the County level, perhaps the most significant policy for agriculture is within the Land Use Element of the Comprehensive Development Master Plan (CDMP) that limits commercial and residential uses in areas designated as Agriculture, only allowing residential development at a density of one unit per five or more acres, which reduces development pressure on agricultural land. The Urban Development Boundary (UDB) and associated policies generally concentrates commercial and residential development in the core urban areas of Miami and Homestead and reduces the incentive to develop agricultural lands for nonagricultural purposes. Conversely, new commercial agricultural uses are not allowed within the UDB except on property designated or zoned for agriculture.

A recent proposal to amend the CDMP to allow clustered development of residential units on small lots with agriculture use designation and the remainder of the property conserved for agricultural uses, was not adopted. When properly executed, clustering could allow for sustainable development in agricultural areas, but may remove some land from production, so the net effect on agriculture depends on the ratio of agricultural to other uses, and the type of development allowed. Adopting a clustering policy may increase conflicts between farmers and new residents over agricultural practices (e.g., pesticide application, livestock manure, noisy machinery, slow-moving farm equipment on roads), and impose needs for improved infrastructure such as roads, water lines, and waste transfer stations. These issues must be addressed for such a policy to be adopted. Palm Beach County has similar density restrictions and requires clustered development in their Agricultural Reserve area.

The County has a program to purchase easements for development rights to preserve agricultural and environmentally sensitive lands; however, to-date only 805 acres have been protected by the program. Transfer of Development Rights (TDR) has not yet been implemented in Miami-Dade County due to market forces. Such programs in Collier County and other Florida counties have been successful where there are tight guidelines and market incentives. Miami-Dade County has other policies supporting higher density development where appropriate, such as bonuses for workforce and affordable housing density and transit-oriented-development. TDR can be effective when there is strong demand for development in the receiving area where developers would willingly pay to increase their development intensity.

The Community Health and Design Element of the CDMP encourages farm-to-school initiatives and community supported agriculture programs to promote local food production and improve access to healthy food products. According to the most recent data, all schools within the Food Authority for County public schools participated in farm-to-school programs during 2018-2019, accounting for nearly $61 million in food purchases (USDA Food and Nutrition Service, 2021). Note that not all of these purchases were from local growers. The primary beneficiaries are large operations and food processors due to a preference among schools for pre-prepared products that are washed, chopped, and packaged.

Among state level policies affecting agriculture in the County, Florida statutes require the assessment of land classified as Agriculture by the property appraiser to be based solely on its agricultural use, rather than its residential or commercial purposes, which helps prevent the premature conversion of agricultural land to other uses by maintaining lower property taxes.

Florida Statute 163.3162 regarding agricultural lands and practices states that agricultural production is a major contributor to the economy of the state; that agricultural lands constitute unique and irreplaceable resources of statewide importance; that the continuation of agricultural activities preserves the landscape and environmental resources of the state, contributes to the increase of tourism, and furthers the economic self-sufficiency of the people of the state; and that the encouragement, development, and improvement of agriculture will result in a general benefit to the health, safety, and welfare of the people of the state.

Florida Statute 163.3177 states that future land use elements of comprehensive plans shall discourage the proliferation of urban sprawl, which is defined as activity that promotes, allows, or designates significant amounts of urban development to occur in rural areas at substantial distances from existing urban areas while not using undeveloped lands that are available and suitable for development or fails to adequately protect adjacent agricultural areas and activities, and prime farmlands and soils. Finally, this statute asserts the state has a compelling interest in preserving the viability of agriculture and protecting rural agricultural communities.

Florida statutes allow the South Florida Water Management District to define restricted allocation areas (RAAs) where new or increased consumptive use permits for use are restricted due to concerns regarding water availability. Florida statutes also require water management authorities to establish minimum flows and levels (MFLs) for all water bodies to avoid harm to water resources. MFLs influence permit applications, declarations of water shortages, and assessments of water supply sources. For example, restricting withdrawals during water shortages could negatively impact commercial agriculture in the short term. Florida statutes also empower water management districts to establish water reserves that prevent new consumptive uses as part of the Comprehensive Everglades Restoration Plan (CERP), which could negatively impact commercial agriculture, although long-term viability of agriculture depends on sustainable use of water resources. The policy may limit existing agricultural producers or discourage new operations; however, water scarcity is generally not an issue in Miami-Dade County and the denial or reduction of consumptive use permits is unlikely.

Florida statutes retain authority at the state level for standards regarding environmental liability for the presence of contaminants on agricultural land converted to a nonagricultural use. This policy ensures a consistent statewide procedure that benefits landowners seeking to use part of their land for nonagricultural uses (e.g., housing for seasonal workers), but also may reduce costs for converting to nonagricultural uses and increase conversion rates.

The Florida Right to Farm Act protects agricultural and agritourism activities from nuisance lawsuits and limits the ability of local government to regulate agriculture if the state already regulates that activity.

Among federal government policies affecting agriculture in the County, the U.S. Department of Labor clarified that H2-A Temporary Agricultural Workers program employers must meet the higher of either the Adverse Effect Wage Rate or the prevailing state or federal minimum wage. Under this rule, Florida H-2A employers are required to pay $14.33 hourly in 2023 as opposed to the state's current minimum wage of $11.00. H-2A employers must also provide housing and transportation for workers, which further increases labor costs. Relaxed regulations on temporary farmworker housing would be helpful for agricultural employers to take advantage of the H-2A program.

The U.S. Farmland Protection Policy Act discourages federal activities that would convert farmland to nonagricultural purposes, and requires federal activities to be compatible with state, local, and private programs and policies to protect farmland. The Act specifically addresses land use conversion of farmland of unique importance, which pertains to a substantial area of farmland in Miami-Dade County.

The Agricultural Conservation Easement Program, part of the U.S. Farm Bill, enables private landowners, land trusts, and state and local governments to protect working farms and ranches by limiting non-agricultural uses through conservation easements or purchase of development rights programs. Miami-Dade County has received approximately $7.4 million in grant funds through this program to purchase development rights on 805 acres.

Climate Change and Sea Level Rise

Agricultural production in Miami-Dade County is vulnerable to climate change and sea level rise, conditions which are expected to bring additional challenges to agriculture in south Florida. As part of this project, climate modeling specialists considered projected changes in climate and sea level to predict impacts on temperature, rainfall, and groundwater quantity and quality. The study considered two widely accepted climate change forecasts and three sea level rise scenarios. Under the most commonly accepted climate scenario, air temperature in the County was projected to increase 1.5 to 1.8 degrees Celsius (2.7 to 3.2 degrees Fahrenheit) in the near future period to 2050 compared to historic averages. Precipitation was projected to become more variable, with greater rainfall extremes leading to more frequent periods of drought and flooding. The Urban Miami-Dade (UMD) groundwater model developed by USGS was used to mathematically represent groundwater flow in the Biscayne Aquifer and the process of seawater intrusion.

The UMD model encompasses 1,842.5 square miles (1.179 million acres) within Miami-Dade County and a small portion of southern Broward County in the C-9 surface water basin, of which 88,320 acres are agricultural lands. Under the NOAA Intermediate-High sea level scenario combined with the common climate scenario, the average groundwater elevation was projected to rise 0.25 m (0.82 feet) by 2050 compared to the baseline period of 1996 to 2020. Groundwater elevation would increase mainly due to projected sea level rise rather than higher rainfall or runoff. Seawater and brackish water were projected to intrude into the fresh groundwater aquifer; however, the impacts are limited to 15-20 km from the shoreline. Area in the UMD modeling domain with seawater intrusion into the aquifer would increase by 3.7 percent (43,688 acres), while area affected by brackish (less salty) water would increase 0.5 percent (5,790 acres). The modeling results indicate that the rise in groundwater level is sensitive to projected sea level change and is controlled mainly by the distance from the coastline rather than the land use/cover. Agricultural land uses would not be substantially affected by saltwater intrusion as long as they do not expand to areas close to the shoreline or surface water areas in the southeastern part of the County. It was estimated that seawater or brackish water would intrude into less than 1 percent (619 acres) of the agricultural areas through the year 2100. Groundwater levels in agricultural areas were projected to increase 0.24 m (0.79 feet) by 2050, but then rise more rapidly by 0.75 m (2.46 feet) in 2100. Groundwater levels are expected to rise faster in agricultural areas than in some other land use types such as upland natural areas. In addition, Water Management may increase freshwater flows to agricultural areas in the County to combat seawater intrusion. As a consequence, agricultural areas may experience root zone saturation more frequently due to the high groundwater levels and more variable precipitation in the future, which may affect crop productivity and require adaptive agricultural management practices to mitigate impacts. For more information on this topic, see Appendix A: Climate and Hydrology Modeling for Miami-Dade County.

County Stakeholder Interviews and Focus Groups

The project study team conducted interviews and focus group sessions with agricultural industry stakeholders in the County to gather insights on current conditions and the outlook for agriculture. Input was obtained from a total of 74 individuals representing vegetable/row crop growers, nursery/floriculture producers, tropical fruit growers, University researchers, agritourism operators, beekeepers, vertical farmers, allied suppliers, and banking/financial service providers. In addition, County Regulatory and Economic Resources staff conducted a separate focus group with commercial and residential developers and builders selected with the assistance of the Builders Association of South Florida.

UF/IFAS study participants were recruited through local contacts with UF/IFAS Extension, UF/IFAS-TREC and the Miami-Dade County Agricultural Manager's Office. The demographic makeup of participants comprised 78 percent male, 22 percent female; 85 percent White, 12 percent Asian, and 4 percent Black/African American (rounded numbers); 25 percent were Hispanic/Latino ethnicity. Participants were asked to sign an informed consent statement agreeing to participate voluntarily and without compensation. The sessions followed a script with a uniform set of instructions and questions that were asked of all participants. Questions covered topics such as strengths and weaknesses of the agriculture industry, threats over the next 10 to 30 years, recommendations for programs and policies to support economic viability and sustainability, and personal visions or aspirations for the future. Sessions were conducted in-person, by telephone, or by online meeting (Zoom), and most were recorded and transcribed. Key observations from the stakeholder interviews and focus groups are briefly summarized as follows.

There was a strong belief from all participants that the agricultural sector in Miami-Dade County has evolved over the past century and will continue to evolve and remain a critical component of the County economy. One participant was quoted as saying “agriculture in Miami-Dade County is valuable but vulnerable.” Nearly all the stakeholders were concerned about increasing input costs shrinking their profit margins.

Free trade agreements have allowed increased foreign competition, perceived by growers to be unfair because of the government subsidies that many foreign growers receive. This competition has caused a sharp contraction in vegetable/row crop acreage in the County. While some sectors have being doing very well--nursery and landscaping industry, agritourism, and certain tropical fruit crops--the vegetable/row crop sector has been challenged in recent years, which nearly all participants blamed on foreign competition. There are concerns that other sectors (i.e., tropical fruits, nursery) could follow the same fate if fair trade practices are not followed. The specialty vegetable crop industry has had much success, especially for Asian vegetables, but increasing foreign competition may inhibit future growth. Nursery and ornamental plant growers have been successful in the last few years, especially during the COVID-19 pandemic, and expect to continue to be profitable; however, there are concerns about higher interest rates, inflation, a potential recession, and declining profitability. Tropical fruit growers have been able to access high-value niche markets, allowing them to remain profitable; however, foreign competition remains a significant concern and has, in some instances, reduced profitability.

Other related local industries that have not traditionally been considered part of the agricultural sector of Miami-Dade County, such as agritourism, aquaculture, vertical agriculture, and honey production have grown over the last few years with expectations of continued success.

Access to labor continues to be a challenge for all growers. For example, housing regulations limit options to provide required farm worker housing for H-2A Temporary Agricultural Workers. Small growers face daunting administrative and logistical difficulties to participate in the H-2A visa program.

High land prices in agricultural areas have limited the expansion of existing businesses and the ability of young farmers to enter the industry. Growers agree that individuals should have the freedom to sell or use their land as they wish. Several organizations suggested that purchasing conservation easements may be a viable solution to preserving cropland and natural areas in the County.

Some growers felt that County policies do not consider the perspectives or concerns of the agricultural sector and that there is an unwillingness at various levels of government to address grower problems. Growers agreed that federal, state, and County government regulations need to be streamlined and harmonized. Better education programs would help growers understand what regulations apply to them and how to comply with multiple layers of regulations.

Stakeholders were frustrated that urban residents in Miami-Dade County are generally unaware of the agricultural sector, the diversity of products produced in the County, and where to purchase local products. Many participants mentioned that more residents and government officials should be aware of the importance of the environmental services provided by the agricultural sector, such as improved air quality, water recharge zones, cooling effects of the tree canopy, and habitat for native animals and plants. A majority expressed a need to educate those who move to south Miami-Dade about how agricultural enterprises operate (e.g., slow moving tractors on the road, sound of irrigation pumps) so that they will be aware of and live in harmony with nearby agricultural activities without creating nuisances for producers.

A significant number of participants were concerned that greater law enforcement presence is needed in south Miami-Dade County to combat illegal dumping, trespassing, and theft of fruit and equipment.

Visions about the future of agriculture in Miami-Dade County vary. Some believe that large-scale production agriculture will continue, especially for ornamental plants, while others expect small-scale farming will become increasingly important, with more growers dedicated to high value specialty crops and agritourism.

Agricultural Commodity Profitability Analysis

As part of this study, production costs and returns were evaluated for a sample of eleven crop commodities that traditionally had significant production volume in Miami-Dade County, including fruits (avocado, mango, carambola), vegetables (snap beans, tomatoes, squash, sweet corn), and nursery/floriculture (hibiscus, chrysanthemum, begonia, daylily). Budgeting is a standard tool used to evaluate the economic/financial situation of agricultural enterprises.

Primary data for this study was obtained through grower interviews to collect information on production costs, harvesting and marketing costs, fixed costs, and average/low/high yields and prices during the last ten years. Secondary data from published reports was used to validate information gathered from the interviews, and to fill in missing data not available from growers. Prices, yields, and costs reported capture differences in production practices and management styles of growers interviewed. Results included a sensitivity analysis to compare revenue changes under different prices and yields. Stochastic analysis of budgets was also conducted to evaluate risks associated with variations in production, receipts, and net returns, with simulations in the *Simetar* software providing a probability cumulative distribution function (CDF) on net return per acre for each commodity, indicating the likelihood that the net return would be less than or equal to any given value.

Information for each commodity includes income, operating costs, harvest and marketing costs, and fixed costs. The income section shows average (expected) yield, and average (expected) price per unit of product prevailing in the area. Revenue is calculated as quantity times price received. Operating costs include inputs such as agrochemicals, fertilizers, labor, and capital. Fixed costs include land rental, taxes, insurance, and overhead costs. Harvest costs include picking, transport, washing and grading, and packing materials.

For fruit crops, the net profit margin ranged from a low of 4.6 percent for avocados to a high of 29.3 percent for mangoes. Under the stochastic analysis that takes risk into consideration, the profit margin ranged from 16.1 percent for avocados to 23.4 percent for carambola. For vegetable crops, net profit ranged from 3.0 percent for sweet corn to 13.5 percent for squash, and under the stochastic analysis ranged from 4.4 percent for snap beans to 12.4 percent for tomatoes. For ornamental crops, profit margin ranged from 40.1 percent for hibiscus to 51.3 percent for begonia, and under the stochastic analysis ranged from 33.4 percent for hibiscus to 45.6 percent for begonia.

Profit margin from the stochastic analysis tends to be higher for crops such as avocado that have benefited from trade disruptions or adverse weather events in competing regions, resulting in higher prices received by local growers. Ornamental crops are a special case as they have higher net returns and profit margins compared to fruits and vegetables. Ornamental growers do not face import competition; however, industry consolidation presents competition between local firms.

Given the low levels of profitability for several of the major fruit and vegetable crops grown in the area, it is worth exploring some reasons why many growers keep operating in the face of shrinking net returns due to import competition and rising operating costs. Economic theory suggests that as long as growers have positive net returns, they will continue operating. Positive net returns mean that production factors of capital and labor are fairly compensated. Growers may decide to cease production or exit the industry when returns do not cover operating costs, much less fixed costs. This profitability analysis indicates that for a sample of important crops grown in Miami-Dade County minimal profits challenge growers to remain in the industry.

Emerging Agricultural Technologies

As part of this project, emerging agricultural technologies for specialty crops were assessed by a technology specialist for their potential to make agriculture more profitable and sustainable in Miami-Dade County. Emerging technologies such as artificial intelligence (AI), automation, and robotics can provide Miami-Dade County growers with low-cost and climate-smart tools to continually monitor crop health status, determine plant needs, and optimize water, nutrient, pest, and disease management. The technologies have potential to deliver more productive and sustainable agriculture through precise and cost-efficient approaches.

Potential issues that emerging technologies can address for the future of Miami-Dade County include labor shortages, climate change, water quantity and quality, land availability, urban development and other rural land uses, rising cost of inputs, complex logistics, and international competition. Continued progress in the fields of AI, mechanization, automation, and genetic engineering can provide solutions to these potential issues.

Some emerging technologies will be adopted and bring changes in the near future (less than 10 years), and others in the medium term (10-30 years). For example, AI-enhanced tools for field scouting imaging utilizing drones (unmanned aerial vehicles/UAVs), satellites, or ground robots are already commercially available for specialty crops such as citrus. In the next 5-10 years, it is expected that these tools will be more reliable and robust and will be applied to other tree crops and vegetables. In the next 10-30 years, technology will be able to detect pests and diseases in early stages accurately and reliably. Variable rate spraying technologies and fertilizer spreaders are commercially available for citrus and other tree crops, providing more precise application, reduced quantity and costs for pesticides and fertilizers. Further improvement of these technologies with the use of sensor fusion and artificial intelligence (AI) is possible in the next 5-10 years. These technologies are currently expensive, not affordable by small-to-medium size growers, and require significant effort to adapt to production systems in Florida. Fully autonomous robotic spraying systems are available now for tree crops, and more such systems are expected to be commercially available in about 10-20 years. Smart spot sprayers for precision weed management are not yet commercially available in Florida, but in the next 5-10 years some will be commercialized, and in 10-20 years fully autonomous robotic systems will be introduced in Florida. A robotic strawberry harvester has been developed and evaluated in commercial fields in Florida. This type of technology can truly transform agriculture by dramatically reducing labor requirements for harvesting specialty crops. Fully autonomous and reliable harvesters for other specialty crops will be commercially available in Florida in 20+ years, but this may be too late for some growers currently facing challenges of high labor costs. Development of these technologies relies on funding, industry support, and political influence.

Challenges to adopting new technology include unknown costs, lack of awareness, unclear benefits, aging grower population, resistance to organizational change, skilled workers shortage, high training costs for employees with special skills, social influences, and need for technology customization for specific production systems for specialty crops.

These technologies will require a more highly trained workforce to operate, maintain, and adapt them to local conditions. AI is transforming the economy into one that is tech-driven and high-wage; agriculture can be part of that transformation. The University of Florida (UF) partners with Florida Agricultural and Mechanical University (FAMU), Miami-Dade College, and Palm Beach State College to develop programs for students, and working with the Florida Department of Education to develop the nation's first AI curriculum for public schools.

Despite the positive impacts of emerging technology on agriculture, the economy, and the environment, new technologies have often had negative impacts through various externalities and unintended consequences. Most studies focus on assessing new technologies based on their economic and environmental impacts; however, some studies identified changes in farm structure and culture, labor requirements, and work patterns as important for technology adoption. An important social concern is that labor displaced by the shift towards automation requires new levels of human capital that will disadvantage the digitally illiterate, including migrants and other less-skilled workers. Farm automation could reduce rural employment and shift farm capital expenditures away from locally sourced products and services to large scale corporate entities, leading to increasing market power for large producers through concentration of critical technology. Access to training, equipment, and infrastructure for small farmers, women, and minorities is vital to reducing the digital divide and social biases. For further discussion of this topic see Appendix B-Emerging Agricultural Technologies.

Scenario Analysis

Scenarios analysis for agriculture in Miami-Dade County was undertaken to provide insight into opportunities and threats to the industry. The analysis was conducted using an economic model of the County from Regional Economic Models, Inc. (REMI©) Policy Insight software licensed to Miami-Dade County Department of Regulatory and Economic Resources. REMI is a general equilibrium modeling system that accounts for changes in industry production, employment, consumption, commodity prices, trade, capital investment, and numerous other economic factors, in response to a variety of policy variables to support long-term economic forecasts out to year 2050 and beyond.

Baseline economic forecasts for Miami-Dade County for the years 2021-2050 were developed for low, medium, and high population growth projections. Under the mid-range baseline population forecast, projected changes for the County economy from 2021 to 2050 included increased population (21%), employment (29%), Gross Domestic Product (GDP, 88%), and personal income (84%), in constant dollar terms. The farm sector was projected to grow faster than the overall economy for output (91%), and GDP (97%), but slower for employment (10%). The REMI model growth forecast for Miami-Dade County is higher than for U.S. population (12%), employment (13%), GDP (65%), farm output (81%), and farm employment (4%). Under the high growth projection for the County, the increases in population (45%), employment (77%), and GDP (154%), were all significantly higher yet. Under the low growth forecast, there would be a decrease in population (-3.2%), and employment (-17.3%), but still an increase in GDP (+23%). The medium, high, and low population growth forecasts are considered in combination with the agricultural scenarios to represent the combined effects of scenarios and population growth assumptions.

A total of 12 different scenarios were evaluated, as follows:

<u>Increased farm output growth</u>: +6 percent annual increase in farm output above the baseline forecast, representing a doubling of the historic growth rate.

<u>Agritourism/local food development</u>: +$25 million annual output change in farms, food and drinking establishments, and amusement and recreation industries.

<u>Best case</u>: a combination of the two scenarios described above for increased farm output growth and agritourism/local food development.

<u>Agricultural technology adoption</u>: new investment of $50 million annually in agricultural machinery, 5 percent net increase in farm output due to higher productivity, and a -5 percent change in farm employment due to labor-saving technology.

<u>Increased foreign import competition</u>: -5 percent loss of farm output to reflect low commodity prices and -10 percent loss of farm proprietor income for reduced farm operating margins.

<u>Agriculture land loss to Urban Expansion Area</u>: -6 percent loss in farm output starting in 2030 and continuing to 2050 to reflect expansion of the Urban Development Boundary in the northwest and southeast parts of the County.

<u>Moderate climate change/sea level rise</u>: farm output loss increasing progressively to -13.1 percent in 2050 to account for higher crop losses and lower yields due to elevated temperatures, root zone flooding, and reduced water quality for irrigation from saltwater intrusion.

<u>Extreme climate change/sea level rise</u>: higher loss of farm output (-26.2%) in 2050 representing the NOAA high climate change projection, with greater losses due to flooding, groundwater salinity, heat stress on crops and animals, and mandatory work stoppages.

<u>Major hurricane</u>: cumulative effects of two separate major hurricane events, reflecting simulated damages by Category 5 hurricanes. For each hurricane, losses in farm output would occur over a three year period (-30% year 1, -20% year 2, -10% year 3) to account for recovery of fruit trees and perennial nursery crops to productive or saleable condition. A -5 percent loss of nonresidential capital stock was assumed for each hurricane to represent structural damages.

<u>Land price increase</u>: +5 percent increase in price of nonresidential real estate (land) to represent increasing scarcity of land in the County. This policy variable affects all sectors in the County, so the results of this scenario are not only for farms.

<u>Worst case</u>: -75 percent reduction in farm output due to any cause or the compound effect of multiple adverse factors. Losses in the agricultural sector would be partly offset by increased urban development on displaced agricultural lands, although that is not captured by the model.

Most likely case: a combination of three scenarios described above for increased foreign import competition, agriculture land loss to Urban Expansion Area, and moderate climate change/sea level rise. These three scenarios are all considered very likely to occur in the forecast timeframe 2021-2050.

Scenario analysis results showed that scenarios for continued growth of farm output, agritourism/local food development, and agricultural technology adoption had positive effects on the County economy, while all other scenarios had negative effects. The best case scenario, which combines growth of farm output and agritourism/local food development, resulted in increased County population (3,130 people), employment (2,540 jobs), and GDP ($286 million) in year 2050. The worst case scenario resulted in decreased population (-20,610), employment (-17,900 jobs), and GDP (-$2.10 billion) in 2050. The worst-case scenario is considered extremely unlikely, although it reflects the level of decline seen over the last 20 years for agriculture in other major metropolitan counties in the U.S. that do not have an urban development or growth boundary or other policies to effectively protect farmland.

The most likely scenario, representing a combination of three negative scenarios described above, resulted in losses in population (-5,930), employment (-5,790 jobs) and GDP (-$690 million) in 2050. Increased foreign import competition is considered highly likely, and would lead to significant losses, particularly in the fruit and vegetable industries, although these losses could be offset by an increased proportion of farmland area available for high value nursery/greenhouse crops. Loss of agricultural land for the Urban Expansion Area is expected to reduce agricultural production starting in 2030 and would result in loss of over 1,300 jobs that year; however, this could be partly offset by the jobs created in new urban development in those areas. Although the climate change/sea level rise scenario projections are very uncertain, it is reasonable to assume that there will be some impacts in Miami-Dade County. Clearly, this scenario analysis indicated a very wide range of possible future trajectories for the agriculture industry in Miami-Dade County in the next 27 years.

Agricultural Land Use Projections

The study projected future agricultural land use in the County in 2030, 2040, and 2050 in support of long-term land use planning for a viable agricultural sector as mandated in the County Comprehensive Plan. To project into the future, historic data for 1959/1969 to 2017/2021 on farmland area, agricultural product sales, total income, employment, and value of assets in the County were compiled from the Census of Agriculture (USDA-NASS) and Bureau of Economic Analysis (USDOC-BEA) and analyzed for trends using various statistical models. A limitation of the USDA-NASS Census of Agriculture is that information is available only every five years, the latest data being for 2017. USDOC-BEA data on farm income, expenses, and employment is annually reported, so it is more robust for forecasting. In addition, forecasts for the farm industry from the REMI model were used, as described in the Scenario Analysis section of the report. Projections using historic data are presumed to capture long-term trends in the mix of crops (nursery/floriculture, vegetables, fruits) and animal commodities, demand, market conditions, prevailing production practices, operating costs, profitability, labor, new technology use, etc. Projected values for agricultural sales, income, employment, and assets were considered measures of the size of the agricultural industry, and projected values per acre for these variables were measures of land use intensity. Taken together, these measures were used to calculate future agricultural land use.

Over the 59-year time span of 1959-2017, farmland area in the County declined from over 128,000 acres in 1959 to 78,543 acres in 2017, including cropland, pastureland, woodland, and other areas used for farm buildings, parking, and service areas. The change in farmland represented a 39 percent decrease, or an annual average change of -0.67 percent. The area used only for growing crops declined from over 80,000 acres in 1959 to around 55,000 acres in 2017. The latest available total farmland area of 78,543 acres (2017) is the starting point for projections of future agricultural land use. Note that this area is higher than the total agricultural land reported by the Miami-Dade County Property Appraiser in 2022 (62,088 acres) because some land that is actually being used for agricultural purposes may not have an agricultural classification, including farm areas used for supporting functions, such as dwellings, offices, storage, parking, driveways, etc. Some of the difference may also be due to loss of agricultural land in the period 2017-2022.

Trends in the historic data on farm activity and land use intensity were analyzed to provide technical forecasts out to year 2050. Regression models were fitted to the data using linear, logarithmic, exponential, and power mathematical functions, which represent different assumptions about the underlying structure of the data. The linear and logarithmic models assume a continued constant rate of change, while the exponential and power function models assume slowing or accelerating growth rates. Correlation coefficients for the various regression models ranged from 0.64 to 0.92, which indicate reasonably good fit to the data.

Farm sales were projected to rise to about $1.21 billion in 2050 under the linear and logarithmic models, and as high as $1.89 billion under the exponential and power function models. Market value of farmland and buildings in 2050 was projected to range from $3.43 to $4.65 billion under the different models. Total farm income in 2050 was projected at $1.01 to $1.39 billion. Projections on net farm income were not statistically reliable due to large yearly variations and low model correlation values. Farm employment in 2050 was projected at 8,651 to 10,699 jobs, but the lower projection is a better fit to the data and appears to be more realistic given the very tight labor market and current and future restrictions on immigrant/visiting labor.

Because of the urbanization of Miami-Dade County and the high cost of land, it is expected that agricultural production will continue to intensify, resulting in higher values per acre. Projected farm sales per acre in 2050 ranged from $15,000 to $25,000. Farm cash receipts per acre were projected at $18,400 in 2050, and total farm income per acre was projected at $19,200. Value per acre of agricultural land and buildings in 2050 was projected at $45,000 to $62,000. Farm employment intensity was projected to increase from 0.0970 jobs per acre in 2017 to 0.1462 jobs per acre in 2050, equivalent to a change from 10.3 acres per job to 6.8 acres per job. The increasing labor intensity associated with higher intensity crops occurs in the context of the broader trend of declining labor use due to substitution of technology for labor. In general, the linear models were a reasonably good fit to the data on land use intensity, implying continued steady growth in production per acre that reflects changes in production practices, technology, market prices, and the shift toward higher value nursery/floriculture products instead of vegetables/row crops.

As another source of information for future projections of agricultural land use in the County in 2030, 2040 and 2050, forecasts of farm sector activity were done using REMI model baseline forecasts for high, medium, and low population growth, and the most-likely case agricultural scenario that includes the combined effects of the Urban Expansion Area, foreign competition, and mid-range climate change/sea level rise (which reduced agricultural output and employment from the baseline population growth forecasts). The REMI model projected farm output in 2050 at $1.25 billion with the medium growth baseline and most-likely agricultural scenario. Farm employment was projected by the REMI model to increase from 8,728 jobs in 2021 to nearly 9,600 jobs in 2050 under the medium growth/most-likely scenario forecast. The high and low growth baseline forecasts coupled with the most-likely scenario were considered unlikely outcomes. The output forecasts from the REMI model were considerably higher than the statistical model projections from the historic data, and represent a more optimistic outlook for the industry, while the employment forecasts from REMI were in line with the statistical model projections of employment data.

Farmland area projections for Miami-Dade County in 2030, 2040, and 2050 were summarized for nine (9) selected best-fitting statistical or forecast models. Projections for year 2050 ranged from a low of about 49,800 acres to a high of 77,100 acres. The overall mean (average) projection in 2050 was 64,134 acres. A group of five best selected model projections for 2050 had a combined average of 56,284 acres, which represents a 28.3 percent decrease of 22,259 acres from the 2017 benchmark, or a -0.86 percent average annual change over the 33-year forecast period. As noted previously, the long time series of annual USDOC-BEA data on cash receipts, total income, and employment were considered robust, and support high confidence in their application in the preferred models for farmland area projections.

All projections were in agreement that agricultural production activity in the County will continue to increase significantly in absolute terms and on a per acre basis, although at lower rates than in the past. This is consistent with general trends in U.S. agriculture and specialty crops farming. The nursery/floriculture industry, the dominant agricultural sector in Miami-Dade County, has been the most rapidly growing major segment of U.S. agriculture for the past 30 years, but is now considered a mature industry with slower growth rates likely in the future. Most projections assume a continuation of historic trends in markets, product mix, labor relations, production practices, and technology; however, the REMI model projections explicitly accounted for the possible effects of favorable or unfavorable factors or events affecting the industry in the future (e.g. climate change). The models also indicated that space use intensity of agricultural production, measured as value per acre of land area for the different variables, will continue to increase, implying a greater demand for labor, technology, and material inputs, but lower demand for land as a factor of production.

The consensus forecast of future land needed for viable agriculture in Miami-Dade County, representing the combined average of five mid-range model projections, are the following point estimates (rounded to the nearest 100 acres): 64,800 acres in 2030; 60,900 acres in 2040; 56,300 acres in 2050. The projected rate of change in farmland from 2017 to 2050 for this estimate (-0.86% per year) is slightly higher than the historic average decrease during 1959-2017 (-0.67% per year), and during the most recent 2012-2017 period (-0.68% per year). Higher estimates of 70,000+ acres in 2050 from some model projections from the USDA-NASS Census of Agriculture were judged to be unlikely or less reliable due to limited historical data (five-year census intervals). The high estimate from the REMI model forecast for farm output assumes the farm sector will continue to grow at rates similar to the County economy, which was deemed unlikely. Similarly, very low farmland estimates by the REMI model under the low growth forecast that assumed negative population growth were also considered unlikely, and were not included in the set of preferred models.

When there is a high degree of uncertainty and it is important to avoid large forecast errors, there is a strong precedent for using combined forecasts by academic and practicing economists in cases where multiple divergent forecasts are available from different sources of information or methods. When there are five or more separate competing forecasts, combined forecasts using means or trimmed means are recommended to reduce bias from extreme forecasts. Thus, we relied upon the combined mean of five selected models with mid-range estimates.

The future farmland projections in this report were made with due diligence and are believed to be the best estimates available; however, there is significant uncertainty in making projections 27 years into the future. It is possible that agricultural land use in the County could change more or less rapidly than indicated by these projections, depending on unforeseen circumstances affecting the agricultural industry or the local economy in general.

Conclusions

The following conclusions for the Miami-Dade County agricultural lands study are based on the extensive body of work for economic analysis and observations from stakeholder focus groups and interviews:

- Miami-Dade County is a unique area of the United States, with a very strong social and cultural identity and an ethnically diverse population influenced by immigration, primarily from Latin America and the Caribbean.
- The local economy is a diverse mix of basic and service industries, including agriculture, construction, real estate, and travel/tourism, and continues to grow faster than the United States.
- The tropical/subtropical climate supports an agricultural sector with a diverse mix of specialty crops, including nursery/floriculture, vegetables, and tropical fruits.
- Agricultural industry production and investment will continue to increase in the future, although at rates less than historically seen due to market forces and other influences.
- Agricultural land use intensity will continue to increase due to adoption of improved technology, improved management and production practices, and changes in crop mix, leading to higher value per acre and reduced land requirements per unit of production.
- Livestock and animal products are currently a relatively small part of the agricultural industry; however, development of a large salmon aquaculture facility could be a significant economic contributor in the future, although such intensive aquaculture systems do not require large land areas and would not materially affect the overall demand for land.
- Stakeholder interviews and focus groups revealed optimism about the future of the nursery/floriculture industry, but pessimism about the fruit and vegetable industries that are threatened by import competition and rising production costs. Stakeholders foresee a future with many smaller farm operations producing more specialized crops.
- Agritourism has potential for development, capitalizing on the high number of domestic and international visitors and unique agricultural systems in the County.
- Local food systems can be significantly more developed to take advantage of the abundance of fresh produce. Most agricultural products currently are shipped out of the region to higher-priced markets in the northeast and central U.S.
- Profitability of the agricultural industry in the County is highly volatile and is declining due to increasing production costs and stable or declining product prices in inflation-adjusted terms.
- Specialty crop industries in the U.S. typically have high debt loads and are at financial risk to changes in macroeconomic conditions and market interest rates.
- Specialty crop industries in South Florida are challenged by pests and diseases, increasing production costs, and product losses.

- Quarantine 37 phytosanitary regulations prohibiting importation of live plants in soil media is a federal government policy that effectively protects the nursery industry from foreign competition and is expected to remain in place.
- The vegetable industry is severely threatened by competition from imported products, particularly from Mexico.
- Public groundwater withdrawals from the Biscayne Aquifer are declining in total quantity and per capita, and water demand for agricultural irrigation is projected to decline in the future due to improvements in water use efficiency. Saltwater intrusion into the aquifer will accelerate due to rising sea levels, especially in low-elevation coastal areas of the County.
- Workforce availability for agriculture is complicated by low compensation rates, difficult working conditions, high cost of living, and lack of affordable housing. Nearly one half of all agricultural workers in the U.S. are unlawful or undocumented immigrants. Labor markets in Florida are highly uncertain due to recent state policy changes to enforce immigration law. Use of foreign workers under the H-2A Temporary Agricultural Workers visa program is expensive and logistically challenging.
- The area frequently experiences hurricanes, tropical storms, and other severe weather events that can disrupt the agricultural industry, in some cases for years. Hurricane Andrew (1992) caused significant losses of products and infrastructure that led to massive reinvestment and rebuilding in the County. A similar major hurricane in the future could cause even greater losses because of higher product values and infrastructure in place.
- Climate change will increase average global temperatures in the future, possibly leading to loss of the comparative advantage for production of subtropical crops in Miami-Dade County, but could make it more suitable for growing truly tropical crops. Precipitation is expected to be more variable, leading to more frequent droughts and flooding from extreme rainfall events, but there is no discernable trend in overall annual amounts.
- Sea level rise will elevate groundwater levels and cause more seasonal flooding of agricultural lands near the coast, leading to increased losses of field crops and perennials, although not necessarily containerized plants. Salinization of the aquifer may render groundwater unusable for irrigation in areas near the coast, but is not expected to impact the main, high-elevation agricultural areas until after the year 2100. South Florida Water Management District actions to increase water releases to mitigate seawater intrusion may also increase flooding in agricultural areas.
- Emerging agricultural technologies, such as Artificial intelligence (AI), smart sensors, robotics, mechanical harvesters, and whole farm information systems, may help reduce product losses, reduce labor and chemical requirements, and control input costs; however, capital costs and adoption rates over the next 5 to 30 years are very uncertain, especially for the large number of small farms with limited capital.

- Greenhouse hydroponic and vertical growing systems have potential to dramatically increase production per unit area and avoid pest pressures, but capital costs are very high and potential for scaled-up capacity is unknown.
- The agricultural industry is increasingly concentrated in the nursery/floriculture sector and is dominated by one large firm in the County.
- Economic forecasts for the County using a regional economic model indicate strong growth for the agricultural sector out to year 2050. A most-likely scenario for agriculture suggests that the combined effects of import competition, loss of farmland to the Urban Expansion Area, and climate change/sea level rise would reduce agricultural production about -24 percent from the baseline forecast.
- The County has very strong land use planning policies to manage urban development and conserve farmland and other open space, implemented through the Urban Development Boundary, which has resulted in the lowest percentage of farmland loss among the ten largest metropolitan counties of the U.S. (1997-2017).
- The study did not evaluate the important non-market environmental services provided by agricultural lands for watershed protection, wildlife habitat, carbon storage, air quality improvement, tree canopy, and climate change mitigation.
- The consensus point estimate for a combined forecast of agricultural land needed under the current land use plan is 56,300 acres in 2050, which represents the minimum acreage required to meet demand for farmland without compromising the viability of the industry.

Recommendations

The following recommendations are provided to Miami-Dade County based on the findings in this study.

Key Recommendations

- Maintain the current land use plan in the County to control urban development, limit low density rural residential development, and maintain open space for agriculture and natural resources, in accordance with best practices in urban planning, and to ensure adequate amounts of farmland for a viable agriculture industry at the projected levels of 64,800 acres in 2030, 60,900 acres in 2040, and 56,300 acres in 2050. Limit changes to the Urban Development Boundary (UDB) to the Urban Expansion Areas already identified, or to areas already demonstrated to be unsuitable for agricultural production or environmental purposes due to impacts of climate change or other environmental factors, as determined by County government based on recommendations from the Agricultural Practices Advisory Board or Agricultural Manager.
- Lobby State and Federal elected leaders to seek more favorable international trade agreements that safeguard domestic agriculture from international competition.
- Work with State and Federal leaders to address labor shortages by developing an agricultural guest worker program that is less burdensome as an alternative to the H-2A Temporary Agricultural Workers visa program. This could include a cooperative program to assist small- and medium- sized growers meet the challenging requirements of H-2A. Also, amend local ordinances to clarify allowance of and ease placement of temporary worker housing in agriculture areas.
- Maintain strong support for existing agriculture-related institutions, including County Government (Agricultural Manager's Office, Agricultural Practices Advisory Board), the State of Florida Land Grant University system (University of Florida-IFAS, UF-Tropical Research and Education Center, County Cooperative Extension Service, Florida A&M University), local or regional post-secondary educational institutions, and other special interest organizations. Specifically, increase support for grower education on marketing, risk management, and succession planning.
- Coordinate with the U.S. Army Corps of Engineers, South Florida Water Management District, and Florida Department of Environmental Protection to consider changes in water management regulations to avoid flooding associated with elevated groundwater levels due to sea level rise.

Other Recommendations

- Consider changes to the County Comprehensive Plan to allow high intensity, closed agricultural production systems such as vertical farming, on properties inside the urbanized area designated or zoned residential, commercial, or industrial, where compatible with surrounding residential or commercial development.
- Increase support for agriculture and related small business formation and management through cooperation with entities such as the U.S. Small Business Administration and other public and private economic development groups in the County.

- Maintain support for local and regional food branding (e.g., “Fresh from Florida,” “Redland Raised”), farmers markets, Farm-to-School programs, and institutional food purchasing arrangements, to increase demand and direct sales from local growers and encourage value added products. A benefit of these programs is enhanced food security and reduced environmental impacts of long-distance transportation.
- Approve appropriate clustered residential development in agricultural areas only where at least 80 percent of the land is protected and maintained in bona fide agricultural use and the location does not disrupt surrounding environmentally sensitive areas and other commercial agricultural uses.
- Expand programs for purchase or transfer of development rights or conservation easements on agricultural land.
- Continue to support or increase law enforcement presence in agricultural areas to prevent trash dumping, other polluting activities, theft, and vandalism.
- Provide strong support for assistance and cleanup after natural disasters, such as major hurricanes, or large pest/disease outbreaks affecting agriculture.
- Periodically review County regulations affecting agriculture to streamline procedures and avoid duplication or conflict with overlapping State and Federal regulations and provide increased support for stakeholder compliance. The formal review process should be conducted every five years and should determine costs for producer compliance and impacts on farm profitability. Encourage Federal, State, and County regulators to meet with agricultural stakeholders to jointly address producer concerns with the regulatory process.
- Support advanced-skills vocational training programs for agricultural workers to manage emerging technologies, such as the curriculum on AI under a partnership between UF, FAMU, Miami-Dade Community College and Palm Beach State College.
- Continue support of research and outreach at the University of Florida-Tropical Research and Education Center in Homestead to develop new crop varieties (e.g. resistant to pests and diseases, tolerance of elevated temperatures, flooding, and saline irrigation), and best management practices that minimize environmental impacts of agriculture and enhance adaptation to climate change.
- Commission an updated research study on non-market benefits of environmental and social services to the community provided by agriculture and estimate willingness of County residents to pay for a farmland conservation program, providing further incentives for agriculture as a local industry. Based on the findings of the study, consider establishment of a program to compensate qualified agricultural and rural landowners for maintaining open space to provide environmental services such as watershed protection, wildlife habitat, air quality improvement, carbon storage, and climate change mitigation. Such a program would provide an incentive for landowners to maintain open space rather than selling for development. Programs to retain agricultural and other undeveloped land should compensate landowners for any loss in property value caused by the program.

- Expand programs to promote citizen awareness of the unique local agricultural systems and products available in Miami-Dade County, and the environmental services provided by farmland and natural areas. The County Agricultural Manager and Agricultural Practices Advisory Board should meet yearly with new County department heads and Board of County Commissioner staff to inform them about the role of agriculture in the County.
- Work with the 30-plus municipalities in Miami-Dade County to secure their support for agriculture in adjacent unincorporated areas of the County.
- Update this agricultural land outlook study report within the next 10 years to inform land use policy and planning in the rapidly evolving situation in the County.

Study Background

This study report was commissioned by the Miami-Dade County Board of County Commissioners under Resolution R-423-2022 to update a previous economic and land use assessment of agriculture in Miami-Dade County conducted by the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) in 2001-2002. The previous study results were published in a 1,000+ page report (Degner et al., 2002). The UF/IFAS study was complemented by the Agriculture and Rural Areas Study, which consisted of stakeholder working groups, consultant study reports, and public charettes to envision alternative future development scenarios for the South part of Miami-Dade County (Freilich et al., 2002). The Miami-Dade County Department of Regulatory and Economic Resources prepared a report based on the findings of the UF/IFAS study, using historic trends in production area for the major types of agricultural crops to project a harvested area of 45,400 acres in 2025 and 22,390 acres in 2050. (MDC-RER, 2003). These projections assumed a constant rate of decline for some major crops that covered a much larger area at that time, resulting in estimates that were well below the actual area currently.

The present study was tasked with the following major elements:

- Assess the current situation, trends, outlook, and economic impacts of agriculture in the County
- Gather opinions from local stakeholders through interviews and focus groups
- Evaluate threats or stressors confronting the agricultural industry
- Assess climate change and sea level rise in the County
- Review emerging agricultural technologies
- Assess profitability of representative agricultural commodities using budgeted costs and returns
- Forecast future economic growth in the County using the REMI regional economic model
- Evaluate impacts of different scenarios for agriculture
- Project future agricultural land use in years 2030, 2040, and 2050

Assessment of the Current Situation and Outlook for Agriculture

Sources and Methods

To assess the current situation for agriculture in Miami-Dade County, Florida, information was compiled on Gross Domestic Product (GDP), agricultural land use, property parcels under agriculture zoning, production area, crop and animal commodity volumes and values, commodity prices, price deflators, annual sales, farm operations by size class, employment and wages by North American Industry Classification Scheme (NAICS) sector, domestic and international exports, imports, farm income, expenses, net operating margin, producer demographics (age, gender, race), and economic contributions, including multiplier effects. Most data sources were available from the early 2000s, late 1990s, or earlier. Monetary time series data were inflation-adjusted to express values in current dollar terms using the U.S. GDP Implicit Price Deflator (USDOC-BEA). In addition, maps were compiled for County zoning/land use, distribution of agricultural crops, urban development boundary, and flooding hazard. Sources of information included U.S. Department of Agriculture-National Agricultural Statistics Service (crop and livestock, farms, demographics), U.S. Department of Agriculture-Agricultural Marketing Service (prices), U.S. Department of Commerce-Bureau of Economic Analysis (GDP, farm income, price deflators), U.S. Department of Labor-Bureau of Labor Statistics (employment, wages), IMPLAN© (output, value added, employment, commodity trade, economic multipliers), Florida Department of Revenue (property parcels), Florida Department of Agriculture and Consumer Services (irrigation demand), University of Florida-Bureau of Economic and Business Research (population), University of Florida-Food and Resource Economics Department (economic contributions), and Miami-Dade County Department of Regulatory and Economic Resources and Property Appraiser (maps). Use of secondary data is necessitated by the scope, timing and funding provided for the project. Secondary data is from credible and reliable sources; however, some data collected by primary agencies is done via sampling and not by direct observation/enumeration, and is subject to statistical, human and reporting errors. Complete references for all information sources are listed at the end of the report.

County Geography

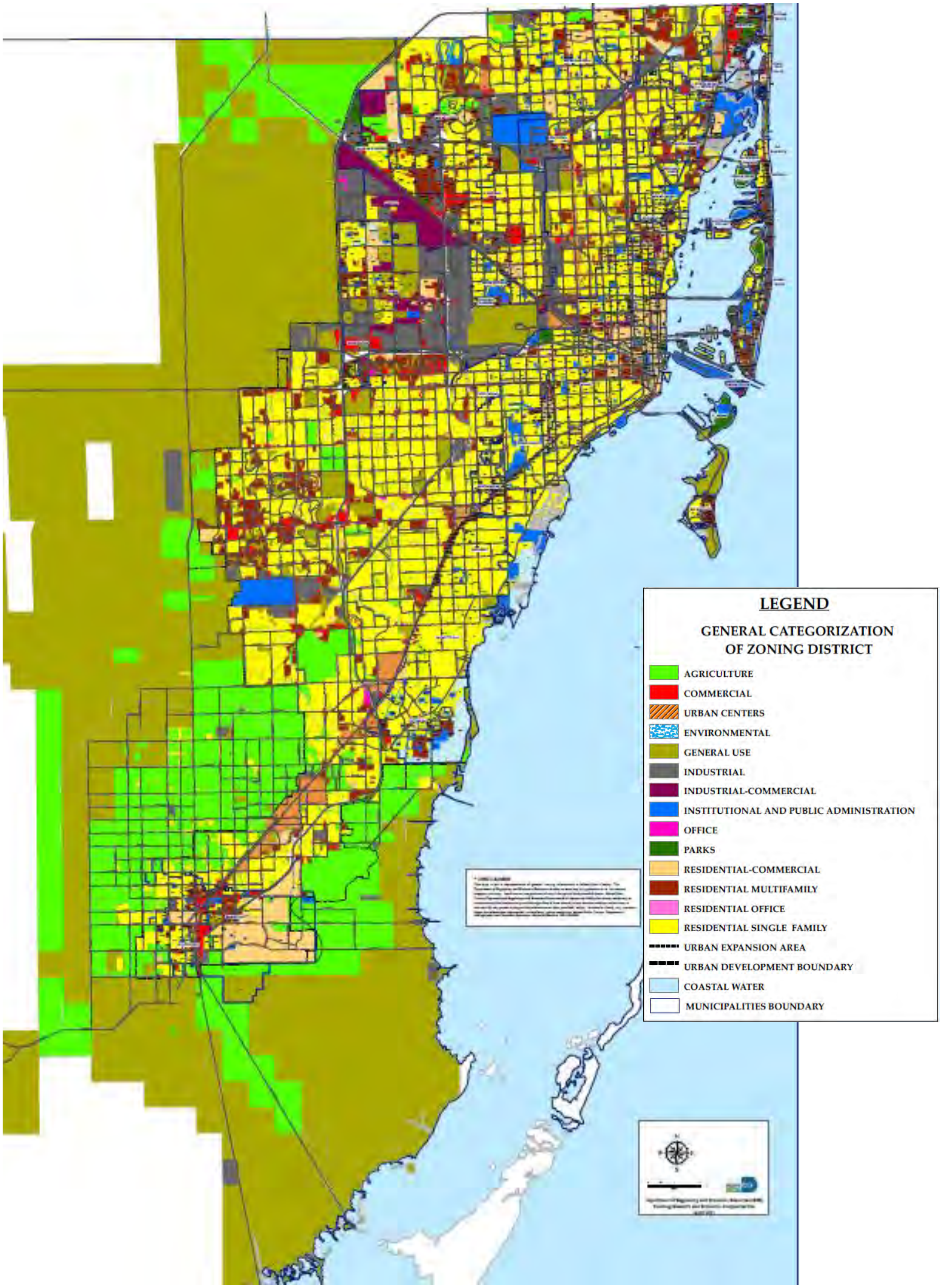
Miami-Dade County is a unique area in the United States, located at the southern end of the Florida peninsula. The warm-humid subtropical environment supports an extremely diverse mix of plant and wildlife species and agricultural crops. The County is home to the globally significant natural areas of the Everglades and Biscayne Bay National Parks.

The County has a long history of agriculture as one of only a few areas in the United States with an extremely mild winter climate that enables production of fruits and vegetables for the wintertime market, and tropical crops not otherwise domestically available. Because of its uniqueness, agriculture in the County also has an important social and cultural identity.

Miami-Dade County has a total land area of 1,900 square miles or 1.216 million acres. A map of current land use zoning in the County is shown in Figure 1.1, and the land use map adopted for 2030-2040 is presented in Figure 1.2. The northeastern part of the County along the coastline and around the City of Miami is highly developed as commercial and residential property, while the southern part surrounding Homestead and Florida City is agricultural, and the western part is protected parkland, wildlife and water conservation areas. Everglades National Park is a UNESCO World Heritage Site and Biosphere Reserve with 1.51 million acres in South Florida including most of the southwestern part of the County. The map also shows the Urban Development Boundary (bold dashed line), which restricts where new commercial and residential development can occur.

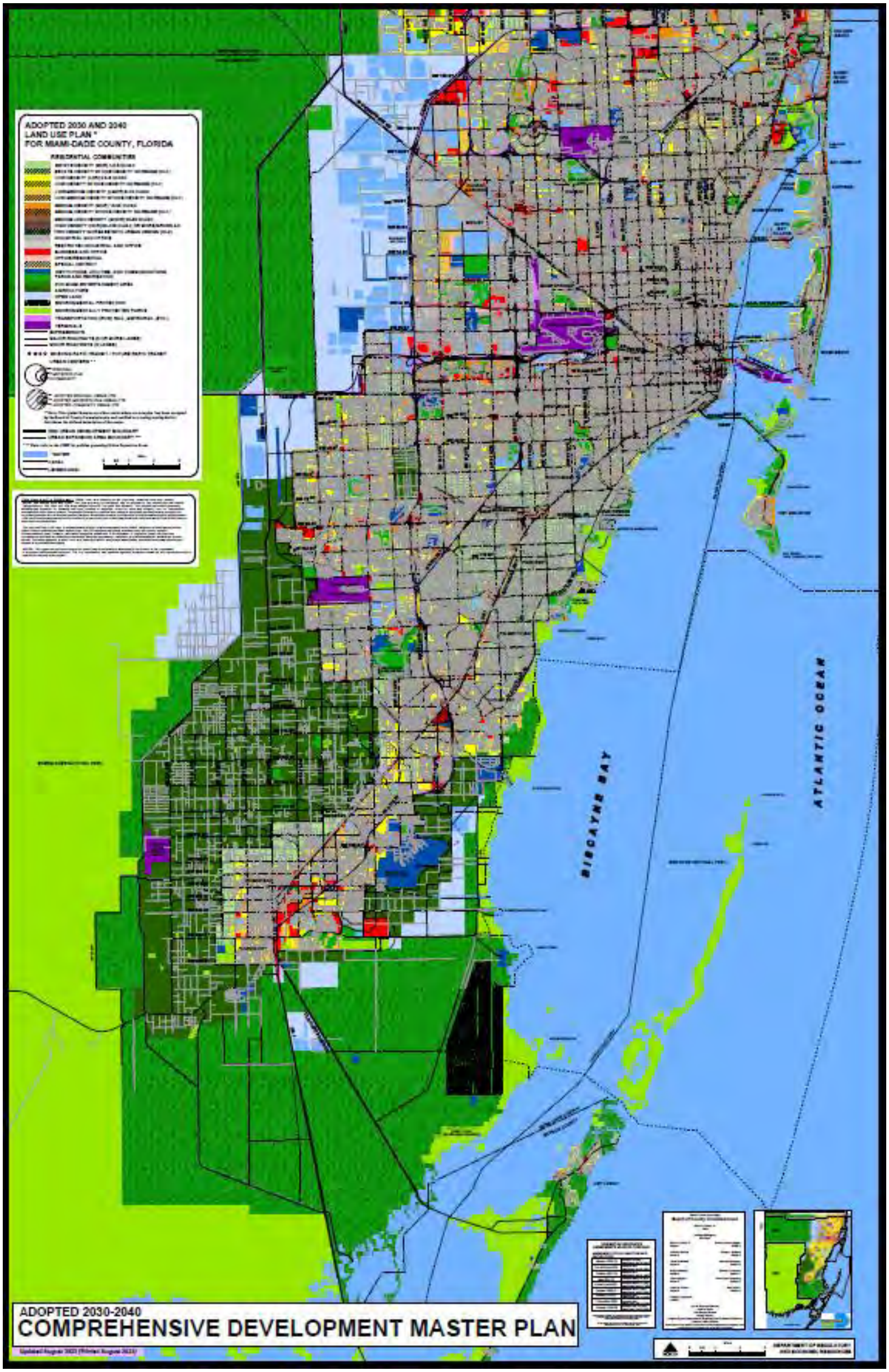
The County Comprehensive Development Master Plan (CDMP) establishes the basis for zoning regulations that restrict commercial and residential development outside of the Urban Development Boundary (UDB). Regulations encourage contiguous or infill development inside the boundary, limit future low-density suburban development to established areas, and maintain open space for agriculture and natural resources. Because of this policy, the County has retained agricultural land and experienced much less conversion of farmland to other uses than other major metropolitan counties in the U.S. over the past two decades.

Figure 1.1. Map of zoning in Miami-Dade County, 2021



Source: Miami-Dade County Department of Regulatory and Economic Resources, 2021.

Figure 1.2. Comprehensive Development Master Plan land use map for Miami-Dade County adopted for 2030-2040



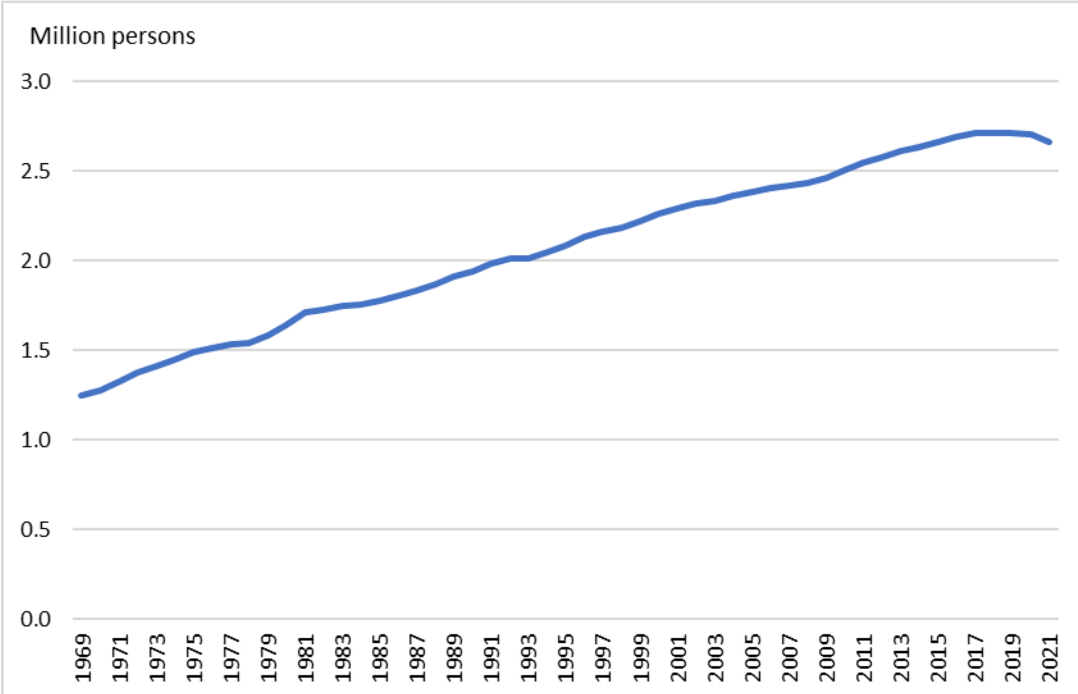
Source: Miami-Dade County Department of Regulatory and Economic Resources, August 2023.

Population and Demographics

The resident population of Miami-Dade County, Florida, in July 2021 was 2.662 million (U.S. Census Bureau). Miami-Dade County Department of Regulatory and Economic Resources estimated the population at 2.716 million in March 2021. Since 1969, population in the County has grown in an almost perfect linear fashion, and since 2000 has grown by 20 percent or an average annual rate of 1.0 percent (Figure 1.3). Population is projected to continue growing robustly through year 2050 to 3.180 million under the medium growth scenario by the University of Florida-Bureau of Economic and Business Research (Table 1.1). Under the high growth scenario, population would grow to 3.816 million, while under the low growth scenario it would decline to 2.553 million. Miami-Dade County Department of Regulatory and Economic Resources projects County population to reach 3.286 million in year 2050, slightly higher than the UF-BEBR mid-range forecast, based on detailed information on County age structure, fertility, and immigration patterns. County population growth was minimal during 2017-2020 and declined by 1.4 percent between April 2020 and July 2021 according to U.S. Census Bureau data. This population loss was consistent with population changes in other major metropolitan areas in recent years, and especially during the Covid-19 pandemic in 2020-21.

Demographic characteristics of the County are compared to the State of Florida and U.S. averages in Table 1.3. The County has an extremely diverse social, racial, and ethnic makeup influenced by immigration from Latin America and rest of the world with foreign-born people representing 54 percent of the population, nearly 70 percent identifying as Hispanic/Latino, and 75 percent speaking languages other than English at home. People under 18 years of age represented 20.2 percent of the population, while people over age 65 were 16.9 percent, which was below the Florida average. Among people identifying with one race, white people represented 79.2 percent of the population, African American people were 17.4 percent, and Asian people were 1.6 percent, while multi-racial people were 1.3 percent. People of Hispanic/Latino ethnicity (both white and non-white) represented 69.1 percent of the population, which was significantly above state and national averages. In terms of education, the share of the population aged 16+ with a high school diploma or equivalent was 81.8 percent (below state and national averages), and those with a four-year college degree or higher was 30.7 percent. The share of the working age civilian population in the labor force was 63.0 percent. Median household income was $53,975 (below state and national averages). The poverty rate was 15.0 percent (above state and national averages). The share of people under age 65 with a disability was 5.9 percent (below state and national averages). The proportion of people without health insurance was 19.4 percent (above state and national averages). The County had 902,200 households, with average household size of 2.95 people (above state and national averages). Population density in 2020 was 1,422 people per square mile (significantly above state and national averages).

Figure 1.3. Population trend in Miami-Dade County, 1969-2021



Source: U.S. Census Bureau, reported by USDOC-Bureau of Economic Analysis.

Table 1.1 Projected population of Miami-Dade County, 2025 to 2050

Growth Scenario	2025	2030	2035	2040	2045	2050
Low	2,682,600	2,674,200	2,649,100	2,615,800	2,579,400	2,543,700
Medium	2,823,800	2,922,600	3,001,800	3,068,400	3,126,600	3,179,600
High	2,965,000	3,171,000	3,354,500	3,521,000	3,673,700	3,815,500

Source: University of Florida-Bureau of Economic and Business Research.

Table 1.2. Demographic characteristics of Miami-Dade County compared to the State of Florida and United States

Data Item	Miami-Dade County	Florida	United States
Population estimates, July 1 2021	2,662,777	21,781,128	331,893,745
Population estimates base, April 1, 2020	2,701,767	21,538,187	331,449,281
Population, percent change - April 1, 2020, to July 1, 2021	-1.4%	1.1%	0.1%
Population, Census, April 1, 2020	2,701,767	21,538,187	331,449,281
Population, Census, April 1, 2010	2,496,435	18,801,310	308,745,538
People under 5 years, percent	5.5%	5.1%	5.7%
People under 18 years, percent	20.2%	19.7%	22.2%
People 65 years and over, percent	16.9%	21.1%	16.8%
Female people, percent	51.0%	50.8%	50.5%
White alone, percent	79.2%	76.9%	75.8%
Black or African American alone, percent	17.4%	17.0%	13.6%
American Indian and Alaska Native alone, percent	0.3%	0.5%	1.3%
Asian alone, percent	1.6%	3.0%	6.1%
Native Hawaiian and Other Pacific Islander alone, percent	0.1%	0.1%	0.3%

Data Item	Miami-Dade County	Florida	United States
Two or More Races, percent	1.3%	2.4%	2.9%
Hispanic or Latino, percent	69.1%	26.8%	18.9%
White alone, not Hispanic or Latino, percent	13.6%	52.7%	59.3%
Veterans, 2016-2020	47,227	1,416,472	17,835,456
Foreign-born people, percent, 2016-2020	54.0%	20.8%	13.5%
Housing units, July 1, 2021, (V2021)	1,084,353	10,054,457	142,153,010
Owner-occupied housing unit rate, 2016-2020	51.60%	66.20%	64.40%
Median value of owner-occupied housing units, 2016-2020	$310,700	$232,000	$229,800
Median selected monthly owner costs -with a mortgage, 2016-2020	$1,882	$1,539	$1,621
Median selected monthly owner costs -without a mortgage, 2016-2020	$631	$513	$509
Median gross rent, 2016-2020	$1,373	$1,218	$1,096
Building permits, 2021	13,393	213,494	1,736,982
Households, 2016-2020	902,200	7,931,313	122,354,219
People per household, 2016-2020	2.95	2.62	2.6
Living in same house 1 year ago, percent of people age 1 year+, 2016-2020	88.2%	84.9%	86.2%
Language other than English spoken at home, percent of people age 5 years+, 2016-2020	75.0%	29.4%	21.5%
Households with a computer, percent, 2016-2020	92.4%	93.1%	91.9%
Households with a broadband Internet subscription, percent, 2016-2020	80.0%	85.4%	85.2%
High school graduate or higher, percent of people age 25 years+, 2016-2020	81.8%	88.5%	88.5%
Bachelor's degree or higher, percent of people age 25 years+, 2016-2020	30.7%	30.5%	32.9%
With a disability, under age 65 years, percent, 2016-2020	5.9%	8.7%	8.7%
People without health insurance, under age 65 years, percent	19.4%	16.3%	10.2%
In civilian labor force, total, percent of population age 16 years+, 2016-2020	63.0%	58.6%	63.0%
In civilian labor force, female, percent of population age 16 years+, 2016-2020	57.3%	54.4%	58.4%
Total retail sales per capita, 2017	$16,651	$15,881	$15,224
Mean travel time to work (minutes), workers age 16 years+, 2016-2020	32.5	27.9	26.9
Median household income (in 2020 dollars), 2016-2020	$53,975	$57,703	$64,994
Per capita income in past 12 months (in 2020 dollars), 2016-2020	$29,598	$32,848	$35,384
People in poverty, percent	15.0%	12.4%	11.4%
Total employer establishments, 2020	90,482	591,046	8,000,178
Total nonemployer establishments, 2019	576,770	2,508,552	27,104,006
All employer firms, 2017	74,627	438,491	5,744,643
Women-owned employer firms, 2017	15,974	93,163	1,134,549
Minority-owned employer firms, 2017	38,353	102,627	1,014,958
Nonminority-owned employer firms, 2017	29,341	309,451	4,371,152
Veteran-owned employer firms, 2017	2,826	28,391	351,237
Population per square mile, 2020	1,422.10	401.4	93.8
Land area in square miles, 2020	1,899.90	53,652.17	3,533,038.28

Source: U.S. Census Bureau, State and County Quick Facts, American Community Survey, 2016-20 five-year averages.

County Economy

A profile of the economy of Miami-Dade County in 2021 is shown in Table 2.1 with data sourced from the IMPLAN economic model for Miami-Dade County (Implan Group, LLC), which may differ slightly from official data reported by the federal government due to accounting adjustments. Total workforce employment in the County was 1.835 million full-time and part-time jobs, total industry output or revenues was $341.623 billion, and total industry value added (equivalent to GDP) was $190.581 billion. Value added included employee compensation for wages, salaries, and benefits ($101.803 billion); proprietor income ($15.397 billion); other property income such as rents, interest, dividends, royalties, etc. ($62.949 billion); and business taxes on production and imports ($10.433 billion). Note that GDP represents personal income and business net income after deducting business expenses, plus other statistical adjustments, and is not equivalent to gross sales revenues.

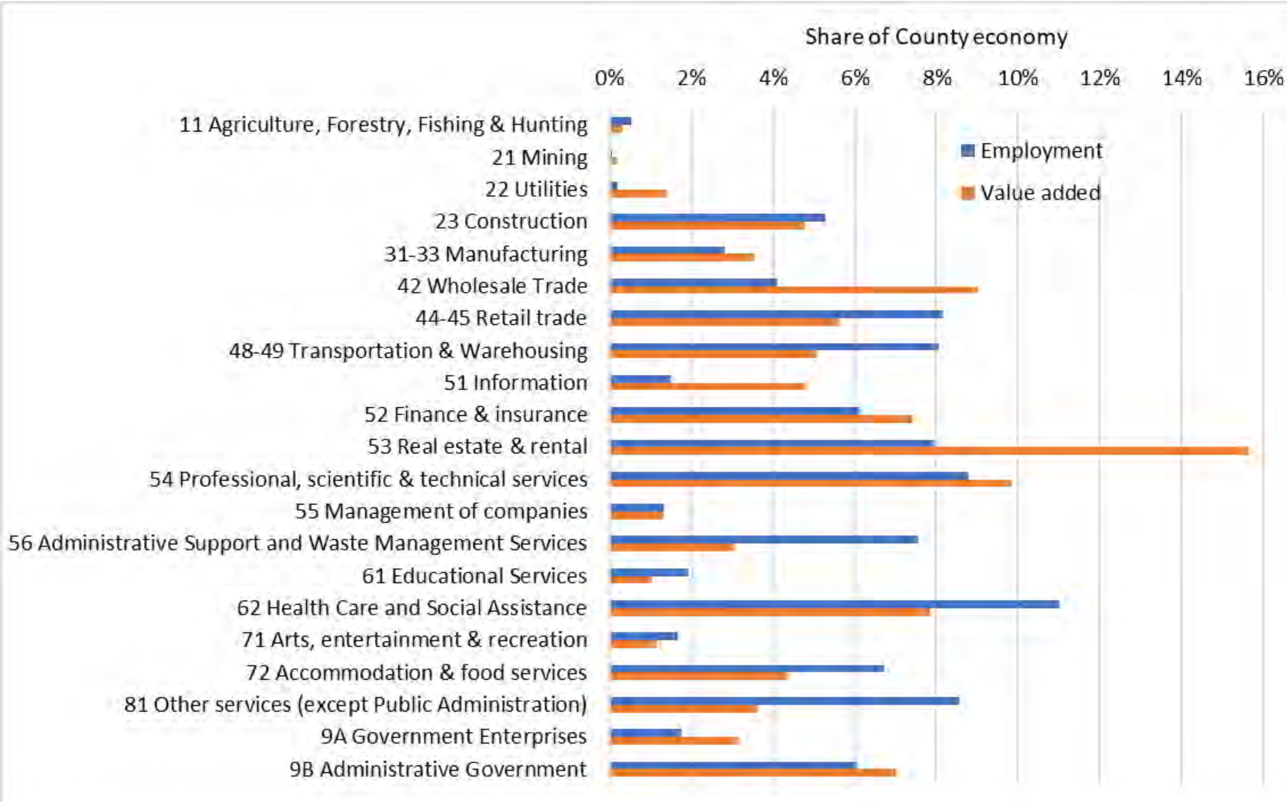
The County had total domestic and international commodity exports of $115.308 billion, representing 34 percent of total output, and had total imports of $85.89 billion. The leading industry sector in terms of employment was health care and social assistance, representing 11.0 percent of all jobs, followed by professional-technical services (8.8%), other services (8.5%), retail trade (8.1%), real estate/rentals (8.0%), transportation-warehousing (8.0%), and administrative-waste services (7.6%), as shown in Figure 2.1. The leading sectors for value added or GDP were real estate/rentals (15.6%), professional-technical services (9.8%), wholesale trade (9.0%), health care-social assistance (7.9%), finance-insurance (7.4%), and administrative government (7.0%). The leading sectors for exports, which bring new money into the County economy, were manufacturing ($17.281 billion, 87% of output within category), wholesale trade ($16.534 billion, 55% of output), real estate-rental ($14.170 billion, 28% of output), transportation-warehousing ($13.395 billion, 58% of output), and professional-technical services ($10.390 billion, 37% of output).

The County economy has a diverse mix of basic and service industries, with large sectors for real estate/rental, finance/insurance, health care/social services, professional/technical services, other services, retail trade, and transportation/warehousing. Travel and tourism (a subset of several industry sectors) is an important industry cluster catering to domestic and international visitors, and the County is an important commercial center for trade in goods and services with Latin America and the Caribbean. County GDP has grown slightly faster than the United States, but slower than the State of Florida over the past two decades, while County employment has grown much faster than the U.S. average (Implan). Note that economic activity in the County in 2021 was affected by the COVID-19 pandemic that started in 2020, with economic recovery continuing into 2022 for the travel/tourism industry.

The agriculture-forestry-fisheries-hunting sector was relatively small in the County's large and highly diverse overall economy, with employment of 9,938 jobs (0.54% of total County employment) and value added of $586 million (0.31% of County GDP) in 2021. Agricultural exports were $866 million, representing 89 percent of output within the sector, the highest share of all industries. It is important to note that agriculture and natural resources are linked to a variety of food manufacturing, distribution, and service sectors in the County and State that collectively represent a significantly larger value to the County economy (Court and Ferreira, 2022).

Output per worker averaged $186,158 for all industries in the County, ranging from a low of $71,907 for educational services to a high of $1.38 million for utilities. Output per worker was $98,054 for agriculture-forestry-fisheries-hunting.

Figure 2.1. Share of employment and value added by industries in Miami-Dade County, 2021



Values in million dollars. Employment represents full-time and part-time jobs. Value added is equivalent to GDP. Industries classified under the North American Industry Classification System (NAICS).
Source: IMPLAN model for Miami-Dade County, FL (Implan Group, LLC).

Table 2.1. Profile of major industries in Miami-Dade County, 2021

NAICS Industry	Employment (Jobs)	Output (M$)	Value Added - GDP (M$)	Employee Compensation (M$)	Proprietor Income (M$)	Other Property Income (M$)	Exports (M$)	Imports (M$)
11 Agriculture, forestry, fishing, hunting	9,938	974	586	346	125	106	866	1,603
21 Mining	827	537	308	64	0	230	257	2,006
22 Utilities	3,561	4,912	2,667	561	125	1,396	2,562	1,146
23 Construction	96,916	17,260	9,091	3,643	3,394	2,205	90	1,423
31-33 Manufacturing	51,459	19,988	6,715	3,239	87	3,144	17,281	54,911
42 Wholesale trade	74,905	29,882	17,175	7,152	992	5,838	16,534	1,225
44-45 Retail trade	149,527	17,375	10,652	6,282	401	2,299	4,252	1,324
48-49 Transportation, warehousing	147,694	23,154	9,658	6,903	507	2,435	13,395	1,440
51 Information	27,439	20,521	9,136	2,846	1,309	4,548	4,223	5,175
52 Finance, insurance	112,367	32,206	14,095	9,849	801	2,969	3,848	8,168
53 Real estate, rental	146,136	49,998	29,790	2,529	1,868	21,997	14,170	431

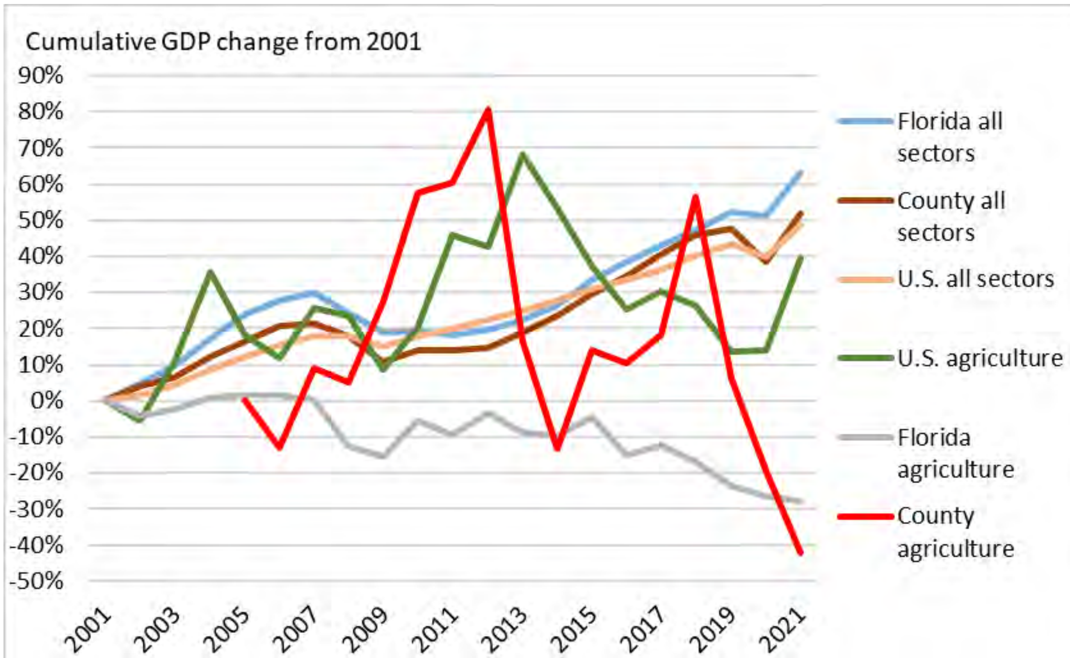
NAICS Industry	Employ-ment (Jobs)	Output (M$)	Value Added - GDP (M$)	Employee Compen-sation (M$)	Proprietor Income (M$)	Other Property Income (M$)	Exports (M$)	Imports (M$)
54 Professional, scientific, technical services	160,769	28,325	18,696	12,737	2,150	2,823	10,390	4,458
55 Management of companies	24,464	4,881	2,515	2,099	170	208	170	1,308
56 Administrative and waste management Services	138,569	12,281	5,807	4,512	893	459	1,567	3,064
61 Educational services	35,383	2,544	1,965	1,791	64	114	1,350	55
62 Health care, social assistance	201,583	24,030	14,954	12,428	825	1,969	8,238	421
71 Arts, entertainment, recreation	30,782	3,209	2,198	1,381	38	685	2,523	797
72 Accommodation, food services	123,137	13,274	8,279	4,896	155	3,004	4,431	3,280
81 Other services (except public administration)	156,750	11,380	6,919	4,529	1,494	448	5,277	253
9A Government enterprises	32,258	11,508	5,991	3,061	0	3,641	3,188	418
9B Administrative government	110,665	13,385	13,385	10,955	0	2,430	0	0
Total	1,835,127	341,623	190,581	101,803	15,397	62,949	115,308	96,081

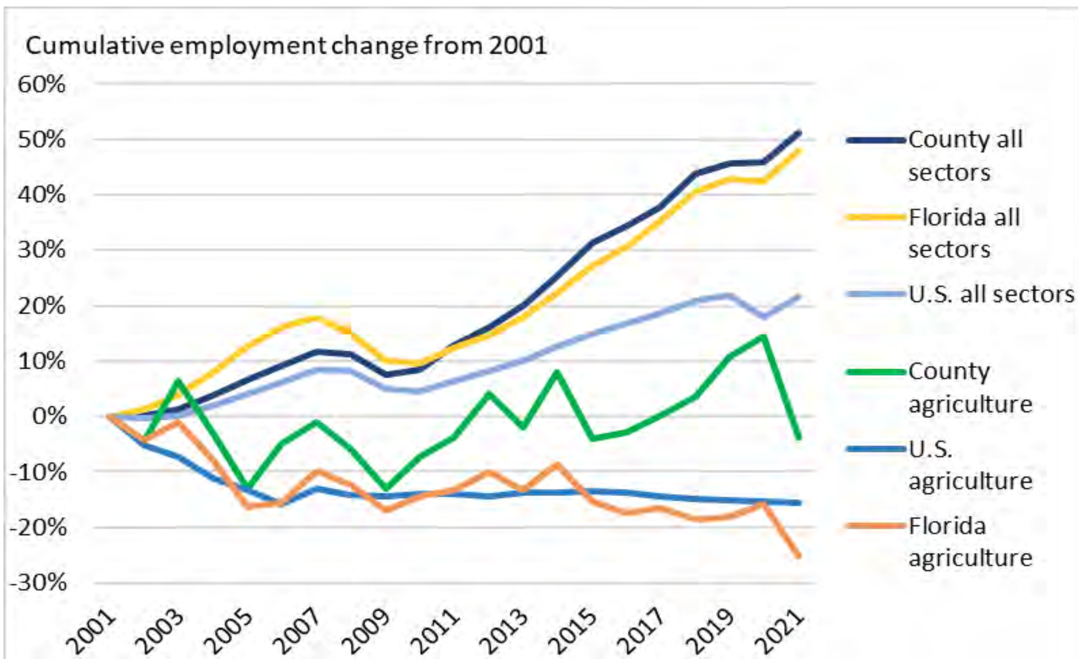
Values in million dollars. Employment represents full-time and part-time jobs.
Industries classified under the North American Industry Classification System (NAICS).
Source: IMPLAN model for Miami-Dade County, FL (Implan Group, LLC).

Agriculture Share of County Economy

The percentage cumulative changes in GDP and employment from 2001 to 2020 for agriculture and all industry sectors in Miami-Dade County, the State of Florida, and the United States are charted in Figure 2.2. County agriculture GDP and employment were highly variable with no clear trend over time, however, county agriculture GDP in 2021 was about 40 percent below what it was in 2005, in constant dollar terms. County agriculture employment was slightly lower in 2021 than in 2001, compared to about a 15 percent decline in employment for U.S. agriculture. This may possibly be due to the greater role of labor-saving technology in conventional agriculture than in specialty crop agriculture.

Figure 2.2. Cumulative percentage changes in GDP (upper) and employment (lower) in Miami-Dade County, the State of Florida, and the U.S., 2001-2021

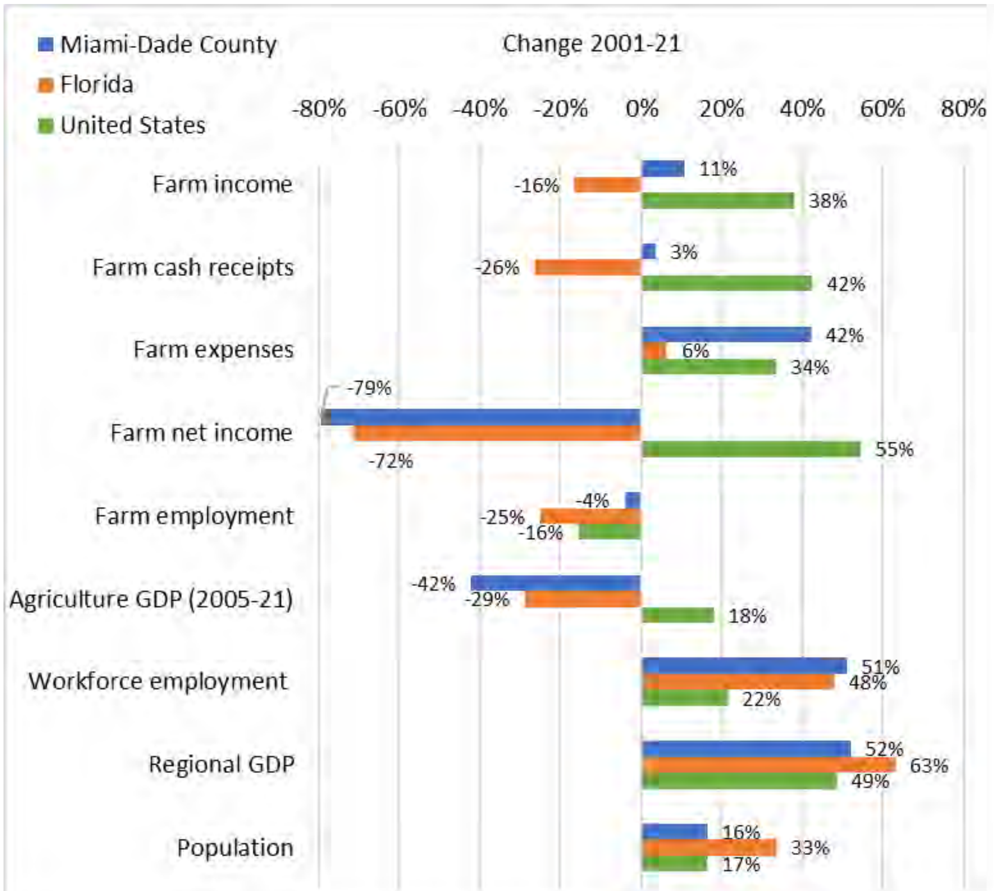




Change since 2005 for agriculture GDP in Miami-Dade County. Values in constant 2021 dollars.
Source: Bureau of Economic Analysis.

Percentage changes in population, GDP, and employment for farm sectors and all industry sectors during 2001-2021 are summarized for the County, State of Florida, and United States in Figure 2.3. Change in population in the County was similar to the U.S., but only about half as high as the percentage increase in Florida. GDP growth was similar for the County, Florida, and United States. Total workforce employment growth was similar in the County and Florida, and more than twice as high as in the U.S. Agricultural sector GDP declined both in the County and Florida, but increased in the United States. Farm sector employment levels declined in the County less than for Florida and the U.S. Farm income declined in Florida but increased in the County and the United States. Farm production expenses increased in the County and the U.S. by similar amounts but increased less in Florida. Farm net income declined by large amounts in the County and in Florida but increased in the United States.

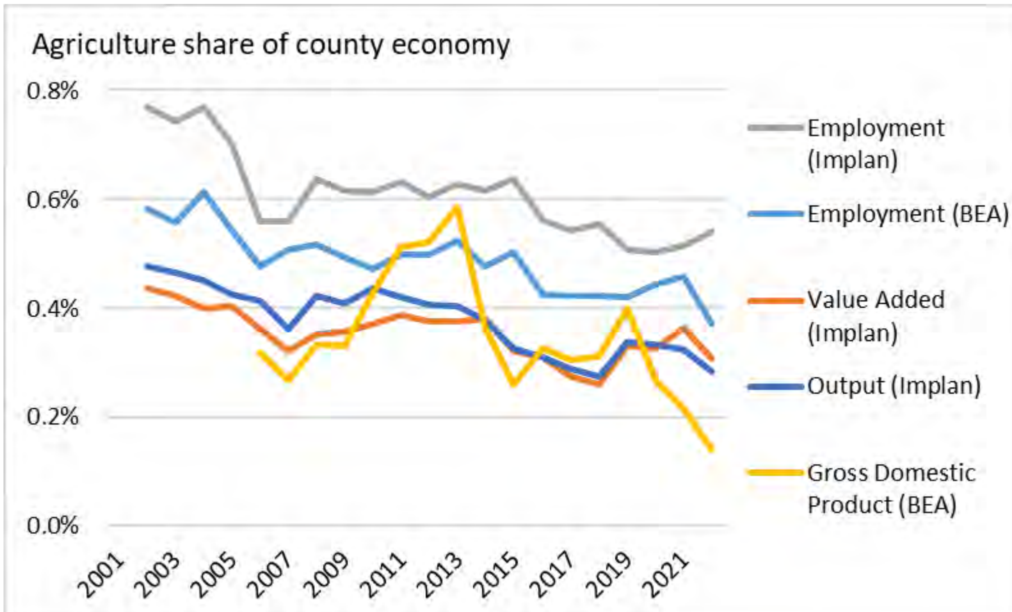
Figure 2.3. Percentage changes in population, GDP, and employment in Miami-Dade County, the State of Florida, and the U.S. for farm sectors and overall economy, 2001-2021



Change since 2005 for agriculture GDP in Miami-Dade County. Monetary changes are in constant 2021 dollars.
Source: Bureau of Economic Analysis.

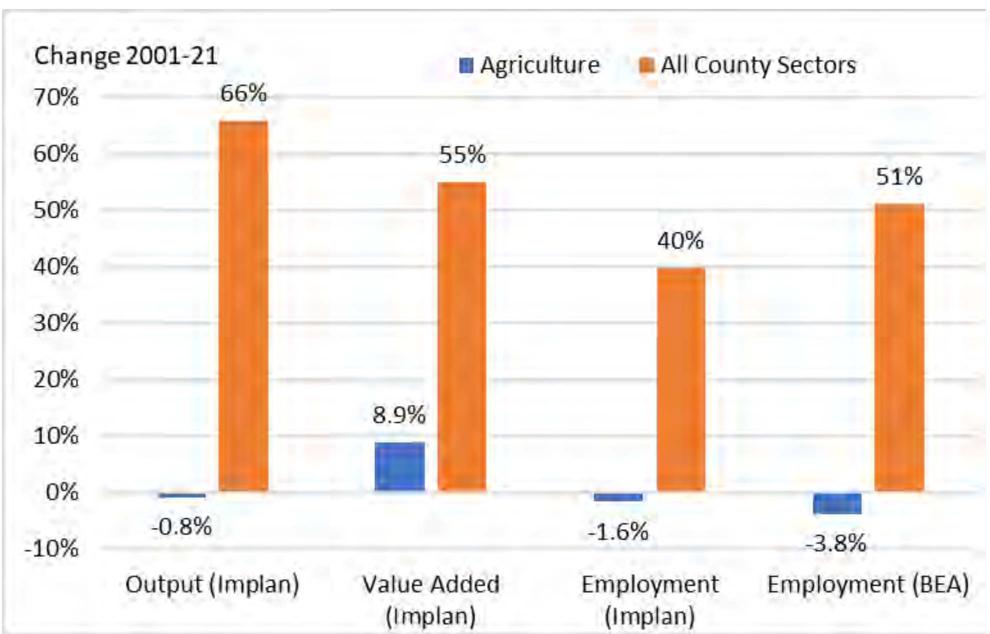
The agriculture share of total employment, value added, and output in Miami-Dade County trended downward during 2001-2021, according to both USDOC-BEA and IMPLAN data sources (Figure 2.4). During this period, agriculture sector employment and output (revenues) decreased, while overall County employment increased significantly, and value added/GDP increased six times more for the County as a whole than for the agriculture sector (Figure 2.5)

Figure 2.4. Trend in agriculture industry share of the Miami-Dade County economy, 2001-2021



Source: Implan and Bureau of Economic Analysis (BEA).

Figure 2.5. Changes in agriculture and all sectors in Miami-Dade County, 2001-2021



Sources: Implan and Bureau of Economic Analysis (BEA).

Farms, Farm Sales and Production Area

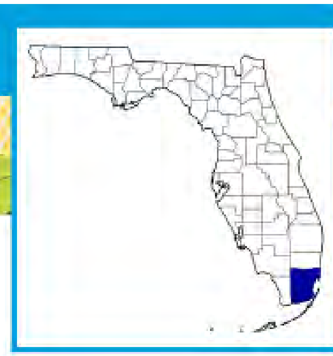
According to the USDA-NASS Census of Agriculture for 2017, Miami-Dade County had 2,752 farms with $837.7 million in market value of products sold, including $827.9 million for crops (98.8 percent of total sales) and $9.9 million for livestock and animal products (Figure 3.1a). Agriculture in the County is dominated by specialty crops, including floriculture, nursery, vegetables, and tropical fruits, with smaller amount of field crops. Floriculture includes flowering plants and tropical foliage plants mostly used in indoors and as patio decorations, while nursery crops are trees and shrubs used for landscaping. Both groups are sometimes jointly referred to as "nursery/greenhouse" or "ornamental horticulture" crops. The largest crop sales were for nursery/floriculture ($697.4 million), followed by vegetables ($86.8 million) and fruits ($43.6 million). The largest livestock/animal product commodities were aquaculture ($3.17 million) and cattle ($2.73 million). Specialty crops and support services accounted for 94 percent of output, 91 percent of value added, and 95 percent of employment in agriculture in the County in 2020 (Implan Group, LLC). The nursery/greenhouse sector alone accounted for 74 percent of output. Miami-Dade County's value of nursery/greenhouse crops was ranked number one among U.S. counties, while vegetables and fruits ranked fourth and tenth among Florida counties, respectively.

Total farm production expenses were $701.25 million, and net cash farm income was $152.02 million in 2017. The average farm size was 29 acres, with 93 percent of farms being less than 50 acres and 73 percent being less than 10 acres. The farms are smaller than average for the U.S., reflecting the high intensity of specialty crops. Annual sales per farm averaged $304,409; however, 82 percent of farms had less than $100,000 in annual sales.

According to the 2017 USDA-NASS Census of Agriculture, the County had 2,752 farms and 4,337 farm producers or operators, who were 62.4 percent male and 37.6 percent female. Consistent with U.S. averages, the age distribution of farm producers in the County was decidedly older, averaging 57.6 years in 2017, with 31.6 percent aged 65 or older, while only 7.3 percent were under age 35 (Figure 3.1b). New and beginning farmers represented 35 percent of producers, indicating that recruitment of new farmers is robust. Although 90.5 percent of producers in the County are White, a majority ethnically identify as Hispanic/Latino (both white and non-white, 58.5%).

Figure 3.1a. Profile of Miami-Dade County agriculture, 2017

2017 CENSUS OF AGRICULTURE County Profile



Miami-Dade County
Florida

Total and Per Farm Overview, 2017 and change since 2012

	2017	% change since 2012
Number of farms	2,752	-7
Land in farms (acres)	78,543	-3
Average size of farm (acres)	29	+4
Total	($)	
Market value of products sold	837,734,000	+39
Government payments	1,733,000	-75
Farm-related income	13,804,000	+51
Total farm production expenses	701,251,000	+60
Net cash farm income	152,020,000	-17
Per farm average	($)	
Market value of products sold	304,409	+49
Government payments (average per farm receiving)	34,659	+25
Farm-related income	19,833	+59
Total farm production expenses	254,815	+72
Net cash farm income	55,240	-11

11 Percent of state agriculture sales

Share of Sales by Type (%)

Crops	99
Livestock, poultry, and products	1

Land in Farms by Use (%) [a]

Cropland	70
Pastureland	13
Woodland	3
Other	14

Acres irrigated: 36,801
47% of land in farms

Land Use Practices (% of farms)

No till	3
Reduced till	1
Intensive till	10
Cover crop	3

Farms by Value of Sales

	Number	Percent of Total [a]
Less than $2,500	840	31
$2,500 to $4,999	307	11
$5,000 to $9,999	344	13
$10,000 to $24,999	387	14
$25,000 to $49,999	212	8
$50,000 to $99,999	171	6
$100,000 or more	491	18

Farms by Size

	Number	Percent of Total [a]
1 to 9 acres	2,001	73
10 to 49 acres	565	21
50 to 179 acres	120	4
180 to 499 acres	37	1
500 to 999 acres	21	1
1,000 + acres	8	(Z)

USDA United States Department of Agriculture
National Agricultural Statistics Service
www.nass.usda.gov/AgCensus

Source: USDA-NASS Census of Agriculture.

Figure 3.1b. Profile of Miami-Dade County agriculture, 2017 (continued)

Miami-Dade County
Florida, 2017
Page 2

2017 CENSUS OF AGRICULTURE *County Profile*

Market Value of Agricultural Products Sold

	Sales ($1,000)	Rank in State [b]	Counties Producing Item	Rank in U.S. [b]	Counties Producing Item
Total	**837,734**	**2**	**67**	**41**	**3,077**
Crops	**827,873**	**2**	**67**	**16**	**3,073**
Grains, oilseeds, dry beans, dry peas	(D)	47	57	(D)	2,916
Tobacco	-	-	5	-	323
Cotton and cottonseed	-	-	13	-	647
Vegetables, melons, potatoes, sweet potatoes	86,834	4	65	39	2,821
Fruits, tree nuts, berries	43,573	10	65	67	2,748
Nursery, greenhouse, floriculture, sod	697,366	1	65	1	2,601
Cultivated Christmas trees, short rotation woody crops	(D)	17	36	(D)	1,384
Other crops and hay	76	58	65	2,696	3,040
Livestock, poultry, and products	**9,861**	**36**	**67**	**2,118**	**3,073**
Poultry and eggs	1,304	19	64	723	3,007
Cattle and calves	2,734	42	65	2,016	3,055
Milk from cows	(D)	36	38	1,152	1,892
Hogs and pigs	(D)	37	61	(D)	2,856
Sheep, goats, wool, mohair, milk	277	5	63	596	2,984
Horses, ponies, mules, burros, donkeys	420	18	66	507	2,970
Aquaculture	3,169	5	55	86	1,251
Other animals and animal products	1,940	9	67	93	2,878

Total Producers [c] 4,337

Sex	
Male	2,707
Female	1,630
Age	
<35	316
35 – 64	2,649
65 and older	1,372
Race	
American Indian/Alaska Native	26
Asian	236
Black or African American	106
Native Hawaiian/Pacific Islander	10
White	3,926
More than one race	33
Other characteristics	
Hispanic, Latino, Spanish origin	2,551
With military service	274
New and beginning farmers	1,517

Percent of farms that:

Have internet access	71
Farm organically	1
Sell directly to consumers	18
Hire farm labor	43
Are family farms	95

Top Crops in Acres [d]

Vegetables harvested, all	20,468
Nursery stock crops	13,415
Beans, snap	7,555
Avocados	6,193
Sweet corn	3,333

Livestock Inventory (Dec 31, 2017)

Broilers and other meat-type chickens	27,135
Cattle and calves	6,876
Goats	950
Hogs and pigs	96
Horses and ponies	2,316
Layers	11,910
Pullets	712
Sheep and lambs	1,674
Turkeys	404

See 2017 Census of Agriculture, U.S. Summary and State Data, for complete footnotes, explanations, definitions, commodity descriptions, and methodology.
[a] May not add to 100% due to rounding. [b] Among counties whose rank can be displayed. [c] Data collected for a maximum of four producers per farm.
[d] Crop commodity names may be shortened; see full names at www.nass.usda.gov/go/cropnames.pdf. [e] Position below the line does not indicate rank.
(D) Withheld to avoid disclosing data for individual operations. (NA) Not available. (Z) Less than half of the unit shown. (-) Represents zero.

Source: USDA-NASS Census of Agriculture.

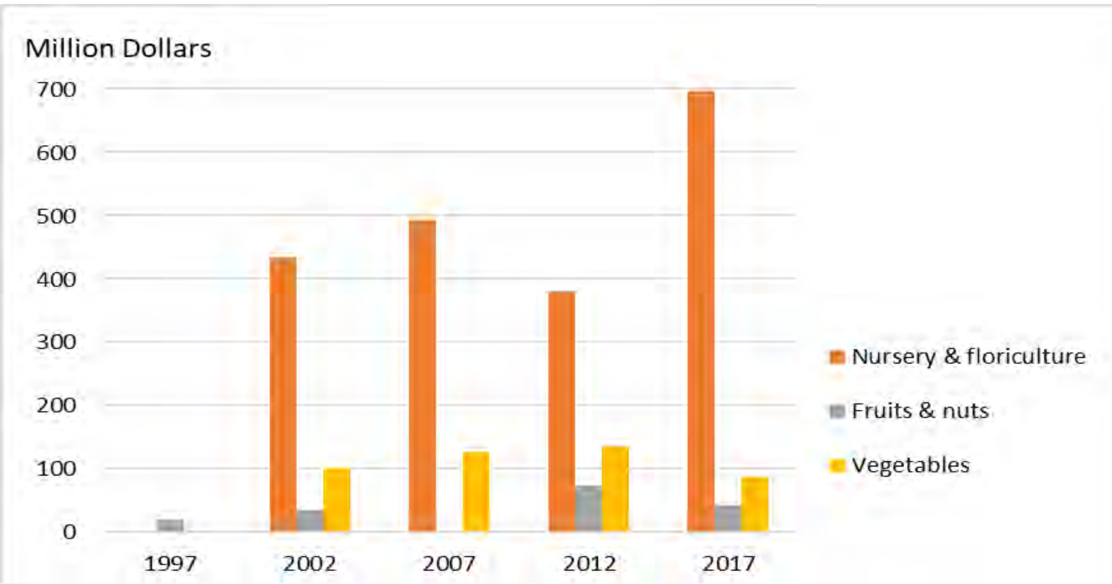
Trends in the number of farm operations, sales, and production area in the County during 1997-2017 from the USDA-NASS Census of Agriculture are summarized in Tables 3.1 through 3.5 and Figure 3.2. Annual sales of specialty crops were $829.5 million in 2017, including $697.4 million (84.1%) for nursery/floriculture, $88.6 million (10.7%) for vegetables/melons, and $43.6 million (5.3%) for fruits (Table 4.1). Total crop sales grew 44.8 percent during 2002-2017, increasing more for nursery/floriculture (+60.5%), but less for fruits (+21.6%), and declining for vegetables/melons (-13.6%). Sales per acre was significantly higher for nursery/floriculture ($39,902) than for fruits ($3,266) or vegetables/melons ($4,663).

Table 3.1. Annual sales by crop group in Miami-Dade County, 1997-2017

Crop Group	1997	2002	2007	2012	2017	Change	Share 2017	Sales/acre 2017
			Million dollars					
Nursery/floriculture	NA	$434.41	$493.71	$380.48	$697.37	60.5%	84.1%	$39,902
Fruits	$20.60	$35.83	NA	$73.69	$43.57	21.6%	5.3%	$3,266
Vegetables/melons	NA	$102.59	$128.10	$136.68	$88.61	-13.6%	10.7%	$4,663
Total	$20.60	$572.83	$621.81	$590.84	$829.54	44.8%	100.0%	$16,650

Data not available (NA) for some crops and years due to nondisclosure rules for small sample size.
Source: USDA-NASS Census of Agriculture.

Figure 3.2. Chart of annual sales by crop group in Miami-Dade County, 1997-2017



Source: USDA-NASS Census of Agriculture.

Trends in the number of farm operations and production area during the 1997-2017 period are summarized in Table 3.2. In 2017 there were 301 floriculture operations, 540 nursery operations, 1,522 fruit tree operations, and 169 vegetable operations. Overall, the number of operations has remained stable or increased over time and has especially increased for fruits. Data are shown for open production areas and protected areas in greenhouses, shade houses, or other structures. Protected production has generally increased for nursery/floriculture and dramatically increased for vegetables. Increased intensification of production under protection is a likely response to extend seasonal activity and to minimize use of scarce land resources in the future. Total crop production under protection in greenhouses or other structures in 2017 was 2,367 acres, representing 4.8 percent of the total crop area of 55,206 acres; protected production area had increased by 126 percent since 1997.

Table 3.2. Crop farm operations and production area in Miami-Dade County, 1997-2017

Crop Group, Item	1997	2002	2007	2012	2017
Floriculture					
Operations with area in production	NA	358	300	377	301
Production area in the open (acres)	2,296	1,793	1,967	2,185	1,702
Production area under protection (acres)	1,000	1,755	1,481	1,423	1,850
Fruits					
Operations with sales	668	1,122	1,354	1,712	1,522
Orchards, area bearing and non-bearing (acres)	13,642	12,862	11,365	21,977	13,343
Production area under protection (acres)	NA	NA	NA	<1	<1
Nursery					
Operations with area in production	NA	380	587	643	540
Production area in the open (acres)	4,320	6,064	10,279	12,584	13,415
Production area under protection (acres)	47	249	991	NA	510
Vegetables/melons					
Operations with production area in the open	149	177	156	108	169
Operations with production under protection (incl. fresh cut herbs)		NA	5	6	20
Production area in the open (acres)		34,473	24,712	21,810	20,632
Production area under protection (acres)	NA	NA	<1	<1	6
Total production area (acres)	55,778	47,436	47,895	58,802	49,824
Total crop area under protection (acres)	1,047	2,005	2,474	1,424	2,367

Note: data not reported for some years due to nondisclosure rules for small sample size (NA).
Source: USDA-NASS Census of Agriculture.

Information on trends in production area or harvested area in the County for 90 specific crops ordered alphabetically is shown in Table 3.3. Data for perennial crops in orchards are given for both bearing (producing) areas and nonbearing areas in development.

Table 3.3. Production area for specific crops in Miami-Dade County, 1997-2017

Crop	1997	2002	2007	2012	2017
Aquatic plants, in the open - acres in production		14	8	11	1
Avocados - acres bearing & non-bearing		7,154	6,773	12,755	6,193
Bananas - acres bearing & non-bearing		105	202	884	680
Beans, snap - acres harvested	17,214	17,924	13,735	11,126	7,555
Bedding plant totals, in the open - acres in production	255	70	126		435
Bedding plant totals, under protection - sq ft in production	320,692	10,181,140			41,378,335
Blueberries - acres grown					59
Bulbs & corms & rhizomes & tubers, dry, under protection - sq ft in production					6,000
Cherimoyas - acres bearing & non-bearing					30
Citrus, other - acres bearing & non-bearing		95	78	149	
Corn, grain - acres harvested	497		503		13
Cucumbers - acres harvested	1,527				867
Cut flowers & cut cultivated greens, in the open - acres in production	332	221	178		191
Cut flowers & cut cultivated greens, under protection - sq ft in production	14,600	45,840		56,360	0
Eggplant - acres harvested	398	0	41	41	50

Crop	1997	2002	2007	2012	2017
Field crops, other - acres harvested		116			
Flowering plants, potted, indoor use, in the open - acres in production	238	265	758	385	660
Flowering plants, potted, indoor use, under protection - sq ft in production	3,828,937	5,964,768		10,512,815	12,448,958
Foliage plants, indoor use, in the open - acres in production	1,471	1,238	904	1,247	301
Foliage plants, indoor use, under protection - sq ft in production	39,399,319	60,271,622	52,498,696	41,412,491	25,599,621
Garlic - acres harvested					6
Ginger root - acres harvested					12
Grapefruit - acres bearing & non-bearing		101	26	12	4
Grapes - acres bearing & non-bearing			0	16	15
Greens, collard - acres harvested			12	11	1
Guavas - acres bearing & non-bearing		306	171	1,270	637
Hay & haylage - acres harvested		369			533
Lettuce - acres harvested			3		17
Limes - acres bearing & non-bearing		622	467	234	0
Loganberries - acres grown					20
Mangoes - acres bearing & non-bearing		1,047	762	1,803	1,808
Melons, watermelon - acres harvested				1	3
Mushrooms - sq ft in production					9,900
Nectarines - acres bearing & non-bearing			15		
Okra - acres harvested	976	383	371	129	183
Onions, green - acres harvested		2			34
Oranges - acres bearing & non-bearing		686	250	28	
Papayas - acres bearing & non-bearing		147	167		126
Passion fruit - acres bearing & non-bearing		12	39	62	61
Peppers, bell - acres harvested		17	0	0	83
Peppers, chile - acres harvested		0	115	41	
Plums & prunes - acres bearing & non-bearing			7	12	41
Potatoes - acres harvested	5,543	1,504		5	
Propagative material, in the open - acres in production			20	42	68
Pumpkins - acres harvested		6			50
Short term woody crops - acres in production		67			59
Sod - acres harvested	0	2,620		1	
Spinach - acres harvested					8
Squash - acres harvested	6,513	5,333	4,689	2,159	1,620
Strawberries - acres harvested				51	
Sugarcane, seed - acres harvested			25	16	
Sugarcane, sugar - acres harvested				689	6
Sweet corn - acres harvested	6,909	4,922	5,490	5,252	3,333
Sweet potatoes - acres harvested	1,457	3,002	2,825		3,197
Tomatoes, in the open - acres harvested	4,038	2,932	3,667	3,809	2,353
Tomatoes, under protection - sq ft in production					5,805
Transplants, commercial, vegetable & strawberry, under protection - sq ft in production			2,800		
Tree nuts, other - acres bearing & non-bearing		176		309	27
Vegetable seeds, under protection - sq ft in production		12,000			
Vegetables, other - acres harvested	1,660		575	20	312

Note: data missing for some years due to small sample size and data nondisclosure rules.
Source: USDA-NASS Census of Agriculture.

Further updated information on diversity and production area of tropical fruit crops in the County in 2018 is shown in Table 3.4. The author commented that area has been increasing in recent years for mango, passionfruit, longan, sugar apple, and guanabana, while area has decreased for avocado due to Laurel Wilt disease (Jonathan Crane, personal communication, August 2023).

Table 3.4. Production area for specific tropical fruit crops in Miami-Dade County, 2018.

Common Name	Scientific Name	Area (acres), 2018
Atemoya	*Annona cherimola x A. squamosa*	Limited
Avocado	*Persea americana*	6,600
Banana	*Musa* hybrids	510
Caimito (star apple)	*Chyrsophyllum cainito*	10
Canistel (egg fruit)	*Pouteria campechiana*	3
Carambola	*Averrhoa carambola*	40
Guanabana	*Annona muricata*	10
Guava	*Psidium guajava*	700
Jackfruit	*Artocarpus heterophyllus*	12
Jujube	*Ziziphus jujube*	10
Longan	*Dimocarpus longan*	1,100
Lychee	*Litchi chinensis*	400
Mamey Sapote	*Pouteria sapota*	600
Mango	*Mangifera indica*	800
Miracle Fruit	*Synsepalum dulcificum*	20
Papaya	*Carica papaya*	300
Passion Fruit	*Passiflora edulis*	60
Pitaya	*Hylocereus undatus* and hybrids	600
Sapodilla	*Manilkara zapota*	200
Soursop	*Annona muricata*	Limited
Spondias	*Spondias* species	4
Sugar Apple	*Annona squamosa*	25
Wax Jambu	*Syzygium samarangense*	2
Total		12,006

Source: Crane, 2018.

Trends in sales and number of operations for livestock and animal products during 1997-2017 are summarized in Tables 3.5 and 3.6. Values of livestock/animal products are relatively small, representing only one percent of overall agriculture sales in the County, although this is changing with the opening of the Atlantic Sapphire aquaculture operation in the County, as described in another section of this report. Livestock/animal product sales fluctuated around $9.37 to $11.97 million over the period 1997-2017. The largest commodities in 2017 were aquaculture ($3.17 million), cattle ($2.73 million), poultry ($1.30 million), specialty animals ($1.94 million), and honey ($1.29 million), although it is difficult to assess relative value of all commodities because sales for some types are reported as number of head rather than dollar value, due to data nondisclosure rules. The total number of livestock/animal product operations in the County has generally increased, although operations are typically very small because of limited land availability and high costs.

Table 3.5. Sales of livestock and animal products (dollars or head) in Miami-Dade County, 1997-2017

Livestock, Animal Product	1997	2002	2007	2012	2017
Total livestock and animal products ($)	9,370,000	4,650,000		11,971,000	9,861,000
Aquaculture ($)				4,185,000	3,169,000
Sheep & goats totals, incl wool, mohair, milk ($)				350,000	277,000
Cattle and calves ($)	429,000	556,000	498,000	918,000	2,734,000
Broiler chickens (head)	320	240			
Layers chickens (head)	506	0	4,351	2,560	2,197
Ducks (head)		800	202	165	22
Equine - horses, ponies, mules, burros, donkeys ($)					420,000
Goats ($)				76,000	73,000
Hogs ($)	29,000	12,000	3,000		
Honey ($)				710,000	1,291,000
Milk and other dairy products ($)	79,000		9,000		
Poultry totals, incl. eggs ($)	432,000				1,304,000
Quail (head)			565		
Rabbits ($)				3,000	66,000
Specialty animal totals, excl. equine ($)		177,000	602,000	2,248,000	1,940,000

Note: data missing for some years due to small sample size and data nondisclosure rules.
Source: USDA-NASS Census of Agriculture.

Table 3.6. Number of livestock and animal products operations with reported sales in Miami-Dade County, 1997-2017

Livestock, Animal Product	1997	2002	2007	2012	2017
Total livestock and animal products	187	199	293	325	388
Aquaculture				53	42
Cattle, calves	54	38	40	48	32
Ducks		4	6	9	3
Equine-horses, ponies, mules, burros, donkeys					82
Geese		5	11	3	4
Goats		15	22	44	18
Hogs	8	10	5	7	10
Honey				26	73
Poultry totals, incl eggs	39	19	120	140	183
Quail			10	8	2
Rabbits, live & pelts			13		
Sheep, incl. lambs	12	11	20	29	44
Specialty animal totals (excl equine)		32	55	45	88
Turkey	9	1	8	10	14
Wool	3	5	3	18	1

Note: Data is missing for some years due to small sample size and data nondisclosure rules.
Source: USDA-NASS Census of Agriculture.

Trends in the number of farms and total farm area by acreage size class in Miami-Dade County are presented in Table 3.7. In 2017, very small farms with less than 10 acres represented 73 percent of farm operations, but only 9 percent of total farm area; small farms with 10 to 99 acres represented 23 percent of operations and 20 percent of the total area; medium sized farms of 100 to 999 acres represented 4 percent of operations and 43 percent of area; large farms with 1,000 or more acres represented 0.3 percent of operations and 28 percent of farm acreage. The highly skewed farm size distribution is typical of U.S. agriculture. The number and aggregate area of small and very small farms in Miami-Dade County has grown over time, while medium and large farms have decreased, a trend that is expected to continue in the future.

Table 3.7. Farm size distribution in Miami-Dade County, 1997-2017

Area Operated (Acres)	1997	2002	2007	2012	2017	Change 1997-2017	Percent of Total, 2017
				Area (acres)			
Less than 10	4,296	5,341	6,601	7,371	6,970	2,674	8.9%
10 to 49	10,012	11,491	10,104	12,919	10,866	854	13.8%
50-99	5,357	6,734	4,671	5,460	4,890	-467	6.2%
100-499	21,745	27,812	17,579	19,649	17,261	-4,484	22.0%
500-999	17,798	16,378	6,203	18,286	16,684	-1,114	21.2%
1,000 or more	25,868	22,617	14,481	17,618	21,872	-3,996	27.8%
Total	85,076	90,373	59,639	81,303	78,543		100%
				Number operations			
Less than 10	1,160	1,423	1,777	2,045	2,001	841	72.7%
10 to 49	520	587	552	697	565	45	20.5%
50-99	78	98	69	84	71	-7	2.6%
100-499	86	103	78	93	86	0	3.1%
500-999	26	22	8	25	21	-5	0.8%
1,000 or more	17	11	14	10	8	-9	0.3%
Total	1,887	2,244	2,498	2,954	2,752	865	

Source: USDA-NASS Census of Agriculture.

Information on farm producer land tenure in the County in 2017 is shown in Table 3.8. Of the total farm acreage, 42,915 acres (54.6%) was owned by the farm producer and 35,628 acres (45.4%) was rented by tenant operators. Trends in cash rents for farmland in the County, region, and state are discussed in the report section on Urban Development.

Table 3.8. Farm producer land tenure in Miami-Dade County, 2017

Farm producer tenure	Farms	Acres	Percent
Full owners	2,313	22,382	28.5%
Part owners	219	42,670	54.3%
Owned land in farms		20,533	26.1%
Rented land in farms		22,137	28.2%
Tenants	220	13,491	17.2%
Total	2,752	78,543	100%
Total owned		42,915	54.6%
Total rented/tenants		35,628	45.4%

Source: USDA-NASS Census of Agriculture.

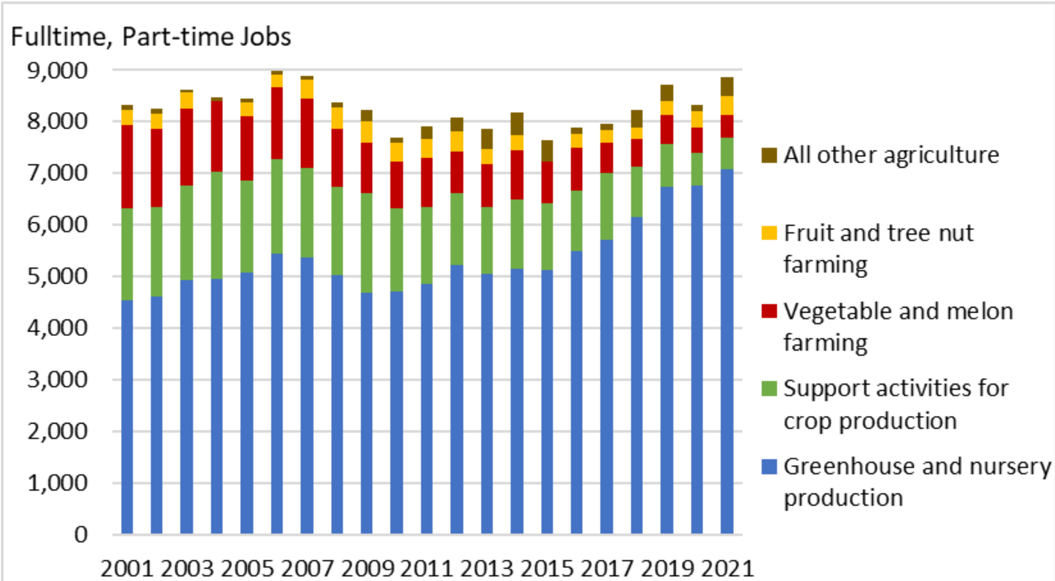
Farm Employment and Earnings

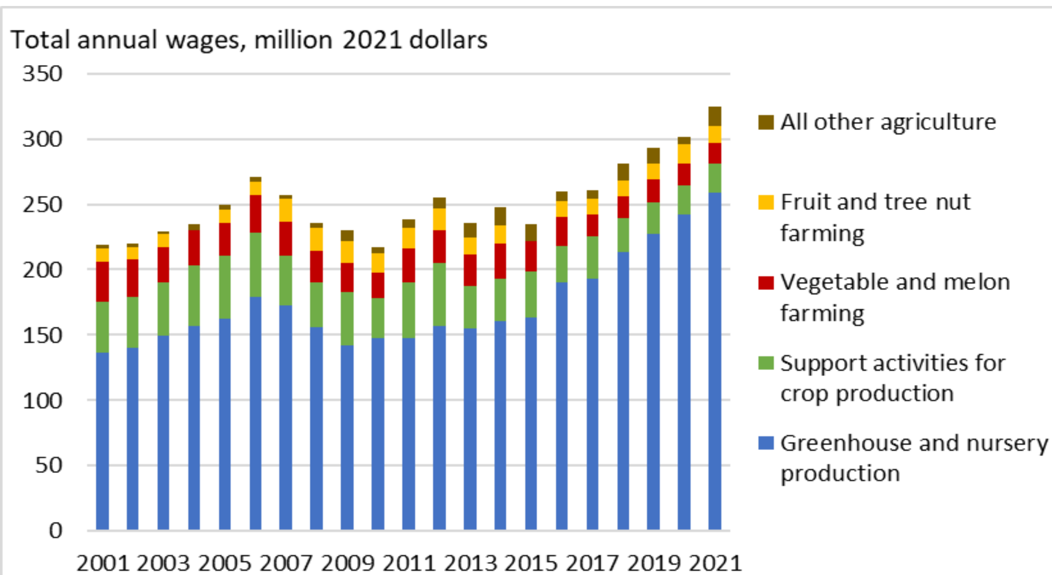
Specialty crop agriculture in Miami-Dade County is highly labor intensive and requires a large workforce for planting, cultivation, and harvesting activities for annual crops, and ongoing maintenance activities for perennial or tree crops. Work in agriculture typically is physically demanding; performed under difficult environmental conditions; sometimes has long hours; often has irregular, part-time, or seasonal schedules; and is relatively low paid compared to other occupations. The workforce is generally young, unskilled, with low-to-moderate educational attainment, and may have few other job opportunities (U.S. Department of Labor, Occupational Outlook, Agricultural Workers). According to the National Agricultural Workers Survey, 44 percent of agricultural workers in the U.S. were determined to be unlawful or undocumented immigrants (Gold et al., 2022).

Increasingly, foreign workers under the H-2A Temporary Agricultural Workers visa program are being used in agriculture, where employers commit to hire workers for a specified period up to a year, with extensions allowed up to three years, pay a guaranteed wage rate, and provide housing and transportation (U.S. Department of Homeland Security). Over the last decade, the number of agricultural jobs in the U.S. under the H-2A program increased from 75,000 in 2010 to 275,000 in 2020 (Castillo et al., 2022). Florida is the leading state for H-2A agricultural workers, with 39,064 jobs certified under the program in 2020. The visas were used by 1,134 farms, mostly for vegetable or fruit harvesting or crop support, and represent about 27 percent of the overall agricultural workforce in Florida. However, only 292 H-2A workers were requested in Miami-Dade County in the fourth quarter of 2022 (U.S. Dept. of Labor, Employment and Training Administration, 2023). The Adverse Effect Wage Rate that H-2A employers are required to pay is $12.41 per hour in Florida in 2022. The H-2A program is not attractive for smaller growers because of the high expenses for wages, housing, transportation, and administrative overhead.

Trends in employment and annual wages in the agriculture, forestry, fisheries, and support services sectors in Miami-Dade County during 2001-2021 are shown in Figure 4.1. According to data from the U.S. Department of Labor Quarterly Census of Employment and Wages (2021) there were a total of 508 agricultural employer establishments reporting in the County; however, it is important to note that not all non-employer establishments or sole proprietorships are required to report employee and payroll information. In 2021, there were an average of 8,872 full-time and part-time jobs, including 7,068 in the nursery/greenhouse sector, 443 in vegetable/melon farming, 351 in fruit farming, and 627 in crop production support services. During 2001-2021, the overall number of jobs increased by 6.6 percent, but fluctuated during these years from almost 9,000 in 2006 to 7,600 in 2015. Reflecting broad trends in the markets for these industries in the County, jobs increased for nursery/greenhouse (56%) and fruit farming (17%), but decreased for vegetable farming (-72%), aquaculture (-3%), other animal production (-53%), and farm support services (-65%). For comparison, the total County workforce increased by 13 percent during this period. Nursery/greenhouse industry employment as a share of total employment in the County is five times more concentrated than for employment in the U.S. as a whole.

Figure 4.1. Employment and annual wages for agriculture and related sectors in Miami-Dade County, 2001-21



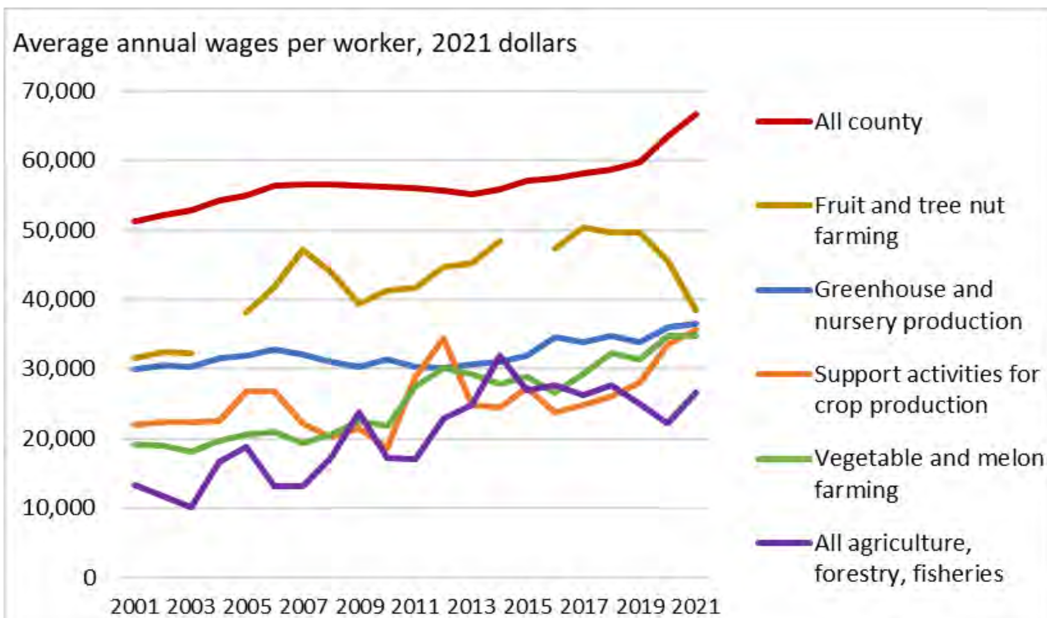


Wages adjusted for inflation with the GDP Implicit Price Deflator (USDOC-BEA).
Source: USDOL-Bureau of Labor Statistics, Quarterly Census of Employment and Wages.

Annual wages paid in the agriculture, forestry, fisheries, and support services sectors in the County were $325 million in 2021, including $259 million for nursery/greenhouse, $15 million for vegetable/melon farming, $14 million for fruit farming, and $22 million for crop production support services. During 2001-2021, total wages increased by 48 percent in inflation-adjusted terms, including increases for nursery/greenhouse (90%), fruit farms (43%), and aquaculture (140%), but decreases for vegetables/melons (-44%), other animal production (-34%), and farm support services (-44%). Wages in most agriculture sectors have steadily grown since 2015, after recovering from the 2007-2009 recession and following period of low growth. For comparison, total wages for all workers in the County grew by 47 percent during 2001-2021, slightly lower than for agriculture/forestry/fisheries/support services sectors.

Trends in average annual wages per worker in Miami-Dade County are shown in Figure 4.2. The average annual compensation per worker in agriculture, forestry, and fisheries was $26,534 in 2021, which was well below the average for the entire County workforce ($66,685). Wages were somewhat higher in the sectors of fruit farming ($38,468), greenhouse/nursery ($36,614), and crop production support services ($35,677), which tend to be more full-time or year-round activities. Annual wages were significantly higher in aquaculture ($62,422), other animal production ($44,342), and animal production support services ($42,939), although these are small sectors in the County (not shown in figure). Overall annual wages for agriculture-related sectors doubled during 2001-2021 in constant dollar terms, compared to a 30 percent increase for the entire County workforce. Wages increased most for vegetable farming (81%) and crop production support activities (62%), but less for fruit farming (22%) and greenhouse/nursery (22%). The increase in average wages in agriculture is a favorable sign for the industry; however, wages still remain well below the average for the County, making it challenging to recruit and retain employees.

Figure 4.2. Average annual wages per worker in the agriculture related sectors and all industry sectors in Miami-Dade County, 2001-2021



Note: data for some years were not available, indicated by discontinuous chart lines.
Values adjusted for inflation with the GDP Implicit Price Deflator (USDOC-BEA).
Source: U.S. Department of Commerce, Bureau of Labor Statistics, Quarterly Census of Employment and Wages.

Farm Income, Expenses, Net Income and Return on Assets

Assessment of trends in income and expenses is critically important to understanding the viability and sustainability of an industry. Data on farm income and expenses in Miami-Dade County in 2021 from the U.S. Department of Commerce, Bureau of Economic Analysis (USDOC-BEA) is shown in Table 5.1. These data are based on systematically collected economic data, including federal income tax returns, and are considered highly reliable; however, data are reported only in aggregate for the farm sector, and do not include related sectors for forestry, fishing, and agricultural support services.

In 2021, total farm income was $950 million, including cash receipts from marketing ($860 million), other income from government payments and miscellaneous ($89 million), and inventory change ($775,000). Total farm production expenses were $905 million, including: $305 million for farm labor, representing 34 percent of total expenses; $139 million for seed purchases (15%); $76 million for fertilizer and chemicals (8%); $27 million for petroleum products (3%); $353 million for other expenses for machinery, depreciation, interest, rent, taxes, etc. (39%); and $5 million for animal feed and livestock (<1%). Net farm income was $45 million.

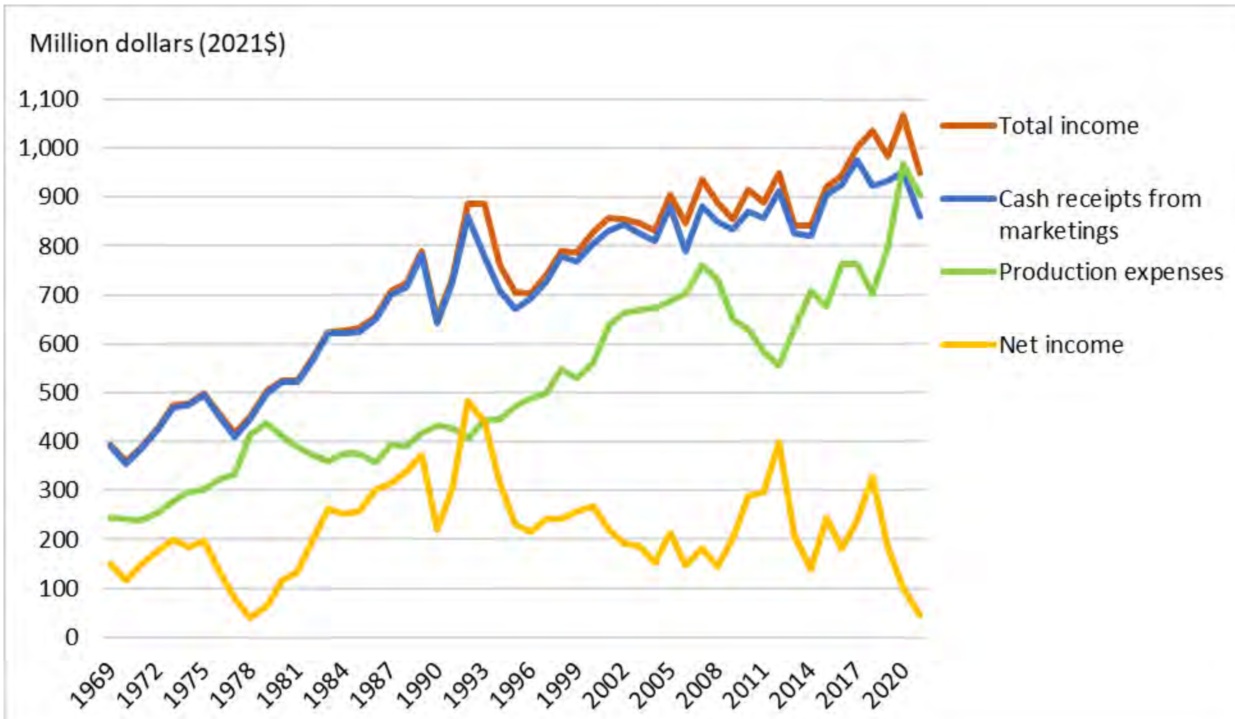
Table 5.1. Farm income and expenses in Miami-Dade County, 2021

Item	Thousand Dollars
Cash receipts from marketings (thousands of dollars)	860,405
Cash receipts: Livestock and products	13,080
Cash receipts: Crops	847,325
Other income	89,146
Government payments	47,406
Imputed and miscellaneous income received	41,740
Value of inventory change	775
Production expenses	904,745
Feed purchased	3,831
Livestock purchased	1,167
Seed purchased	138,893
Fertilizer, lime, and ag. chemicals	75,824
Petroleum products purchased	26,945
Hired farm labor expenses	305,040
All other production expenses	353,045
Value of inventory change	775
Total income	949,551
Net income	44,806

Source: USDOC-Bureau of Economic Analysis.

Trends in farm income and expenses in the County over the 53-year period of 1969 to 2021 are shown in Figure 5.1. In general, production expenses have risen faster than total income in recent years, leading to a downward trend in net income. Total farm income in constant dollar terms increased 2.4 times from $395 million in 1969 to $950 million in 2021, or an average of 2.7 percent annually. Income decreased in 2021 from a peak of $1.024 billion in 2020. Production expenses increased from $360 million in 1969 to $905 million in 2021. Expenses dramatically increased in 2020-2021, possibly due to higher labor costs for increasing use of H-2A workers, supply chain disruptions stemming from the COVID-19 pandemic, and additional costs associated with pandemic safety protocols. Net income fluctuated widely during the period of record from under $50 million to nearly $500 million. As a result of reduced revenues and higher production costs, net income was significantly reduced in 2021, reaching the lowest level since 1978. Further analysis and discussion of trends in farm production expenses is provided in the report section *Increasing Production Costs*.

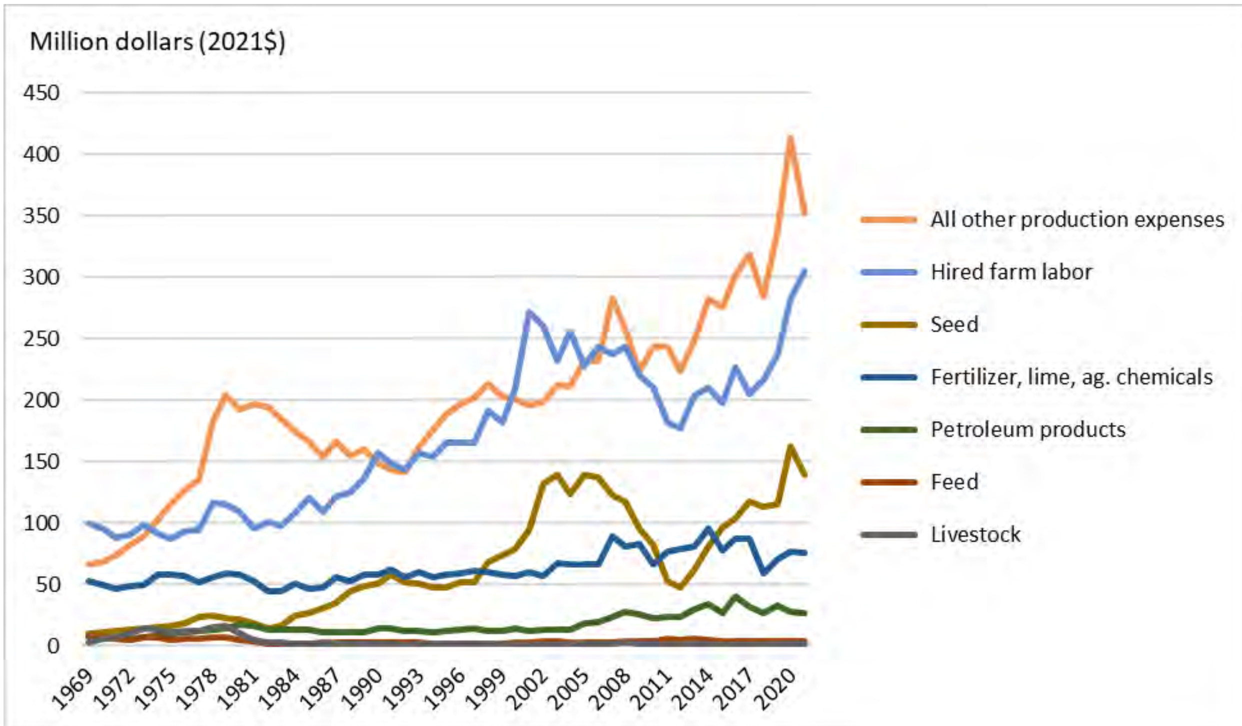
Figure 5.1. Trend in farm income, production expenses and net income in Miami-Dade County, 1969-2021



Values in constant 2021 dollars adjusted using GDP Implicit Price Deflator. Source: USDOC-Bureau of Economic Analysis.

A breakdown of trends in farm production expenses shows that hired farm labor, seeds, and all other miscellaneous production expenses have increased significantly during 1969-2021 (Figure 5.2).

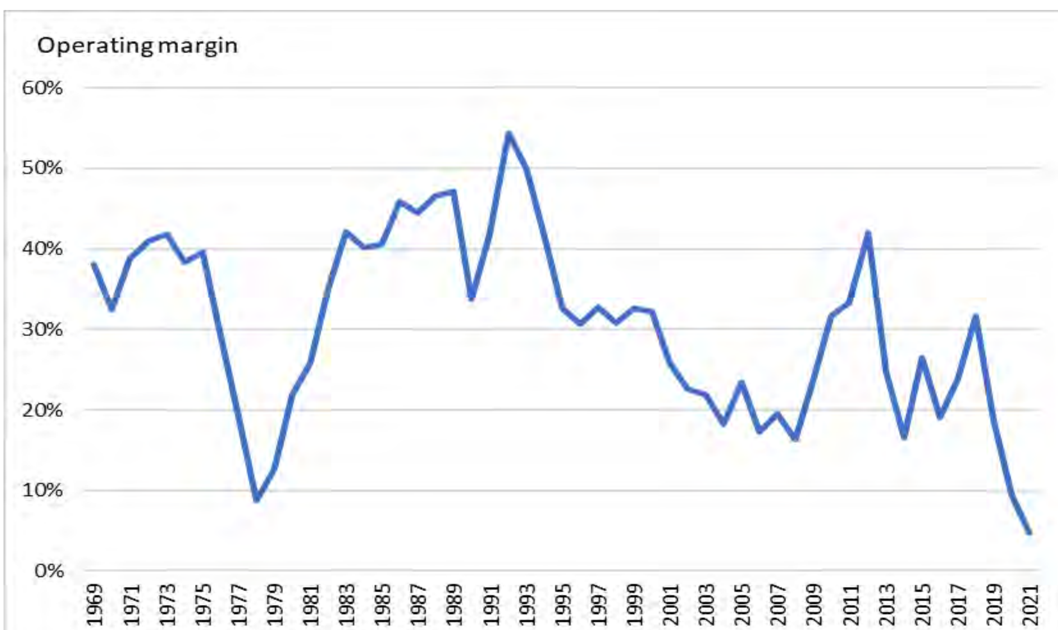
Figure 5.2. Trend in farm production expenses in Miami-Dade County, 1969-2021



Values in constant 2021 dollars adjusted using GDP Implicit Price Deflator. Source: USDOC-Bureau of Economic Analysis

Operating margin is a measure of profitability calculated as the ratio of net income to total income. Farm operating margin in the County during 1969-2021 is shown in Figure 5.3. It is apparent that net margin has been extremely volatile, ranging from less than 10 percent to over 50 percent of total income in some years, with an average of 30 percent over the period. Farm operating margin fell to 4.8 percent in 2021, the lowest on record.

Figure 5.3. Farm operating margin in Miami-Dade County, 1969-2021



Source: USDOC-Bureau of Economic Analysis.

Information on assets, net income, and return on investment for farms in Miami-Dade County during 1997-2017 are summarized in Table 5.2. Total current value of fixed assets in land, buildings, machinery, and equipment increased from $1.18 billion in 1997 to $3.25 billion in 2017 in constant dollars. Land and buildings represented over 90 percent of total assets. Machinery and equipment are considered intermediate assets with a useful life of up to 10 years, while land and buildings are long-term assets with a life of more than 10 years. Note that this information does not account for working capital such as inventories, cash on hand, and accounts receivable. As a measure of capital investment intensity, total assets per acre of agricultural land increased steadily from $14,157 to $41,475 during this period.

Rate of return on assets was calculated by adding back interest expenses to net farm income, then dividing by total assets. The rate of return on assets for Miami-Dade County farms has been quite variable over time, but generally declined from over 21 percent in 1997 to under 8 percent in 2017 (Table 5.2). For perspective, the rate of return on assets for all farms in the U.S. was 4.48 percent in 2017, so Miami-Dade County farms are still relatively profitable (USDA-ERS, Farm Income and Wealth Statistics). Note that this figure for U.S. farms includes real capital gains on farmland values through sales of farmland, while the rate of return on operating income was only 1.39 percent, indicating that many farmers capitalized on gains in farmland values.

Table 5.2. Farm assets, net farm income and return on assets in Miami-Dade County, 1997-2017

	1997	2002	2007	2012	2017
	Million 2020 dollars				
Current Value Land, Buildings	$1,054.1	$1,716.7	$2,274.0	$2,348.8	$3,102.2
Current Value Machinery, Equipment	$129.2	$135.3	$138.9	$159.9	$149.9
Total Fixed Assets	$1,183.3	$1,852.1	$2,412.8	$2,508.8	$3,252.1
Total Assets Per Acre	$14,157	$20,806	$36,028	$31,022	$41,475
Net Farm Income	$232.6	$185.2	$174.8	$382.6	$233.5
Interest Expense	$17.9	$17.1	$16.0	$13.8	$17.3
Rate of Return on Assets	21.2%	10.9%	7.9%	15.8%	7.7%

Values deflated with GDP Implicit Price Deflator to 2020 dollars.
Sources: USDA-NASS Census of Agriculture (assets, interest expense, land area), and Bureau of Economic Analysis (net farm income).

Economic Contributions of Agriculture

Information on agricultural sector activity in 2021 was used to estimate total economic contributions to Miami-Dade County using the IMPLAN regional economic modeling system licensed from Implan Group, LLC. This type of model is known as an input-output, social accounting matrix (I-O/SAM). A premise of input-output analysis is that the structure of the economy is technologically fixed, such that a given change in the final demand, output, or employment for a particular industry or region will lead to predictable changes in other linked sectors of the economy (Miller and Blair, 2009). The IMPLAN model and database contains economic and sociodemographic data for all U.S. states and counties, with 546 industry sectors, 10 household income groups, and local, state, and federal government sectors. Industries are defined according to the North American Industry Classification System (NAICS) based upon the principal types of goods and services produced. Results are available for the economic metrics of employment (full-time and part-time jobs), output (business revenues), value added, employee compensation (wages, salaries, benefits, business owner income), other property income (dividends, interest, rents, royalties, etc.), business taxes, and detailed local-state and federal government tax revenues. Value added represents the difference between the value of input materials and services purchased and the value of sales revenues for finished products or services delivered, and is a basic measure of personal and business net income, equivalent to Gross Domestic Product (GDP). Note that output and value added are separate economic measures and should not be added together. Results were estimated for direct, indirect, and induced multiplier effects. Direct effects represent the original activity in the sectors being analyzed, while indirect effects represent the supply chain activity of businesses providing input goods and services to agricultural production, and induced effects represent household income used for personal consumption spending by directly and indirectly supported employees. Direct, indirect, and induced effects can be reflected in employment, value added (GDP), output numbers, and other metrics.

In this study, the 2021 IMPLAN regional economic model for the County was used to evaluate economic contributions of the agricultural sector. This analysis assesses ongoing economic activity associated with the agricultural industry rather than treating it as a new industry, so the results represent “economic contributions” instead of “economic impacts” (Watson et. al, 2007). The analysis was specified as an industry contribution analysis in the IMPLAN online app, with input values adjusted (Cheney, 2016).

IMPLAN model data for the agriculture/forestry/fisheries/hunting sectors in Miami-Dade County in 2021 is summarized in Table 5.3. These sectors had direct employment of 9,938 full-time and part-time jobs, output or revenues of $975 million, and value added of $586 million, which included employee compensation of $346 million, proprietor income of $125 million, property income of $106 million, and business taxes on production and imports of $9.9 million. Total domestic and international exports of agricultural commodities were $866 million and total imports were $1.603 billion. Note that information is not shown for agricultural commodities of tree nuts, grains, oilseeds, cotton, and tobacco, which had little or no production in the County. Total exports by the agricultural sector represented 89 percent of industry output, bringing new dollars into the County economy to stimulate additional final demand and greater economic activity through economic multiplier effects.

Table 5.3. Agriculture-forestry-fishing-hunting sector data for economic contribution analysis in Miami-Dade County, 2021

Industry Sector	Employ -ment (Jobs)	Output (M$)	Value Added (M$)	Employee Compen-sation (M$)	Proprietor Income (M$)	Other Property Income (M$)	Business Tax (M$)	Exports (M$)
Greenhouse, nursery, and floriculture production	6,026	695.6	384.4	206.1	88.8	84.2	5.3	558.3
Support activities for agriculture and forestry	2,090	99.7	97.0	100.8	4.0	-8.8	1.0	87.2
Vegetable/melon farming	698	84.0	40.1	13.0	15.8	10.2	1.1	86.7
Fruit farming	434	43.7	25.7	6.4	10.4	8.1	0.8	42.9
Commercial fishing	345	11.9	11.8	1.1	0.2	9.1	1.4	24.2
Commercial logging	140	14.6	9.3	8.7	0.0	0.5	0.2	14.5
Forestry, forest products, and timber tract production	85	10.8	9.0	8.0	0.0	0.9	0.1	9.6
Sugarcane and sugar beet farming	54	1.7	1.0	0.8	0.4	-0.1	-0.1	1.8
Animal production, except cattle and poultry and eggs	43	6.5	5.9	0.8	4.3	0.8	0.0	16.5
Beef cattle ranching and farming	13	2.3	0.8	0.0	0.5	0.3	0.0	2.0
Commercial hunting and trapping	4	0.6	0.5	0.0	0.0	0.4	0.0	16.7
Dairy cattle and milk production	3	1.5	0.3	0.1	0.1	0.1	0.0	1.5
Poultry and egg production	2	1.3	0.2	0.1	0.0	0.0	0.0	1.0
Total	9,938	974.5	586.2	346.0	124.5	105.8	9.9	866.1

Values in million dollars or full-time and part-time jobs.
Source: IMPLAN model online application and County data, 2021 (Implan Group, LLC).

Economic contributions of agriculture-forestry-fisheries-hunting industries in Miami-Dade County in 2021 are summarized in Table 5.4. Total economic contributions included employment of 12,836 full-time and part-time jobs, industry output or sales revenues of $1.555 billion, and value added (GDP) of $902 million, which included employee compensation ($494 million), proprietor income ($148 million), other property income ($220 million), and business taxes on production and imports ($40 million). Contributions to government tax revenues totaled $183 million, including federal taxes ($129 million), state taxes ($24 million), and Countywide and sub-County taxes for municipal service districts such as schools, police, fire services, libraries, and waste collection ($30 million). The ratio of total output contribution ($1.55 billion) to direct output ($974 million) implies an overall multiplier effect of 1.60; in other words, $60 in additional sales dollars are generated per $100 of direct agricultural activity. Indirect (industry supply chain) and induced (employee household spending) multiplier effects accounted for about one-quarter to one-third of total contributions to employment, value added, and output.

Table 5.4. Economic contributions metrics of the agriculture-forestry-fisheries-hunting industries by multiplier type in Miami-Dade County, 2021

Impact	Direct	Indirect	Induced	Total
		Number of Jobs		
Employment (Jobs)	9,938	1,016	1,882	12,836
Wage and salary employment	7,860	602	1,254	9,716
Proprietor employment	2,078	414	629	3,120
		Million Dollars		
Output	974.49	247.76	332.32	1,554.57
Value Added	586.25	122.89	193.48	902.62
Employee Compensation	345.99	53.56	94.68	494.23
Proprietor Income	124.55	11.09	11.98	147.62
Other Property Income	105.82	42.05	72.90	220.76
Tax on Production and Imports	9.90	16.19	13.92	40.01
Total Tax	111.73	31.53	39.54	182.79
County and Sub-County	7.53	12.15	10.46	30.13
State Tax	6.48	9.04	8.10	23.62
Federal Tax	97.72	10.33	20.99	129.05

Source: IMPLAN online model application and County data, 2021 (Implan Group, LLC).

Total economic contributions of agriculture are summarized by North American Industry Classification System (NAICS) industry group in Table 5.5. These results show the direct contributions of agriculture, along with the indirect and induced contributions of agriculture to other industry sectors in the County. Sectors in which agriculture generated large employment contributions included health care-social assistance (402 jobs), real estate-rentals (307 jobs), transportation-warehousing (309 jobs), retail trade (301 jobs), accommodation/food services (225 jobs), finance-insurance (248 jobs), and administrative-waste services (220 jobs). Other sectors with large value added (GDP) contributions generated by agriculture included real estate-rentals ($68 million), wholesale trade ($51 million), finance-insurance ($33 million), health care-social assistance ($29 million), retail trade ($21 million), transportation-warehousing ($17 million), and professional-technical services ($19 million).

Table 5.5. Economic contributions by agriculture/forestry/fisheries/hunting sectors to major industry groups in Miami-Dade County, 2021

NAICS Industry	Employ-ment (Jobs)	Output (M$)	Value Added (M$)	Employee Compen-sation (M$)	Proprietor Income (M$)	Property Income (M$)
11 Agriculture/forestry/fishing/hunting	9,938	974.5	586.2	346.0	124.5	105.8
21 Mining	1	1.0	0.6	0.1	0.0	0.5
22 Utilities	11	15.9	8.8	1.8	0.3	4.9
23 Construction	25	6.4	2.7	0.9	0.9	0.9
31-33 Manufacturing	18	13.5	3.8	1.4	0.0	2.3
42 Wholesale trade	209	84.0	51.4	19.2	2.4	14.7
44-45 Retail trade	301	35.1	21.3	12.0	0.9	4.9
48-49 Transportation, warehousing	309	42.1	16.8	11.6	2.0	3.7
51 Information	39	27.2	12.2	4.0	1.5	6.1
52 Finance/insurance	248	77.5	32.8	21.6	1.7	8.2
53 Real estate/rental	307	114.6	68.3	6.1	4.9	49.2
54 Professional/scientific/technical services	155	27.5	18.5	11.8	2.0	4.0
55 Management of companies	45	8.9	4.6	3.8	0.3	0.4
56 Administrative support/waste management services	220	20.3	9.7	7.0	1.4	1.4
61 Educational Services	48	3.7	2.7	2.4	0.1	0.2
62 Health care/social assistance	402	45.6	28.6	24.0	1.8	3.5
71 Arts/entertainment/recreation	46	4.2	2.9	1.9	0.0	0.8
72 Accommodation/food services	225	22.6	13.3	8.2	0.1	4.9
81 Other services (except public administration)	247	15.9	9.9	6.4	2.7	0.0
9A Government enterprises	41	14.1	7.5	3.9	0.0	4.4
Total direct, indirect, and induced effects	12,836	1,554.6	902.6	494.2	147.6	220.8

Values in million dollars or full-time and part-time jobs.
Industries are classified by the North American Industry Classification System (NAICS).
Source: IMPLAN online model application and County data, 2021 (Implan Group, LLC).

Detailed sources of tax contributions are shown in Table 5.6. These tax contributions reflect prevailing tax rates at federal, state, and local levels in 2021. Contributions to government tax revenues totaled $183 million, including: federal taxes of $129 million for personal and corporate income, payroll, severance and excise taxes and customs fees; and state and local taxes of $54 million for payroll, property, sales, motor vehicle and fuel taxes, and local police and fire services, schools, libraries, and Water Management district assessments. The largest items were federal personal income tax ($66.8 million), federal social insurance ("Social Security") tax paid by employees ($37.5 million) and employers ($28.4 million), state and local sales tax ($23.4 million), and property tax on production and imports ($21.6 million). Note that there is no personal income tax or estate/gift tax in Florida; however, there is a state corporate profits tax.

Table 5.6. Tax contributions by type and government level from the agriculture-forestry-fisheries-hunting sectors in Miami-Dade County, 2021

Tax Level/Item	Million dollars
State and Local	53.75
OPI: Corporate Profits Tax	1.71
Personal Tax: Motor Vehicle License	0.37
Personal Tax: Other Tax (Fish/Hunt)	0.03
Personal Tax: Property Taxes	0.14
Social Insurance Tax- Employee Contribution	0.04
Social Insurance Tax- Employer Contribution	0.05
TOPI: Motor Vehicle License	0.29
TOPI: Other Taxes	5.10
TOPI: Property Tax	21.61
TOPI: Sales Tax	23.38
TOPI: Severance Tax	0.02
TOPI: Special Assessments	1.01
Federal	129.05
OPI: Corporate Profits Tax	7.78
Personal Tax: Income Tax	66.76
Social Insurance Tax- Employee Contribution	37.54
Social Insurance Tax- Employer Contribution	28.37
TOPI: Custom Duty	-5.82
TOPI: Excise Taxes	-5.58
Grand Total	182.79

OPI is other property income, and TOPI is tax on production and imports.
Source: IMPLAN online model applicaton and County data, 2021 (Implan Group, LLC).

The previous agricultural land study for Miami-Dade County in 2002 reported total economic impacts of agriculture in the County in 1997-98 at total output of $1.075.7 billion, employment of 14,795 jobs, and earnings (labor income) of $362.1 million in. In inflation-adjusted 2021 dollars, the output impact would be $1.702.6 billion and the earnings impact would be $641.9 million, so the estimated economic contributions in 2021 were 8.6 percent lower than 1997-98 in terms of output, 13.2 percent lower for employment, and 12.1 percent higher for earnings. Note that the previous study used an export base approach for estimating economic impacts, while the current study used a different approach to estimating economic “contributions”, as described by (Watson et. al, 2007).

To provide comparable results between the current study and the original study, the original 1997-98 data for agriculture sales in the County were reanalyzed using the same approach with the IMPLAN model for 2001.The results of this comparison in Table 5.7 show that total economic contributions increased between 1997-98 and 2021 for all indicators, including employment (15.6%), output (11.3%), value added (14.1%), labor income/earnings (25.6%), and government taxes (108.5%).

Table 5.7. Comparison of economic contributions of agriculture in Miami-Dade County, 1997-98 and 2021.

Measure	1997-98	2021	Change 1997-98 to 2021
Employment (Jobs)	11,100	12,836	15.6%
Output (M$)	1,396.8	1,554.6	11.3%
Value added (M$)	791.4	902.6	14.1%
Labor income/earnings (M$)	510.9	641.9	25.6%
Local, state, federal government tax (M$)	87.7	182.8	108.5%

Values in million 2021 dollars.
Source: IMPLAN online application, County model data for 2002 and 2021 (Implan Group, LLC), and industry sales data for 1997-98 and 2021.

In addition to these economic contribution results, UF/IFAS routinely publishes estimates of the economic contributions of agriculture, natural resources, and food industries in the state of Florida and its counties using the IMPLAN model, broadly considering activities of food and fiber manufacturing, distribution, supporting inputs and services, mining, and nature-based recreation, as well as basic production of crops, livestock, forestry, and fisheries that are the focus of this report. The most recent UF/IFAS results for economic contributions of agriculture in Miami-Dade County in 2019 are summarized in Table 5.8, which shows direct employment of 197,688 jobs, total employment contributions of 294,791 jobs, direct output of $24.57 billion, output contributions of $41.73 billion, and value added contributions of $22.68 billion (Court and Ferreira, 2022). The contributions estimates reflect the indirect and induced multiplier effects as described above. These results show that the complex of agriculture, natural resources, and food industries in Miami-Dade County is much larger than just production agriculture, forestry, and fisheries. In particular, note the very large contributions from food and kindred product distribution that includes wholesale food distributors, retail food stores and garden centers, and restaurants. Agricultural inputs and services also include industry sectors such as veterinary services, fertilizer and chemical manufacturing, and landscape and horticultural services, which are closely allied with the nursery/greenhouse industry in Miami-Dade County. Within the food and kindred product manufacturing group, the County has major activity in frozen foods, bread-bakery products, bottled water, spices-extracts, and meat processing. Within the forest products manufacturing group, there is large activity for paperboard containers, sanitary paper products, and engineered wood members and trusses. In the mining industry, Miami-Dade County has significant limerock mining in the western region. Nature-based recreation includes activities such as golf and recreational fishing and hunting guides.

Table 5.8. Economic contributions of agriculture, natural resources, and food industries in Miami-Dade County, 2019

County/Industry Group/Sector	Direct Employment (Jobs)	Employment Contributions (Jobs)	Direct Output (M$)	Output Contributions (M$)	Value Added Contributions (M$)
Crop, Livestock, Forestry & Fisheries Production	9,444	12,249	1,032.1	1,553.8	843.6
Agricultural Inputs & Services	11,304	15,536	961.8	1,674.1	850.2
Food & Kindred Products Manufacturing	11,654	22,295	5,409.6	7,281.7	2,861.1
Forest Products Manufacturing	1,902	3,971	802.0	1,169.0	394.1
Food & Kindred Products Distribution	160,942	236,127	15,743.7	28,976.6	16,731.4
Mining	1,052	2,844	546.3	930.8	928.0
Nature-based Recreation	1,371	1,769	74.7	144.5	72.8
Total	197,668	294,791	24,570.2	41,730.4	22,681.2

Values in full-time and part-time jobs or million dollars. Source: Court and Ferreira, 2022.

Agricultural Land Use

Property Appraiser Agricultural Land Classification

Information on Miami-Dade County property use classification from the County Property Appraiser, which is location-specific within the County, for 2022 indicates a total of 922,594 individual parcels, with a current estimated market value of about $548 billion, and bare land value of $213 billion. Property designated for agricultural use totaled 7,317 individual parcels, occupying 61,173 acres, with a bare land value of $4.329 billion, and total value of $5.180 billion, as shown in Table 6.1. Note that the agricultural use classification entitles landowners to a lower property tax assessment, however, obtaining the agricultural exemption requires submission of an application and documentation to the County Property Appraiser's Office for approval, and some landowners may choose not to do this for personal or business reasons. In addition, the Property Appraiser may identify a portion of agricultural properties that are not strictly used for agricultural purposes, such as homes or storage buildings. The net area of agricultural classified property in the County determined to be actually used for agricultural production was 52,383 acres in September 2023 and 52,293 acres in 2022, or about 85 percent of the gross area.

Table 6.1. Summary of agricultural property parcels in Miami-Dade County, 2022

Agricultural Land Use	Number of Properties	Area (Acres)	Percent of Area	Land Value (Million $)	Total value (Million $)
Container nursery	1,537	11,997	19.6%	805	808
Orchard/Grove	1,263	9,317	15.2%	521	524
Vegetables	1,290	19,845	32.4%	1,010	1,011
Livestock	174	2,010	3.3%	484	485
Improved Ag-Residential	2,172	9,164	15.0%	919	1,642
Improved Ag-Commercial, other	881	8,840	14.5%	590	710
Total all	7,317	61,173	100%	4,329	5,180

Source: Miami-Dade County Property Appraiser.

County properties are summarized by agricultural use groups and with respect to the Urban Development Boundary (UDB) in Table 6.2. Across use groups, vegetables comprised 19,845 acres, representing 32.4 percent of total agricultural land area, followed by container nurseries (11,997 acres, 19.6%), fruit orchards/groves (9,317 acres, 15.2%), improved agriculture-residential (9,164 acres, 15.0%), improved agriculture-commercial-other (8,840 acres, 14.5%), and livestock (1,089 acres, 3.3%). With respect to the County Urban Development Boundary (UDB), agricultural classified properties outside the UDB totaled 55,708 acres, with current land value of $3.02 billion averaging $54,200 per acre, while properties inside the UDB totaled 5,464 acres, valued at $1.31 billion, and averaging $239,200 per acre. The difference in average land values per acre inside vs. outside the UDB ranged from $83,500 to $388,400. Note that the land values are conservative estimates of market value, based on a variety of data and methods. This information indicates that the UDB policy for zoning effectively keeps land and property taxes more affordable for farmers. In Table 6.3, an analysis of agricultural properties by size groups shows that 52 percent of properties were less than 5 acres in size outside the UDB, while 75 percent of properties were less than 5 acres inside the UDB.

Table 6.2. Agricultural property acres, land value, and average land value per acre by land use group and location with respect to the Urban Development Boundary in Miami-Dade County, 2022

Agricultural Use Group	Number Properties	Acres			Current Land Value (M$)			Average land value per acre ($1,000)		
		Outside UDB	Inside UDB	Total	Outside UDB	Inside UDB	Total	Outside UDB	Inside UDB	Diff.
Container nursery	1,537	11,230	767	11,997	682	122	805	60.8	159.4	98.7
Orchard/Grove	1,263	8,938	380	9,317	465	55	521	52.1	146.1	94.1
Vegetables	1,290	18,267	1,578	19,845	808	202	1,010	44.2	127.8	83.5
Livestock	174	1,089	920	2,010	69	416	484	63.2	451.6	388.4
Improved Ag-Residential	2,172	8,086	1,079	9,164	586	333	919	72.5	308.7	236.3
Improved Ag-Commercial, other	881	8,099	741	8,840	411	179	590	50.7	241.9	191.2
Total all	7,317	55,708	5,464	61,173	3,021	1,307	4,329	54.2	239.2	185.0

Source: Miami-Dade County Property Appraiser and authors' calculations.

Table 6.3. Number of agricultural property parcels by land use group, size class, and location with respect to the Urban Development Boundary in Miami-Dade County, 2022

Agricultural Use Group	Outside UDB by size class (acres)					Inside UDB by size class (acres)				
	<1	1-4.9	5-9.9	10+	Total	<1	1-4.9	5-9.9	10+	Total
Container nursery	74	544	462	298	1,378	53	74	15	17	159
Orchard/Grove	43	530	345	260	1,178	27	33	11	14	85
Vegetables	62	415	275	412	1,164	13	44	33	36	126
Livestock	2	49	23	15	89	1	24	43	17	85
Improved Ag-Residential	39	1,188	427	95	1,749	53	334	30	6	423
Improved Ag-Commercial, other	7	336	278	150	771	11	70	16	13	110
Total all	227	3,062	1,810	1,230	6,329	158	579	148	103	988

Source: Miami-Dade County Property Appraiser and authors' calculations.

Farmland in the Census of Agriculture

According to the Census of Agriculture conducted by the U.S. Department of Agriculture-National Agricultural Statistics Service (USDA-NASS), agricultural land in the County in 2017 totaled 78,543 acres, including 55,206 acres of cropland, 9,846 acres of pastureland, 2,141 acres of woodland, and 11,218 acres for other areas used for farm buildings, parking, and service areas, but excluding double-uses (Table 6.4). Farms reported in the Census of Agriculture must have at least $1000 in annual production of agricultural products. Note that these acreage numbers are substantially higher than the agriculture classified land area reported by the Miami-Dade County Property Appraiser presented above because some land reported may not have an agricultural classification if it does not meet the strict requirements for an agricultural use exemption, or because the landowners may choose to not apply for the agricultural use exemption. Historically, agricultural classified land in the County represented about 75 percent of the area reported in the Census of Agriculture. The USDA-NASS Census of Agriculture is considered the most reliable information available on the agricultural sector; however, all such survey-based data are subject to sampling and estimation errors and statistical anomalies.

During 1997-2017, agricultural land in the County decreased by 6.2 percent overall, with larger decreases for cropland (-19.3%) and woodland (-56.5%), but it increased for pastureland (22.9%) and other land (96.2%). Farmland area reported for 2002 (89,015 acres) appears to be above the long-term downward trend, while farmland area for 2007 (66,970 acres) is below the long-term trend. Stakeholders in Miami-Dade County have observed that the acreage reported for avocados in the 2012 USDA-NASS Census of Agriculture was overstated by 6,000 to 7,000 acres (Edward Evans, personal communication). Unfortunately, more current information from the 2022 USDA-NASS Census of Agriculture will not be available until 2024.

Table 6.4. Agricultural land area (acres) by land use in Miami-Dade County, 1997-2017

Land Use	1997	2002	2007	2012	2017	Change 1997-2017
Cropland	68,442	66,564	53,816	64,904	55,206	-19.3%
Pastureland	8,598	13,028	9,108	8,814	10,567	22.9%
Pastureland-Excluding cropland & woodland	5,688	7,370	5,937	7,922	9,846	73.1%
Woodland	5,228	3,740	1,712	3,337	2,273	-56.5%
Woodland-Excluding pastured	3,734	2,382	1,632	2,903	2,141	-42.7%
Other-excluding cropland, pastureland, woodland	5,718	12,699	5,585	5,140	11,218	96.2%
Total net acreage (excluding double use)	83,582	89,015	66,970	80,869	78,543	-6.2%

Source: USDA-NASS Census of Agriculture. Note, numbers may not sum due to rounding.

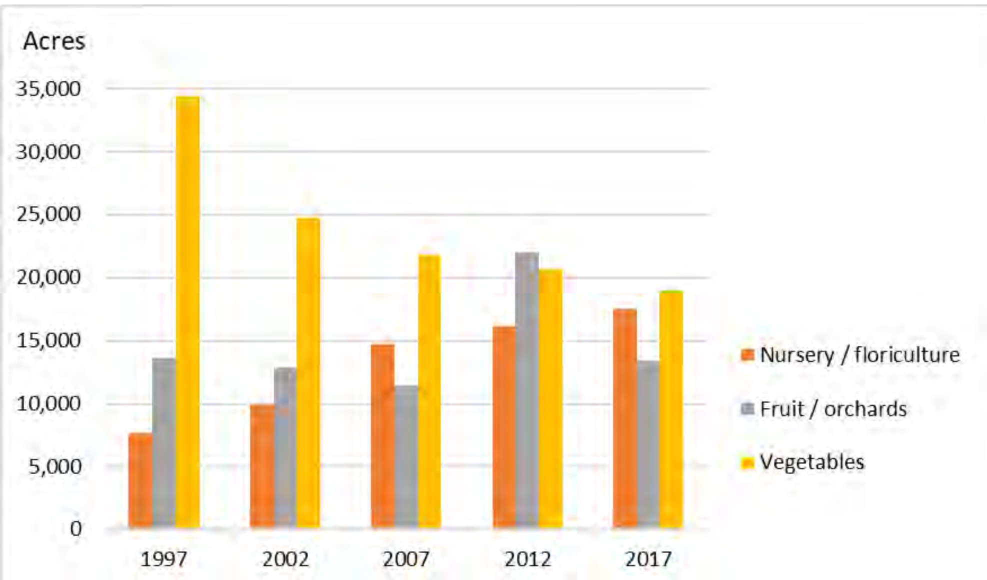
Among major crop groups reported in the USDA-NASS Census of Agriculture in 2017, vegetable crops occupied 19,003 acres or 38.1 percent of total cropland area, nursery/floriculture crops occupied 17,477 acres (35.1%), and fruit crops/orchards occupied 13,343 acres (26.8%). During 1997-2017, nursery/floriculture land use increased dramatically (+128%), while fruit orchards decreased marginally (-2.2%) and vegetable area decreased significantly (-45%), as shown in Table 6.5 and Figure 6.1.

Table 6.5. Cropland area (acres) by crop group in Miami-Dade County, 1997-2017

Crop Group	1997	2002	2007	2012	2017	Percent Change	Share 2017
Nursery/floriculture	7,663	9,862	14,719	16,192	17,477	128.1%	35.1%
Fruit/orchards	13,642	12,862	11,365	21,977	13,343	-2.2%	26.8%
Vegetables	34,473	24,712	21,811	20,633	19,003	-44.9%	38.1%
Total	55,778	47,436	47,895	58,802	49,824	-10.7%	100.0%

Source: USDA-NASS Census of Agriculture.

Figure 6.1. Chart of cropland area by crop group in Miami-Dade County, 1997-2017



Source: USDA-NASS Census of Agriculture.

Other Agricultural Land Use Data Sources

In addition to the USDA-NASS Census of Agriculture and the County Property Appraiser, other sources of agricultural land use data were considered to offer additional insight on the amount, types and trends of agricultural land in the County.

Information on agricultural land use in the U.S. is available from Landsat satellite imagery, classified by crop type or natural vegetation type under the Cropscape-Cropland Data Layer program (USDA-NASS). The area in four categories of land use in Miami-Dade County over the period 2008-2021 is summarized in Table 6.6. Total cropland area fluctuated between 22,000 and 59,000 acres, averaging 46,869 acres, while forests and other natural areas, which may include nursery and fruit tree farming areas, averaged over 900,000 acres, open water area averaged 36,936 acres, and developed land averaged 253,921 acres. There was no consistent trend in the data over time for these broad categories or specific crop types. An issue with these data is that satellite imagery is taken during the midsummer period when many winter vegetable croplands in south Florida are fallow, and specialty crops might not be well identified, therefore this source is not recommended for use in this study.

Table 6.6. Landsat satellite classification of land use in Miami-Dade County, 2008-2021

Year	Crops	Natural-Forest	Developed	Water
		Acres		
2008	34,692	947,566	255,240	33,475
2009	21,796	960,766	254,924	33,488
2010	57,768	938,128	242,123	32,955
2011	52,862	931,026	252,697	34,388
2012	44,740	935,898	253,732	36,604
2013	47,738	935,088	253,259	34,888
2014	51,020	930,061	252,917	36,976
2015	50,257	930,286	252,344	38,086
2016	54,589	927,206	252,327	36,852
2017	54,063	926,657	252,318	37,937
2018	59,360	918,851	251,604	41,158
2019	48,738	926,735	257,661	37,840
2020	46,574	926,536	258,189	39,674
2021	31,975	930,654	265,560	42,784
Average	46,869	933,247	253,921	36,936

Source: USDA-NASS, Cropland data layer.

Agricultural land in Florida was assessed to forecast future water demand by the Florida Department of Agriculture and Consumer Services (FDACS), under the Florida Statewide Agricultural Irrigation Demand (FSAID) program, which reviews consumptive water use permits from the Florida Water Management Districts, together with information from the USDA Cropland Data Layer described above, and ground truthing of a sample of parcels by the U.S. Geological Survey (USGS) to verify acreage, crops, and irrigation system type. Note that not all farms in the County have irrigation systems requiring a consumptive use permit; in particular some field tree nurseries and fruit groves in the County do not use irrigation. Information from FDACS-FSAID is compiled and made publicly available through the Agricultural Lands Geodatabase (ALG) and Irrigated Lands Database (ILD). This information doesn’t include ancillary farm areas such as packinghouses, offices, storage buildings, shops, parking areas, etc., which are accounted for in the USDA-NASS Census of Agriculture.

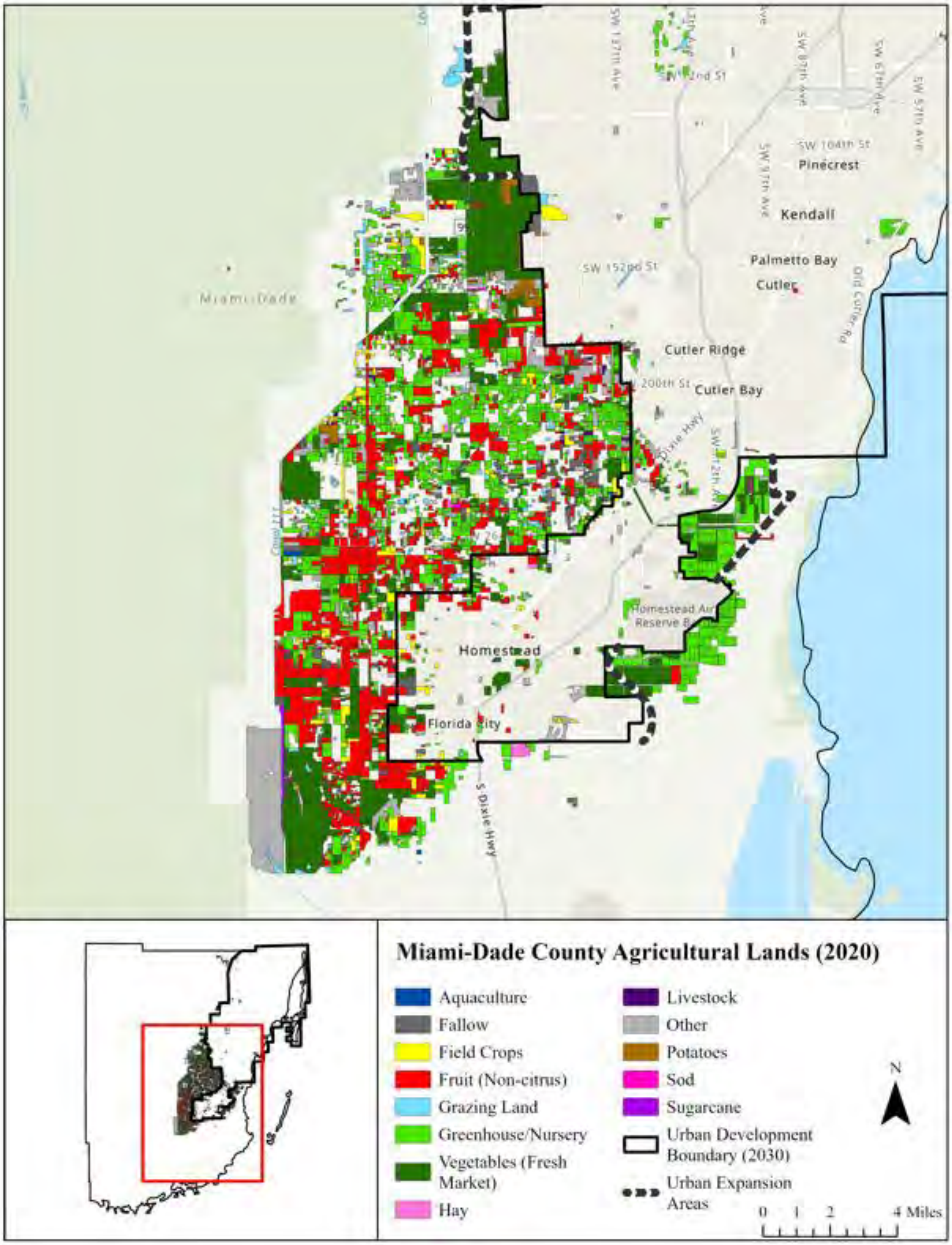
Agricultural land areas assessed under the FDACS-FSAID-ALG program in Miami-Dade County during 2015 through 2020 are summarized in Tables 6.7, and a map of these data for crop types on agricultural lands in the southern part of the County in 2020 is shown in Figure 6.2. Detailed information from FDACS -FSAID on area and number of parcels for specific agricultural commodity subtypes in 2020 is shown in Table 6.8. In 2020, agricultural parcels covered 63,152 acres, including: greenhouse/nursery (19,777 acres, 31.3% of total), vegetables (15,348 acres, 24.3%), fruits (13,712 acres, 21.7%), all other minor commodities (11,934 acres, 18.9%), and fallow lands (2,381 acres, 3.8%). According to these data, overall production area decreased between 2015 and 2020 by -7.7 percent, decreasing for all commodity groups except fruits.

Table 6.7. Agricultural commodity production area in Miami-Dade County, 2015-2020

Commodity	2015	2016	2017	2018	2019	2020	Share 2020	Percent change 2015-20
				Acres				
Greenhouse/Nursery	23,108	19,936	19,938	19,009	19,849	19,777	31.3%	-14.4%
Vegetables	17,936	17,522	17,407	15,939	15,684	15,348	24.3%	-14.4%
Fruit (Non-citrus)	5,998	9,170	9,214	13,403	13,653	13,712	21.7%	128.6%
All Other	15,070	16,543	16,440	12,368	12,262	11,934	18.9%	-20.8%
Fallow	6,278	3,075	5,200	2,182	2,284	2,381	3.8%	-62.1%
Total	68,390	66,246	68,199	62,901	63,732	63,152	100%	-7.7%

Source: Florida Department of Agriculture and Consumer Services and Balmoral Group, Agricultural Land Geodatabase.

Figure 6.2. Map of agricultural lands in the southern part of Miami-Dade County, 2020



Source: Florida Department of Agriculture and Consumer Services, Agricultural Land Geodatabase. Map produced by UF/IFAS Food and Resource Economics Department.

Table 6.8. Area and number of parcels by agricultural commodity subtype in Miami-Dade County, 2020

Commodity Subtype	Number Parcels	Acres
Greenhouse/Nursery	1,443	19,777
Container Nursery	746	8,175
Field Nursery	12	124
Nursery	120	993
Ornamentals	288	3,716
Palm Nursery	75	1,530
Tree Nurseries	202	5,238
Vegetables (Fresh Market)	404	15,348
Beans	2	137
Green Beans	69	2,780
Peas	1	5
Small Vegetables	203	6,214
Sweet Corn	78	4,494
Tomatoes	29	1,096
Vegetables	22	622
Fruit (Non-citrus)	740	13,712
Avocados	479	10,229
Carambola	1	15
Dragonfruit	16	120
Fruits/Nuts	7	26
Fruit Trees	2	11
Grapes	1	4
Mangos	29	372
Other Groves	151	2,532
Papaya	2	10
Tropical Fruit	52	393
Other	229	6,556
Brushland/Shrub	9	97
Cropland/Pastureland	27	2,739
Grass/Pasture	4	15
Herbaceous Dry Prairie	4	95
Open Lands	2	11
Row Crops	178	3,550
Specialty Farms	5	48
Fallow	138	2,381
Field Crops	117	2,023
Corn	4	65
Field Crops	112	1,943
Mixed Crops	1	15
Grazing Land	112	1,922
Potatoes	29	677
Potatoes	29	677
Sod	12	174
Sugarcane	2	164
Hay	4	163
Livestock	17	151
Aquaculture	24	104
Grand Total	3,271	63,152

Source: Florida Department of Agriculture and Consumer Services, Agricultural Land Geodatabase.

Irrigated farmland area in Miami-Dade County is important to consider for the future sustainability of the agricultural sector, in view of loss of land to development with impervious surfaces, increasing weather variability and droughts, and rising sea levels that could contaminate groundwater supplies in the Biscayne Aquifer. Irrigated land in the County in 2017 according to the USDA-NASS Census of Agriculture was 36,801 acres, representing 47 percent of farmland area.

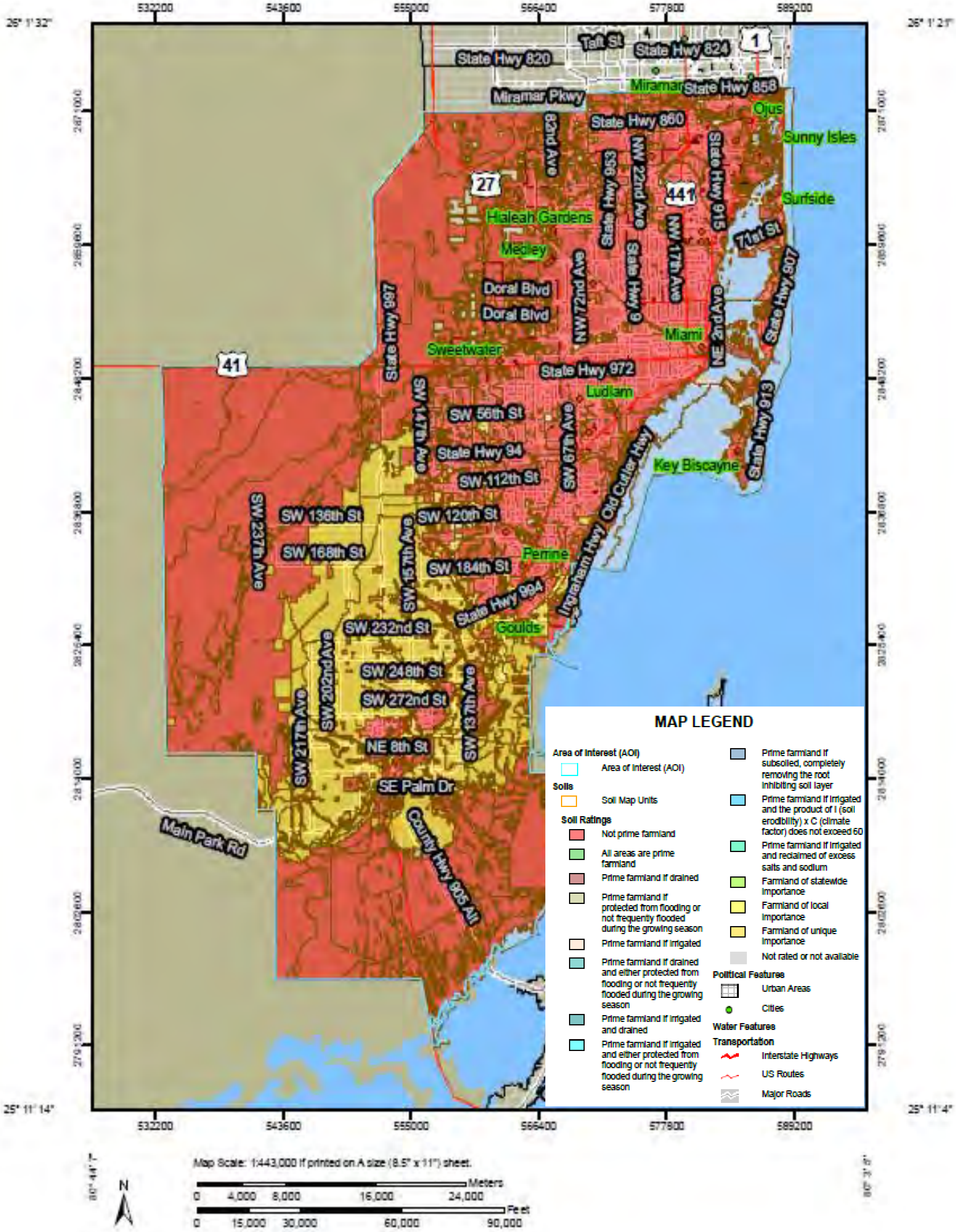
Miami-Dade County has extensive areas that are considered farmlands with soils of unique importance for agriculture. The map in Figure 6.3 shows these lands shaded yellow in the southern part of the County in the Homestead and Redland areas, roughly corresponding with areas designated Agriculture on the Comprehensive Development Master Plan Land Use Map and located outside the UDB. The County has a total of 146,258 acres of land with soils of unique importance, representing 22 percent of the total area evaluated, as shown in Table 6.9. These soil types include Krome very gravelly marly loam, Chekika very gravelly marly loam, Biscayne marly silt loam, Perrine marly silt loam, and the Udorthents-urban land complex. Farmland with soils of unique importance is defined by USDA as land used for the production of specific high-value crops, such as fruits and vegetables, that has the special combination of soil quality, growing season, water supply, temperature, humidity, and elevation needed to economically produce sustainable high yields, as well as good access to markets. The loss of these soils should be avoided for agricultural viability.

Table 6.9. Soils of unique importance in Miami-Dade County

Map Unit	Map Unit Name	Acres
2	Biscayne gravelly marly silt loam, drained, 0 to 1 percent slopes	7,209
52	Biscayne gravelly marly silt loam, drained-Urban land complex, 0 to 1 percent slopes	NA
16	Biscayne marly silt loam, drained, 0 to 1 percent slopes	18,068
53	Biscayne marly silt loam, drained-Urban land complex, 0 to 1 percent slopes*	NA
23	Chekika very gravelly marly loam, 0 to 2 percent slopes	26,840
7	Krome very gravelly marly loam, 0 to 2 percent slopes	58,657
6	Perrine marly silt loam, drained, 0 to 1 percent slopes	11,905
18	Tamiami muck, frequently ponded, 0 to 1 percent slopes	3,094
9	Udorthents-Water-Urban land complex, 0 to 60 percent slopes*	20,485
	Total area soils of unique importance	146,258
	Total area of interest	662,683
	Percent of total area in soils of unique importance	22.1%

Source: USDA-NRCS custom soil resource report for Miami-Dade County Area, Florida, 2012.

Figure 6.3. Map of farmlands of unique importance in Miami-Dade County

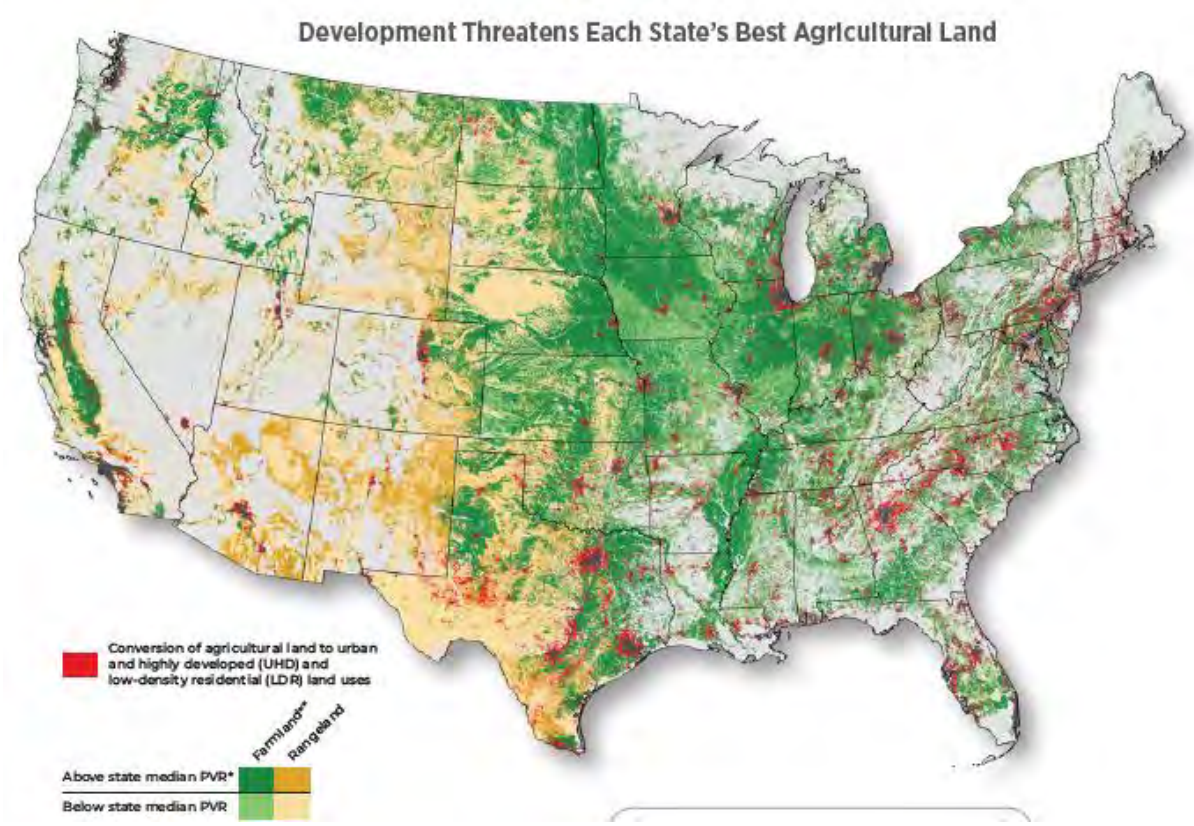


Source: USDA-NRCS custom soil report for Miami-Dade County Area, Florida, 2012.

Farmland Loss

As previously stated, during the period 1997-2017, agricultural land in Miami-Dade County decreased by 6.2 percent (USDA-NASS Census of Agriculture). To put this change in context with broad trends in the U.S., a recent study by American Farmland Trust (2020) analyzed conversion of farmland and ranchland to urban/highly developed or low-density residential uses between 2001 and 2016. A map of farmland areas lost during this time (shaded in red) is shown in Figure 6.4. Agricultural lands were classified as above or below average in terms of productivity, versatility, and resiliency (PVR), which reflects soil fertility, long-term crop yields, existence of special microclimates, location near urban centers, availability of irrigation, and ability to support production of a wide range of crops. Results showed that during 2001-16 over 11 million acres of farm and ranchland were lost to development, including 299,000 acres in Florida representing 3.4 percent of total farmland, as well as in other rapidly growing states such as Texas (1.37 million acres, 1.0%), North Carolina (732,000 acres, 6.7%), Tennessee (699,000 acres, 5.1%), Georgia (544,000 acres, 4.4%) and California (466,000 acres, 1.4%).

Figure 6.4. Map of farmlands converted to urban and low-density residential use in the United States, 2001-2016



Source: American Farmland Trust, 2020.

A comparison of change in agricultural land use, population, and population density in the ten largest metropolitan counties in the U.S. is shown in Table 6.10. Miami-Dade County is ranked eighth on this list for

2023 population (2,763,366), seventh for population density (1,455/square mile), second in population density of the largest city in the County (12,110/square mile), and lowest in percentage of agricultural land change between 1997 and 2017 (-6.2%), excluding Kings County/Brooklyn NY, which has no significant agriculture. These findings indicate that land use policies in the County have been effective in limiting loss of agricultural land. Note that large urban areas in California, Arizona and Texas have scarce water resources that limit growth of agriculture.

Table 6.10. Comparison of agricultural land loss in the ten largest U.S. counties

County (Largest city)	Population 2023	County/City land area (sq.mi.)	Density (pop./sq.mi.) 2023	Largest city density 2023 (pop./sq.mi.)	Ag. land 2017 (acres)	Ag. land 1997 (acres)	Change ag. land 1997-2017 (%)
Los Angeles County, CA	10,072,629	4,059/470	2,482	8,038	57,809	130,838	-55.8
Cook County, IL (Chicago)	5,299,802	945/228	5,608	11,472	11,903	42,174	-71.8
Harris County, TX (Houston*)	4,922,752	1,707/640	2,887	3,538	218,659	311,005	-29.7
Maricopa County, AZ (Phoenix)	4,601,603	9,202/518	500	3,190	474,438	708,656	-33.1
San Diego County, CA	3,359,630	4,210/326	799	4,217	222,094	474,901	-53.2
Orange County, CA (Anaheim)	3,240,017	793/50	4,096	6,829	32,401	58,113	-44.2
Kings County, NY (Brooklyn)	2,805,485	69/69	36,732	36,732	23	8	+187.5
Miami-Dade County, FL	**2,763,366**	**1,900/36**	**1,455**	**12,110**	**78,543**	**83,582**	**-6.2**
Dallas County, TX	2,687,159	873/67	3,078	3,712	63,949	148,862	-57.0
Riverside County, CA	2,486,747	7,209/81	345	3,969	263,796	509,031	-48.2

Sources: https://worldpopulationreview.com/us-counties, U.S. Census Quickfacts.
*The city of Houston is in parts of 3 counties.
Miami-Dade County encompasses 34 incorporated municipalities.

Outlook for the Aquaculture Industry

Tables 7.1 and 7.2 summarize the Miami-Dade County aquaculture industry size and production data as reported in the five-year Census of Agriculture reports since 2007 (USDA-NASS 2007, 2012, 2017). Table 7.1 shows the number of producers responding to the census and Table 7.2 the estimated revenue reported by those respondents, each table subdivided by product type. The “other aquaculture products” category captures aquaculture production not associated with other categories, e.g., alligators, frogs, leeches, eels, live rock, salamanders, and turtles. In Miami-Dade County, most of the other aquaculture products category is assumed to be associated with the aquarium/pet trade based on FDACS licensing data that shows multiple growers indicating production of corals, live rock and sand, turtles, and other aquarium trade specimens not covered under “ornamental fish.” Species included in the “other food fish” category include hybrid striped bass, perch, salmon, sturgeon, and tilapia. Other food fish production in the County is likely focused on tilapia production based on FDACS licensing data and discussions with UF/IFAS Aquaculture Extension personnel. Lastly, the sport or game fish category includes fish raised on farms to be used primarily for sport. Revenue data labeled as "NA" represents product categories where data was withheld from the report to avoid disclosing data for individual operations.

Table 7.1. Number of aquaculture producers in Miami-Dade County

Product Group	2007	2012	2017
Catfish	1	3	0
Crustaceans	1	0	1
Mollusks	1	1	1
Ornamental Fish	22	24	23
Other Aquaculture Products	3	15	7
Other Food Fish	2	15	18
Sport or Game Fish	0	1	0
Total Producers	30	59	50

Source: USDA-NASS Census of Agriculture, 2007, 2012, 2017

Table 7.2. Aquaculture farm gate (market) value in Miami-Dade County

Product Group	2007	2012	2017
Catfish	NA	$1,000	$0
Crustaceans	NA	$0	NA
Mollusks	NA	NA	NA
Ornamental fish	$3,297,000	$1,804,000	$2,641,000
Other aquaculture products	$25,000	$2,136,000	$198,000
Other food fish	NA	$159,000	$322,000
Sport or Game Fish	$0.00	NA	$0
Total disclosed value	$3,322,000	$4,100,000	$3,161,000
Share of County agriculture	0.50%	0.68%	0.38%

Source: USDA-NASS Census of Agriculture, 2007, 2012, 2017.

Historically, aquaculture production in Miami-Dade County has been dominated by production of ornamental fish and other aquaculture products for the aquarium/pet trade market. Based on USDA-NASS Census of Agriculture data, these two product categories have accounted for at least 60 percent of producers and 90 percent of product revenues reported since 2007. While the USDA-NASS Census of Agriculture data indicates increasing production of other food fish (tilapia) in Miami-Dade County, overall production across all aquaculture products has varied with no clear trend in growth. Aquaculture revenues, as reported by the Census of Agriculture data, account for less than 1 percent of total County agricultural revenues for all report years.

Since the last USDA-NASS Census of Aquaculture in 2017, a seismic shift in the County's aquaculture industry occurred with the start of Atlantic salmon production by Atlantic Sapphire at its Homestead facility. In the first half of 2022 alone, Atlantic Sapphire sold 1,217 tonnes of head-on gutted (HOG) weight Atlantic salmon produced in their Miami-Dade County facility for $9.7 million, more than three times the total annual production reported in the 2017 Census of Agriculture for all County aquaculture combined (Atlantic Sapphire 2022a, USDA-NASS 2017). Additionally, Atlantic Sapphire had 2,934 tonnes of salmon worth approximately $21.3 million as of June 30, 2022 (Atlantic Sapphire 2022a). The remainder of this discussion of changes expected to Miami-Dade County's aquaculture industry focuses on Atlantic Sapphire, both their current role within the industry and their expansion plans. We examine the company's growth-to-date, planned expansion, obstacles and challenges based on company financial statements and press coverage. Atlantic Sapphire is a publicly traded company on the Norwegian stock market (Oslo Bϕrs) and is required to provide publicly available financial statements in accordance with generally accepted accounting principles.

Background on Atlantic Sapphire

Aquaculture of Atlantic salmon historically involved production of smolt (juvenile fish) in land-based single pass-through (no water recirculation) farms, followed by grow out in net-pens in coastal marine waters (Bergheim et al., 2009). Using traditional methods, production was limited to areas with access to cold and deep coastal marine waters close to shore, often in bays, inlets, or fjords that provide protection from wind and wave action associated with coastal storms. Since 1990, the largest salmon producers have been Norway, Chile, the Faroe Islands, Canada, and the United Kingdom (Iversen et al., 2020).

Atlantic Sapphire produces Atlantic salmon using a completely indoor facility, known as their "Miami Bluehouse," employing a recirculating aquaculture system (RAS). Recirculation refers to the reuse of water, although the facility does discharge a small amount (less than 1%, Atlantic Sapphire 2022b). Indoor RAS-based aquaculture employs advanced water filtration and water monitoring systems that allow growers to stock fish at higher densities and grow fish faster than traditional aquaculture production strategies. However, these advantages come at a cost as RAS-based systems require more capital and higher-skilled labor than other aquaculture strategies. High stocking densities and the need to constantly filter and monitor water quality in RAS-based systems can lead to mass mortality events when production systems break down.

The use of an indoor RAS-based system along with the County's unique aquifer that includes the ability to pump both fresh and salt groundwater allows Atlantic Sapphire to grow Atlantic salmon, a cold-water species, in Miami-Dade County's tropical climate. Atlantic Sapphire's business strategy is based on lowering costs through economies of scale and producing salmon closer to North American consumer markets than the largest salmon aquaculture producers (Norway and Chile), leading to lower transport costs and fresher, higher-quality product (Iversen et al., 2020).

Atlantic Sapphire Current Production and Expansion Plans

Atlantic Sapphire's Homestead-based operations have expanded rapidly. The company began construction on the Miami Bluehouse in 2017 and began harvesting and selling salmon in 2020 (Atlantic Sapphire 2022b). Although the Miami Bluehouse suffered mass mortality events in 2020 and 2021, the company has increased production rapidly enough to become a significant portion of U.S. salmon aquaculture production (Chase 2022, Atlantic Sapphire 2022b). If the company were able to match its production rate in the first half of 2022, it would have harvested and sold approximately 2,434 tonnes of Atlantic salmon in the second half of

2022, equivalent to 16.8 percent of 2019 U.S. salmon aquaculture production (Atlantic Sapphire 2022b, National Marine Fisheries Service 2022).

Atlantic Sapphire's production expansion plans related to the Miami Bluehouse involve several steps. The company has completed its Phase I production facility which includes 66,000 m^3 of tank space and is currently working to realize an expected annual capacity of 9,400 tonnes at the Phase 1 facility which would equal 64.9 percent of 2019 U.S. salmon aquaculture production (National Marine Fisheries Service 2022). The facility's annualized production rate during the first half of 2022 was 25.9 percent of planned production for the Phase 1 facility. The Phase 2 facility at the Miami Bluehouse is expected to have 15,000 tonnes HOG annual production capacity and increase total production capacity to approximately 25,000 tonnes HOG, representing 173 percent of total U.S. 2019 salmon aquaculture production. Construction on Phase 2 of the Miami Bluehouse began in the second quarter of 2021, but construction has been delayed, potentially for months. Atlantic Sapphire is required to achieve EBITDA (earnings before interest, taxes, depreciation, and amortization) break-even before it can access debt financing earmarked for Phase 2 (Chase 2022). Adjusted EBITDA for the first half of 2022 was -$32.93 million (Atlantic Sapphire 2022a). While the company has not halted Phase 2 construction, they are waiting until EBITDA break-even is reached and debt-financing is accessible to begin the capital-intensive portion of Phase 2 expansion. The company's stated long-term goal for the Miami Bluehouse is to achieve an annual production capacity of approximately 220,000 tonnes HOG by 2031. If the 2031 goal is met, it would represent 8.5 percent of 2019 total global salmon aquaculture production and Miami Bluehouse production would be greater than the 2019 production of every country except Norway and Chile (Tveteras et al., 2019). To reach its goal of producing 220,000 tonnes HOG by 2031, Atlantic Sapphire will have to purchase more land. The company currently operates on a 160-acre tract of land and estimates that it can annually produce 1,000 tonnes of salmon per acre, therefore a minimum of an additional 60 acres will be needed (Atlantic Sapphire 2022b). It is possible that more than 60 acres will be needed to reach 220,000 tonnes HOG salmon production per year, as Atlantic Sapphire does not indicate if the production figure of 1,000 tonnes per acre per year includes secondary activities associated with production (administration, storage, site infrastructure, etc.). Table 7.3 provides information on Miami Bluehouse annualized production rates to-date and planned.

Table 7.3. Atlantic Sapphire Miami Bluehouse production, actual and planned.

Time Period	Annualized Production Rate (tonnes - HOG)	Actual/Planned	Source
First half 2021	2,550	Actual	Evans 2022
Second half 2021	2,200	Actual	Atlantic Sapphire 2022c
First half 2022	2,434	Actual	Atlantic Sapphire 2022a
First half 2023	9,400	Planned	Atlantic Sapphire 2022a
2025	50,000	Planned	Atlantic Sapphire 2021
2031	220,000	Planned	Atlantic Sapphire 2022a

Atlantic Sapphire is a growth company attempting to break into an established market (Atlantic salmon aquaculture) using a new, high-technology production technique (RAS-based production). Atlantic Sapphire's long-term success is far from guaranteed. The company has yet to reach profitability, but profitability measures are improving. Its value is based on expected future earnings. Atlantic Sapphire's adjusted EBIT (earnings before interest and taxes), a measure used to analyze the performance of a company's business operations without considering the impacts of capital structure and tax expenses, improved from -$41.69 per kg of gutted weight product in 2021 to -$32.50 in the first half of 2022 (Atlantic Sapphire 2022a). The adjusted EBIT figures excludes irregular gains, losses, and other one-time items that can distort performance measures. According to company personnel, the negative performance to date is largely due to excess capacity due to the company increasing production to meet their steady state production goals. In October 2022 Atlantic Sapphire's managing director (Karl Øystein Øyehaug) indicated that based on August 2022 growth rates and a fully stocked phase 1 facility, the company would be able to produce 8,500 tonnes annually and would achieve profitability (Fish Farming Expert 2022).

If Atlantic Sapphire reaches profitability and increases production at the Miami Bluehouse as planned, it has the potential to make Miami-Dade County an aquaculture hub in the United States and globally. At the company's current sales price of $12 per kg, reaching the 2031 goal of producing 220,000 tonnes of salmon per year would result in revenues of $2.64 billion per year, approximately three times the value of total Miami-Dade County 2017 agricultural revenues (Atlantic Sapphire 2022a, USDA-NASS 2017). Based on the Fish Pool Index (https://fishpool.eu/prices/), Atlantic Sapphire currently receives a premium for its product relative to European spot prices for salmon, however, at 220,000 tonnes of annual production it is unlikely such a premium would be sustained. Intensive salmon aquaculture does not require large land areas, so development of this industry would not substantially change the demand for land in the County.

Local and Direct Marketing and Agritourism

Direct Marketing

Sales of agricultural products directly to consumers and to local grocery stores and food service establishments rather than through wholesale distribution channels is increasing in the U.S., particularly for small and medium sized farms and organic growers. Direct marketing of agricultural products includes roadside stands, farmers markets, self-harvesting or "U-pick" operations, consumer owned cooperatives, and Community Supported Agriculture (CSA) buying clubs. Local food distribution is a means to diversify producer income, enhance nutrition, increase food safety and security, and stimulate local economic development (Martinez et al, 2010; Low and Vogel, 2011). A survey of Florida households found that purchases of locally branded foods from farm stands, farmers markets, grocery stores and restaurants represented an average of $1114 per household in 2011, or about 20 percent of total food purchased for at-home consumption (Hodges, Stevens, Wysocki, 2014).

In Miami-Dade County in 2017, 495 farms reported selling food directly to consumers, valued at $3.95 million, which represented 18 percent of County farms and about one half percent of total agricultural sales (Table 7.4). In addition, local or regionally branded agricultural products sold to retail markets, institutions and food hubs by 224 farms (2.8%) in the County were valued at $23.5 million, and processed or value-added agricultural products valued at $3.8 million were sold by 42 farms (0.5%), giving an overall value of direct local sales of $31.3 million, representing 3.7 percent of total County farm sales. The number of participating farms and value of direct-to-consumer sales has grown since 2002 when the Census of Agriculture started collecting this information, however, sales of branded products and value added products were not reported until 2017.

Table 7.4. Miami-Dade County direct local food marketing and agritourism revenues, 2017

Value of food sold directly to consumers	$3,950,000
--number farms	495
Share of total sales	0.5%
Share of total farms	18.0%
Value of local or regionally branded products agricultural products sold directly to retail markets, institutions and food hubs	$23,504,000
--number farms	224
Share of total sales	2.8%
Share of total farms	8.1%
Value of processed or value-added ag products sold	$3,810,000
--number farms	42
Share of total sales	0.5%
Share of total farms	1.5%
Total sales agricultural products direct to consumers, local markets or value added products	$31,264,000
Share of total sales	3.7%
Agritourism and recreational services revenues	$2,279,000
--number farms	71
Share of total farms	2.6%

Source: USDA-NASS, Census of Agriculture, 2017.

According to the most recent USDA Farm to School Census, 100 percent of schools within the School Food Authority for Miami-Dade County Public Schools participated in some farm-to-school activity during the 2018-2019 school year, accounting for approximately $61 million in food costs (USDA Food and Nutrition Service, 2021), however, not all of this food was sourced from local farms.

Miami-Dade County currently has 21 regularly operating farmers markets and local food hubs, as listed in Table 7.5. The descriptions of the venues indicate the types of products and amenities offered. In addition, there are 17 markets in the neighboring southeast Florida counties of Broward, Monroe, and Palm Beach Counties that would be within reach of growers/vendors in Miami-Dade County.

Table 7.5. Farmers markets and local food hubs in Miami-Dade County

Aventura Farmers Market, 19501 Biscayne Blvd., Aventura, FL. This market-within-a-mall features food artisans and other local vendors, air conditioned and indoors, 50+ vendors.

Aventura Gardens Farmers Market, 2360 NE Miami Gardens Drive, Aventura, FL. Outdoors farmers market in Aventura features local farmers, artisans, entertainment.

Coconut Creek Farmers Market, 4400 Sample Rd, Coconut Creek, FL. This every-other-week market features locally grown/produced assorted fruits and vegetables, meats, farm-fresh eggs, local honey and honey by-products, jams and jellies, homemade baked breads.

Coconut Grove Foodie & Artisan Market, St. Stephens, 3439 Main Highway, Coconut Grove, FL. Local vendors, prepared foods, artisans and crafts in the shade of St. Stephens in the heart of the Grove, making this a perfect place to spend a Sunday afternoon.

Coconut Grove Organic Market, 3300 Grand Ave., Coconut Grove, FL. One of the longest-running markets in South Florida, this market revolves around Glaser's organic produce, and includes artisans selling kombucha, arts and crafts and plant-based and fermented foods.

Coral Gables Farmers Market, Merrick Way and LeJeune Road, Coral Gables, FL. One of the longest-running markets, this brief but popular winter market is dog- and kid-friendly and includes fresh fruits and vegetables, seafood, artisan breads, chocolates, pastries, ceviche, etc.

Village of Merrick Park, 358 San Lorenzo Ave., Coral Gables, FL. Food artisans, olive oil, juices, prepared foods in this open-air mall.

Bayside Marketplace, 401 Biscayne Blvd., Miami, FL. Weekly market with artisan and prepared foods, crafts, produce.

Redland Community Farm and Market, 12690 SW 280 St, Homestead, FL. This seven-day-a-week market is sponsored by local nonprofit Redland Ahead, which supports the underserved and helps veterans to become farmers. They showcase local produce and local artisan fare.

Redland Market Village, 24420 South Dixie Highway, Miami, FL. Part farmers market, part flea market, this huge market off U.S. 1 is known for fresh and affordable produce, some of it local, fresh-air casual restaurants and taco stands.

Sunshine Market Co., 12455 SW 104th Street, Miami, FL. Artisan market featuring local honey and eggs, aprons, skin care, baked goods, candles, soaps, fresh salsa and more.

Key Biscayne Farmers Market, 355 Glenridge Road, Key Biscayne, FL. Local produce, artisan foods in this community market at the church.

Legion Park Market, NE 66 St. & Biscayne Blvd., Miami, FL. Friendly and hyper-local in the ever-growing Biscayne corridor, the Upper Eastside market includes seasonal produce from local farms via Urban Oasis Project. Freshly made juices to order.

Vizcaya Village Farmers Market, 3250 S. Miami Ave, Miami, FL. Shop for local produce and artisan foods, hand-crafted goods, and explore Vizcaya’s historic farm and village. The Village was once part of the estate when it served as a private home.

Lincoln Road Green Market, Lincoln Rd. Meridian & Washington Ave., Miami Beach, FL. This market on busy pedestrian-only Lincoln Road is practically an institution. Fresh produce, juices, prepared foods and artisan foods for tourists and locals.

Miami Lakes Farmers Market, Main Street and New Barn Rd., Miami Lakes, FL. Produce, prepared food, coffee, snacks, acai bowls, homemade soaps, ice cream and other artisan fare and wares.

Miami Springs Farmers Market, 100 block Curtiss Parkway, Miami Springs, FL. This homegrown market, held in the broad median of Curtiss Parkway a block from the Circle, captures the spirit of the neighborhood. Vendors include organic and local produce, and seasonal seafood.

Palmetto Bay Farmers Market, 7895 SW 152 St., Palmetto Bay, FL. Local farmers, artisans and food vendors.

Pinecrest Farmers Market, Pinecrest Gardens, Pinecrest, FL. Under the shady trees of the Pinecrest Gardens parking lot, this market features produce and local artisans.

South Miami City Hall Farmers Market, 6130 SW 72nd St., South Miami, FL. Urban Oasis Project runs this market, featuring local produce from area farms, honey, artisan foods, plants and flowers. SNAP/EBT accepted. Parking next to the library.

Surfside Farmers Market, 9500 Collins Ave., Surfside, FL. Vendors include Wavey Açai Bowls, Ciabella baked goods, fruits and veggies, Bussdown Vegans, Yessis ceviche, plants, art, soaps, jewelry, crafts and more.

Source: Edible South Florida, 2022.

Agritourism

Agritourism is another form of direct marketing that encompasses a wide range of recreational, entertainment or educational activities for visitors, such as farm tours, pick-your-own produce, horseback riding, hay rides, camping, product tasting, and seasonal harvest festivals. It can also include facilities such as rural wedding venues and event spaces, which may not have a direct connection to farming. Agritourism is increasingly popular in the U.S., especially for small and medium sized farms located near urban areas, as a means of diversifying and increasing income. It also serves to educate the public about agricultural practices, preserve agricultural heritage, and provide jobs in rural communities. Farm agritourism revenues in the U.S. more than tripled between 2002 and 2017, reaching $950 million in 2017, representing 5.6 percent of total farm-related income (Whitt, Low, and Van Sandt, 2019).

Miami-Dade County has had significant development of agritourism in the past two decades, including organized farm tours, roadside fruit stands, and various on-farm venues for events such as weddings, birthdays, family gatherings, and parties. The rural location of such activities is important, but the connection to agriculture may sometimes be tenuous. For example, the County-owned *Fruit and Spice Park* is a popular destination for visitors to learn about tropical and subtropical fruits and spices. According to the Census of Agriculture, agritourism revenues in the County in 2017 were $2.3 million (Table 1), although this is certainly a low estimate because it only counts activity for farmer-owned businesses. There is no comprehensive accounting of agritourism business volume in the County.

It appears that Miami-Dade County has potential to significantly expand agritourism, which can be beneficial to the County if managed properly. According to visitor statistics, the County had a total of 24.2 million overnight and day visitors in 2021, with visitor spending of $19.22 billion (Greater Miami Convention and Visitors Bureau). Note that visitation in 2021 was about the same as in 2019 before the COVID19 pandemic. The share of visitors who reported visiting the south part of the County, including Homestead and the Everglades, ranged from 7 to 16 percent for different visitor groups (day/overnight, domestic (U.S.)/Florida resident) as shown in Table 7.6. Based on these visitor patterns, we estimate that about 2.38 million visitors come to the south part of the County, including 870,000 to the Homestead area that is the primary agricultural area for agritourism venues, with associated visitor spending of $474 million. These estimates exclude international visitors for whom data were not available on neighborhoods visited. One caveat is that traffic, lighting, and noise from agritourism venues can affect nearby farming activities. Also, policy should ensure that agritourism activities have a real connection to agriculture.

Table 7.6. Estimated visitation to neighborhoods in south part of Miami-Dade County, 2021

Visitor group	Neighborhood visited (% of visitors)			Neighborhood visitors (1000)		
	South of County	Homestead	Everglades	South of County	Homestead	Everglades
Domestic Overnight	14%	4%	1%	1,221	349	87
Florida Resident Overnight	11%	8%		380	276	
Domestic Day	16%			537		
Florida Resident Day	7%	7%	8%	246	246	281
Total				2,383	870	368

Source: Greater Miami Convention and Visitors Bureau, and author’s calculations.

Figure 7.1. Image of an agritourism venue in Miami-Dade County

Photo credit: William Messina, University of Florida.

Local Food Branding

Local food brands are another means of promoting local agriculture as part of “buy local” campaigns. The Florida Department of Agriculture and Consumer Services developed the *Fresh From Florida* brand to advertise Florida produce both in the state and in other domestic markets. Promotional materials are available to indicate seasonal availability of produce and provide cooking and recipe ideas for using Florida products.

In Miami-Dade County, the *Fresh From Florida* program has been implemented jointly with the *Redland Raised* local food brand, starting in 2010 to promote local agricultural products under the leadership of the Miami-Dade County Agricultural Manager’s office. The brand is reportedly featured in more than 1200 local stores (https://southeastfloridaclimatecompact.org/case-studies/redland-raised/). Marketing logos, brochures and posters are available as point-of-purchase promotional materials for retailers. In addition, a cookbook focused on food grown in south Miami-Dade County was published, entitled *Local Flavor: Recipes Raised in the Florida Redland* (2013). In 2015, another promotional effort was launched at Miami International Airport with several local restaurants showcasing dishes made with local produce.

Figure 7.2. *Redland Raised* / *Fresh from Florida* brand logo

Source: Florida Department of Agriculture and Consumer Services.

Non-Market Value of Agricultural and Rural Lands in Miami-Dade County

Although not formally part of this study on agricultural land use, it is important to understand that rural and agricultural landscapes provide significant non-market values associated with environmental services such as watershed protection, air quality, wildlife habitat, and mitigation of climate change, as well as social values such as community sense of place.

As part of the Miami-Dade County Agriculture and Rural Area Study in 2002, an assessment of non-market values associated with agricultural and rural lands in Miami-Dade County, was performed by Dr. Douglas Krieger, Environmental Economist at Michigan State University (Krieger, 2003). The study conducted six focus groups and a survey of 1500 randomly sampled County residents to gather input on preferences for retention of farmland in the County. Various development and agricultural land retention scenarios with different levels of associated cost were presented to survey respondents, and from the pattern of choices one can infer the willingness to pay using the contingent valuation methodology. Information from that study is summarized as follows.

- A large majority of county residents believed that retaining some lands in the County in the existing state in agricultural and other undeveloped uses is important for the future.
- Retaining agricultural and other undeveloped land was important to residents to preserve the agricultural industry, maintain a source of locally grown food, provide wildlife habitat, protect environmental quality, preserve quality of life, provide scenic views, and provide opportunities for outdoor recreation. Loss of farmland and other undeveloped land was ranked second only to traffic congestion as the growth-related problem that concerned them most.
- Programs to retain undeveloped land should focus on farmland, while other undeveloped private land and public parks were somewhat less important objectives. When asked how they would allocate land preservation efforts, respondents allocated just under half to agricultural land, about 30 percent to preserving other undeveloped land, and only about a quarter to providing additional public land for recreational use. Respondents from urban and rural areas did not differ significantly in their preferences for retaining different types of undeveloped land.
- Almost 70 percent of respondents believed that Miami-Dade County should consider purchasing land outright or purchasing development rights as a means to retain some undeveloped land.
- Low density rural residential development was generally favored, but many residents were willing to accept some higher density residential development in areas adjacent to or within existing residential areas in exchange for retaining agricultural and other undeveloped land in areas most suited to undeveloped uses.
- Programs to retain agricultural and other undeveloped land should compensate landowners for any loss in

property value caused by the program.

- The preferences expressed were consistent with the “preferred development scenario” that evolved from the Agricultural and Rural Area Study.
- A majority of respondents would consider financially supporting a program to permanently retain some agricultural and rural lands in the southern part of the County in an undeveloped state. The number of households that would be willing to support a program depends on the cost and how they are asked to pay. If the payment is in the form of a voluntary donation to a nonprofit conservation organization, over 60 percent of households would likely be willing to make a one-time donation of between $5 and $25. However, paying for a retention program through taxes to local government was unacceptable to many households.
- County residents, in aggregate, expressed a willingness to pay or donate $79 to $190 million to support a program that would ensure some undeveloped land remains in the future. In inflation-adjusted 2022 dollars, the willingness to pay would be $125 to $300 million.

Threats to Agriculture in Miami-Dade County

Introduction

The long-term viability of agriculture in Miami-Dade County is affected by various stressors or risk factors. An international review of 3,283 peer-reviewed studies on risks in agriculture published between 1974 and 2019 outlined five categories of stressors: production, market, institutional, personal, and financial (Komarek et al., 2020). Production risks arise from uncertainty in the natural growth processes of crops and livestock, including weather patterns (temperature, precipitation, solar radiation), extreme weather events (hurricanes), pests and diseases, and other yield-limiting factors such as soil contamination by heavy metals or salinization. Market risks represent uncertainty in farm commodity prices, input costs, and market access. Commodity prices may be affected by: weather shocks that affect overall market supply; costs for energy, fertilizer, or chemical inputs; or competition from imports. Institutional risks relate to government policies and regulations, such as those affecting worker compensation and safety, environmental compliance, food safety, and international trade agreements. Personal risks relate to problems with human health or personal relationships of farm operators or employees, such as workplace injuries, owner death, illness, divorce, estate succession, and business continuity. Financial risks are associated with farm credit, debt structure, cash flow, and changes in interest rates. Nearly two-thirds of the studies reviewed by Komarek et al. (2020) focused on production stressors, which are more readily quantified than other stressors. Most studies focused on only one type of risk; however, different risks may be interrelated, and multiple factors are typically simultaneously in effect. The ability of local and regional agricultural systems to respond to economic, social, environmental, and institutional shocks may be understood in terms of resilience to adapt robustly to both specific challenges and uncertain or unknown challenges (Meuwissen et al., 2020).

In this study, we consider the following types of threats to agriculture in Miami-Dade County that could affect the viability or sustainability of the industry over the next 30 years. This list includes factors of importance to Miami-Dade County as a tropical, coastal metropolitan area.

1. International import competition
2. Increasing production costs
3. Invasive pests and diseases
4. Water resources
5. Workforce availability and quality of life
6. Urban development and competition for land
7. Weather hazards
8. Climate change and sea level rise
9. Financial risk
10. Market disruptions

11. Government regulations

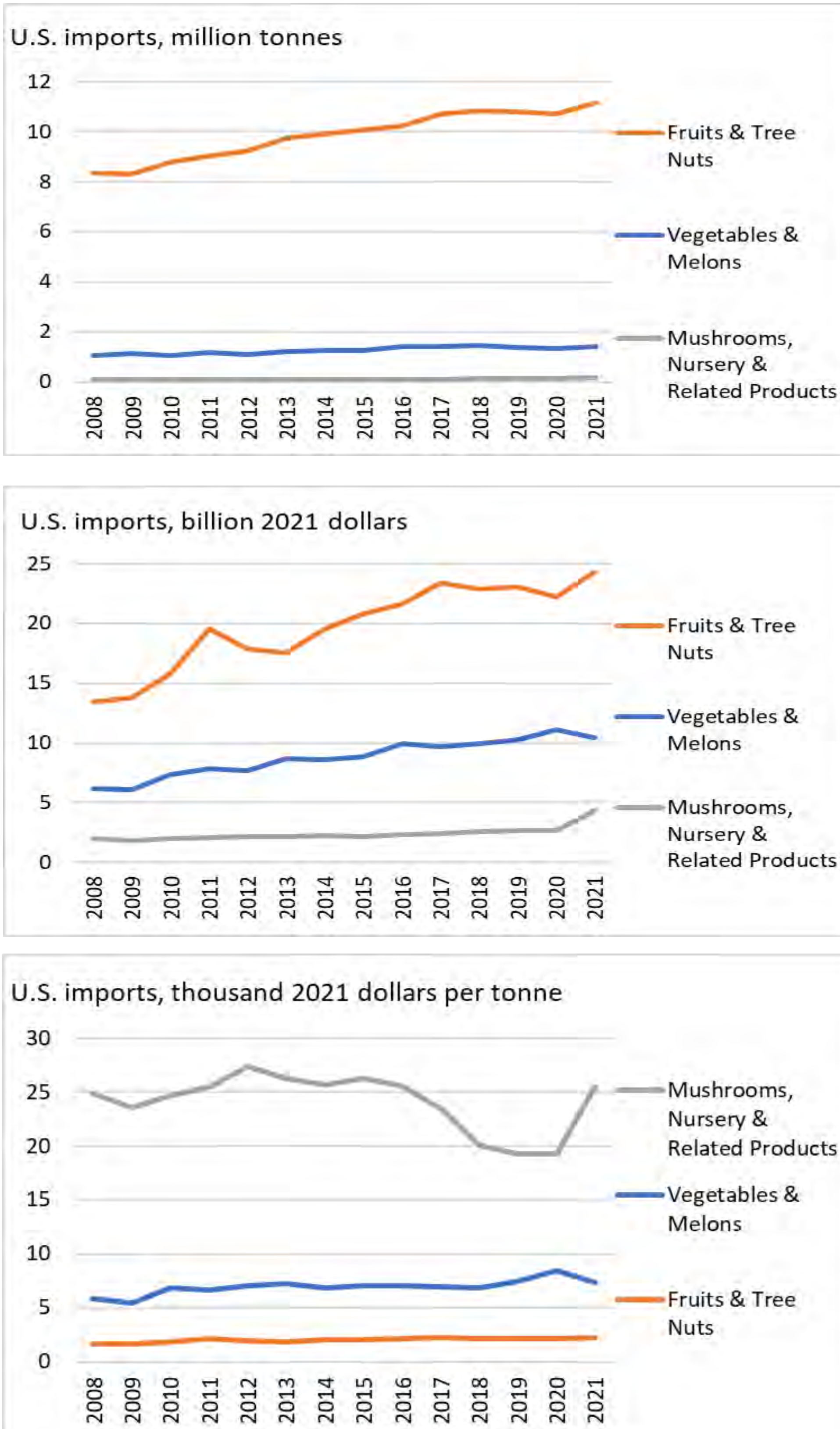
In addition, sea level rise and groundwater hydrology was formally modeled in this project and is discussed in Appendix A: Climate and Hydrology Modeling for Miami-Dade County.

International Import Competition

There is a high level of import competition for most specialty crop commodities in the U.S., Florida, and Miami-Dade County. Imports of fruits, vegetables, and other specialty crops to the U.S. market from Latin America have dramatically increased, depressing commodity prices and reducing market share for domestic producers. Note that imported nursery products are mainly cut flowers, foliage, dried plant products, or unrooted plants without soil media because live plants in soil media are not allowed for import to the U.S. under the rule known as Quarantine 37, enforced by the U.S. Animal and Plant and Health Inspection Service (APHIS) and designed to prevent the inadvertent introduction of soil-borne pests and diseases.

Information on imports of specialty crops to the U.S. from all countries and through all ports of entry is shown in Figure 8.1. In 2021, imports of all specialty crop products exceeded 12.72 million tonnes, including fruits/tree nuts (11.14 million tonnes), vegetables/melons (1.42 million tonnes), and mushrooms/nursery products (170,000 tonnes). These imports were valued at $39.03 billion, including fruits/tree nuts ($24.32 billion), vegetables/melons ($10.39 billion), and mushrooms/nursery products ($4.32 billion). During the 2008-2021 period, import volumes increased by 34 percent overall, 33 percent for fruits/tree nuts, 36 percent for vegetables/melons, and 113 percent for mushrooms/nursery products. In constant dollar value terms, imports grew by 81 percent overall, 81 percent for fruits/tree nuts, 69 percent for vegetables/melons, and 119 percent for mushrooms/nursery products. Average import prices during this period increased 25 percent for vegetables/melons, 36 percent for fruits/tree nuts, and 3 percent for mushrooms/nursery products. Average prices per tonne in 2021 were $2,184 for fruits/tree nuts, $7,317 for vegetables/melons, and $25,476 for mushrooms/nursery products.

Figure 8.1. Imports of specialty crops to the U.S. by volume (a), total values(b), and average price (c), 2008-2021

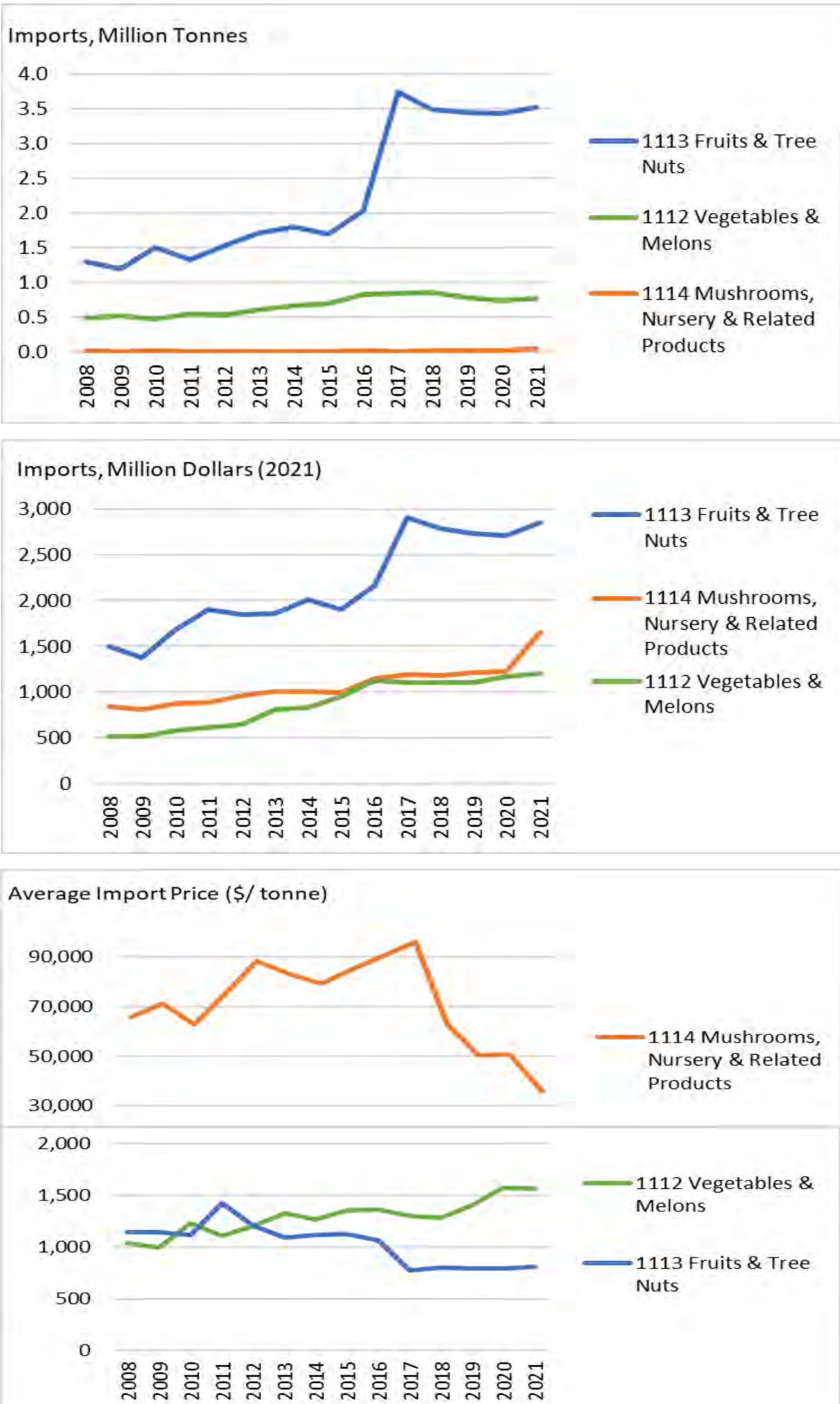


Source: U.S. Commerce Department, Census Bureau, USA Trade Online.

Data on trends in imports of specialty crops specifically to the Florida market regardless of the port of entry are shown in Figure 8.2. These imports compete more directly with producers in Florida and Miami-Dade County. In 2021, imports of all specialty crop products to Florida were 4.34 million tonnes, valued at $5.71 billion, including fruits/tree nuts ($2.85 billion), mushrooms-nursery related products ($1.65 billion) and vegetables/melons ($1.21 billion). During 2008-2021, import volumes to Florida increased by 140 percent overall, 170 percent for fruits/tree nuts, 56 percent for vegetables/melons, and 256 percent for mushrooms/nursery products. Fruit/tree nut imports remained at an elevated level after spiking in 2017. In deflated value terms, imports to Florida grew by 100 percent overall, 91 percent for fruits/tree nuts, 135 percent for vegetables/melons, and 95 percent for mushrooms/nursery products. Average prices per tonne for Florida imports in 2021 were $809 for fruits/tree nuts, $1,564 for vegetables/melons, and over $35,000 for mushrooms/nursery products. The very high prices for nursery products predominantly reflect imports of cut flowers such as roses, carnations, etc. Import prices increased 50 percent for vegetables/melons, but declined 29 percent for fruits/tree nuts and 45 percent for mushrooms/nursery products. We conclude that imports to Florida have increased more rapidly than for the U.S. as a whole and pose a greater threat to growers in Miami-Dade County.

Imports to the U.S. have particularly increased from Mexico under the 1994 North American Free Trade Agreement (NAFTA) and have continued with respect to agricultural goods under the 2020 United States-Mexico-Canada Agreement (USMCA). Foreign competition is exacerbated by large government-sponsored investments in greenhouse production facilities in Mexico (Wu et al., 2018).

Figure 8.2. Imports of specialty crops to Florida by volume, value, and average price, 2008-2021

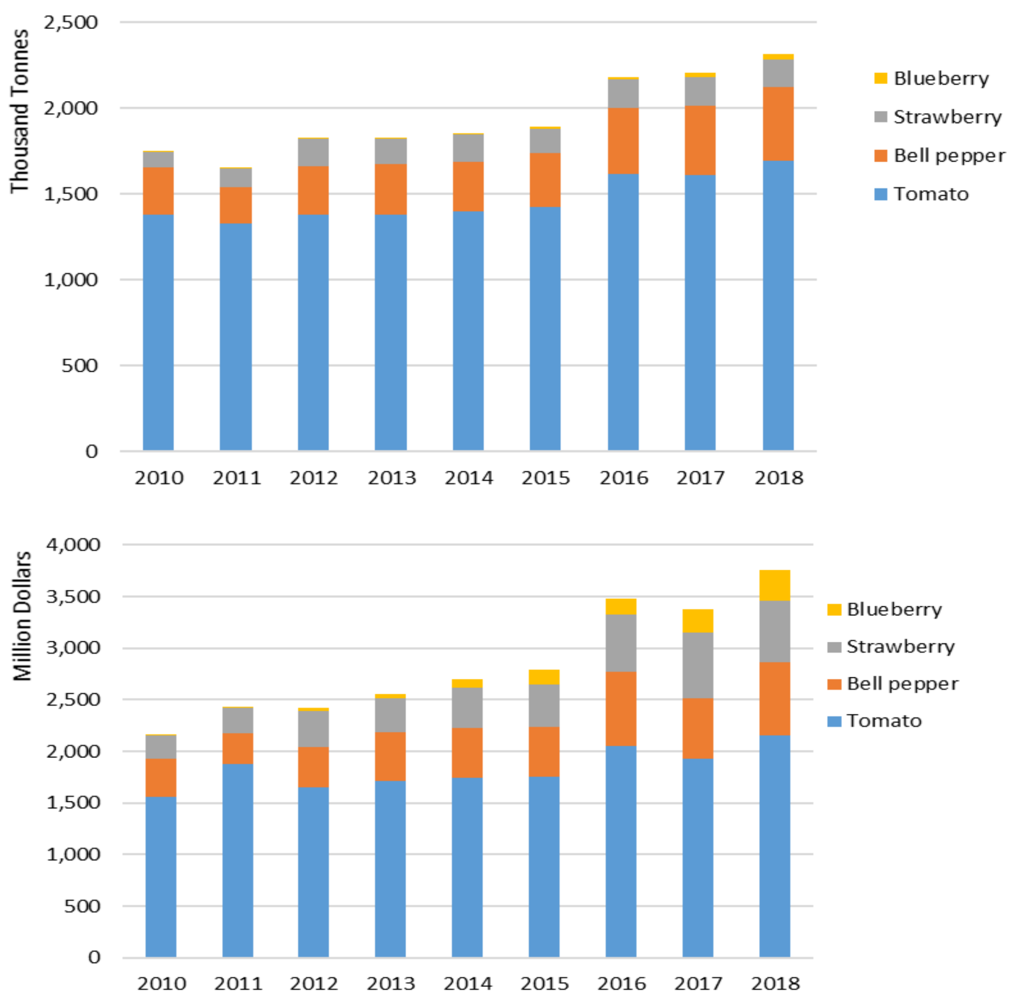


Source: U.S. Commerce Department, Census Bureau, USA Trade Online. Commodities are identified by North American Industry Classification System (NAICS). Note that the scale for price information is split for separate ranges of values.

Recent trends in Mexican imports to the U.S. were analyzed for the major crops of tomatoes, strawberries, blueberries, and bell peppers (Hodges et al., 2019). Mexican imports of these crops increased from 1.75 to

2.32 million tonnes from 2010 to 2018, representing a 33 percent increase, including 23 percent for tomatoes, 56 percent for bell peppers, 79 percent for strawberries, and a 34-times increase for blueberries (Figure 8.3). In value terms, imports of these commodities increased from $2.16 to $3.76 billion, a 74 percent increase, or 65 percent when adjusted for inflation using the GDP Implicit Price Deflator.

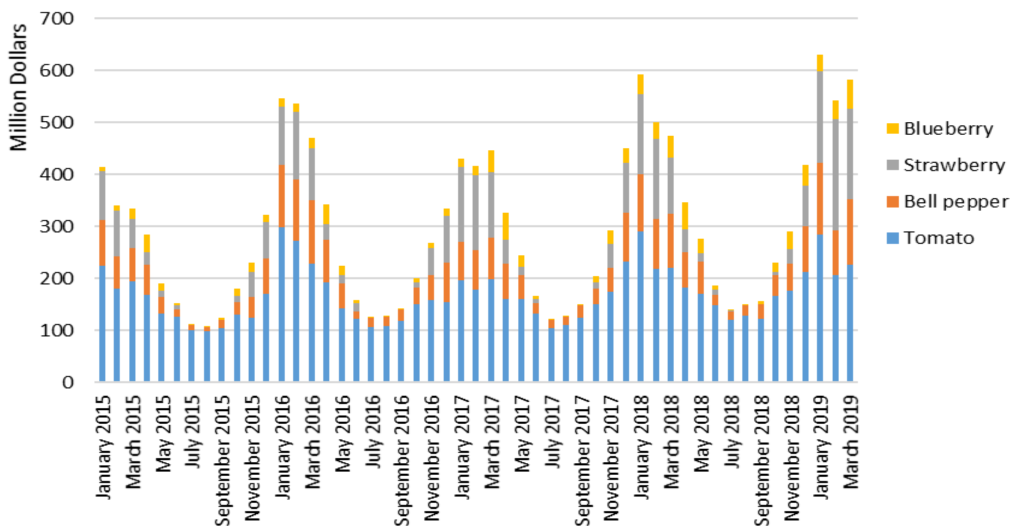
Figure 8.3. Import quantity and value of selected fruits and vegetables from Mexico to the United States, 2010-2018



Source: U.S. Commerce Department, Census Bureau, USA Trade Online database.

Although NAFTA eliminated trade barriers and encouraged year-round imports from Mexico, similarities in climate and growing seasons have resulted in increased imports from Mexico during the same wintertime market window as Florida's fruit and vegetable production, with imports peaking during the December-March period as shown in Figure 8.4.

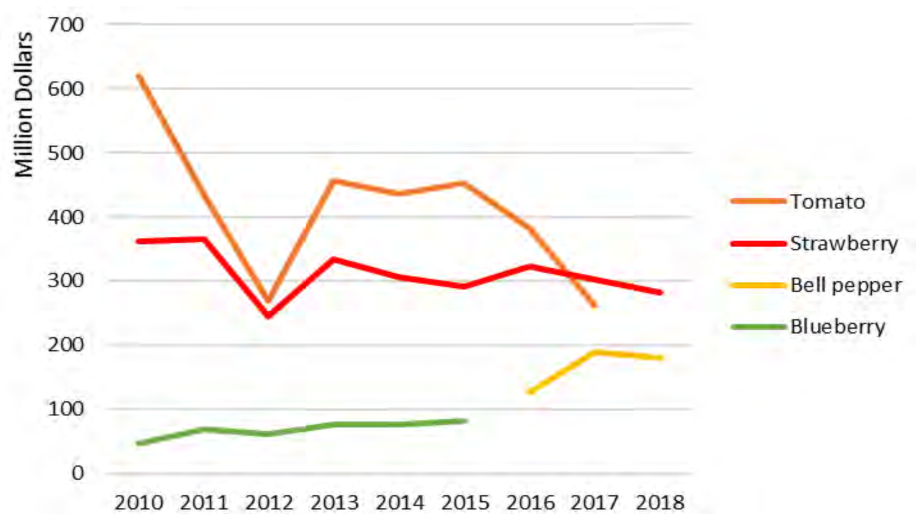
Figure 8.4. Monthly import value of selected fruits and vegetables from Mexico to the United States, 2015-2019



Source: U.S. Commerce Department, Census Bureau, USA Trade Online database.

Concurrent with increased Mexican imports, the production value of some fresh fruits and vegetables in Florida has declined. Between 2010 and 2018, the production value of tomatoes and strawberries decreased by 58 percent and 22 percent respectively, while bell peppers increased moderately (Figure 8.5). In addition, in 2018 the volume of vegetables in Florida that were not sold, presumably due to poor market conditions, nearly doubled from the previous year to over 90 million pounds, representing 2.7 percent of all vegetables produced (USDA-NASS). As an indication that other major producers in the U.S. have been affected, the production value of tomatoes in California also declined by 42 percent during 2010-2018.

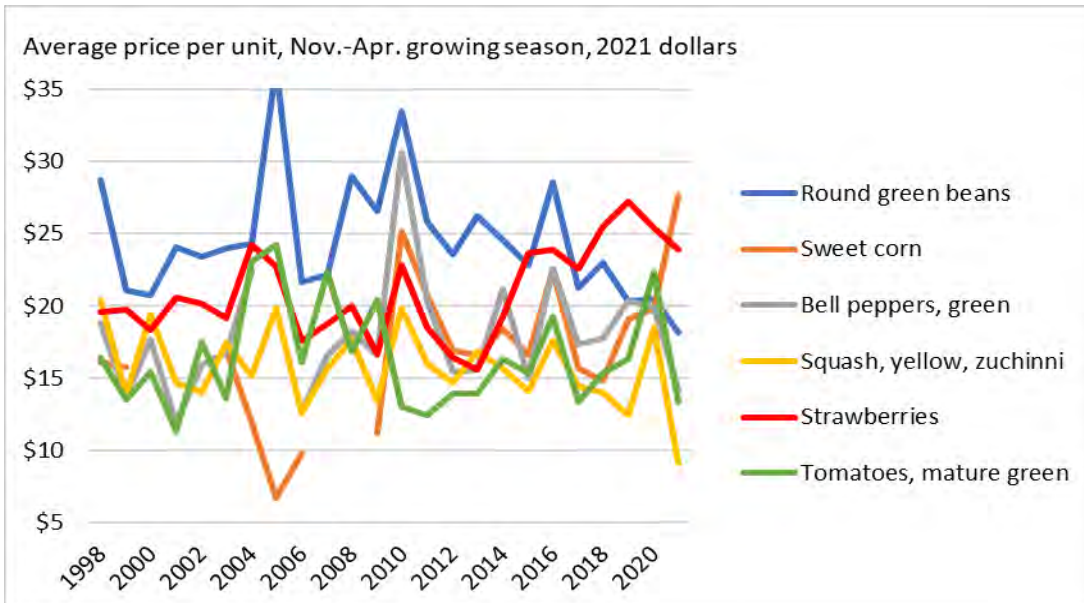
Figure 8.5. Production value of selected fruits and vegetables in Florida, 2010-2018



Source: USDA-NASS, Quickstats database. Note that data were not available for some years and commodities.

As a further indication of variability in market conditions, shipping point prices for selected fruits and vegetables that are produced in Miami-Dade County are shown in Figure 8.6. Data from USDA-Agricultural Marketing Service were summarized as annual average seasonal prices adjusted to constant 2021 dollars using the U.S. GDP Implicit Price Deflator. Prices represent various packaging units. In general, prices were highly variable from year to year. Linear regression analysis of the data indicates that prices have decreased for green beans (round type), squash, and tomatoes, and have increased marginally for sweet corn, bell peppers, and strawberries. Prices have been widely variable over the past two decades, but it is difficult to draw any firm conclusions on long-term trends in commodity prices resulting from import competition.

Figure 8.6. Florida district season average shipping point prices for selected domestically produced fruits and vegetables, 1998-2022



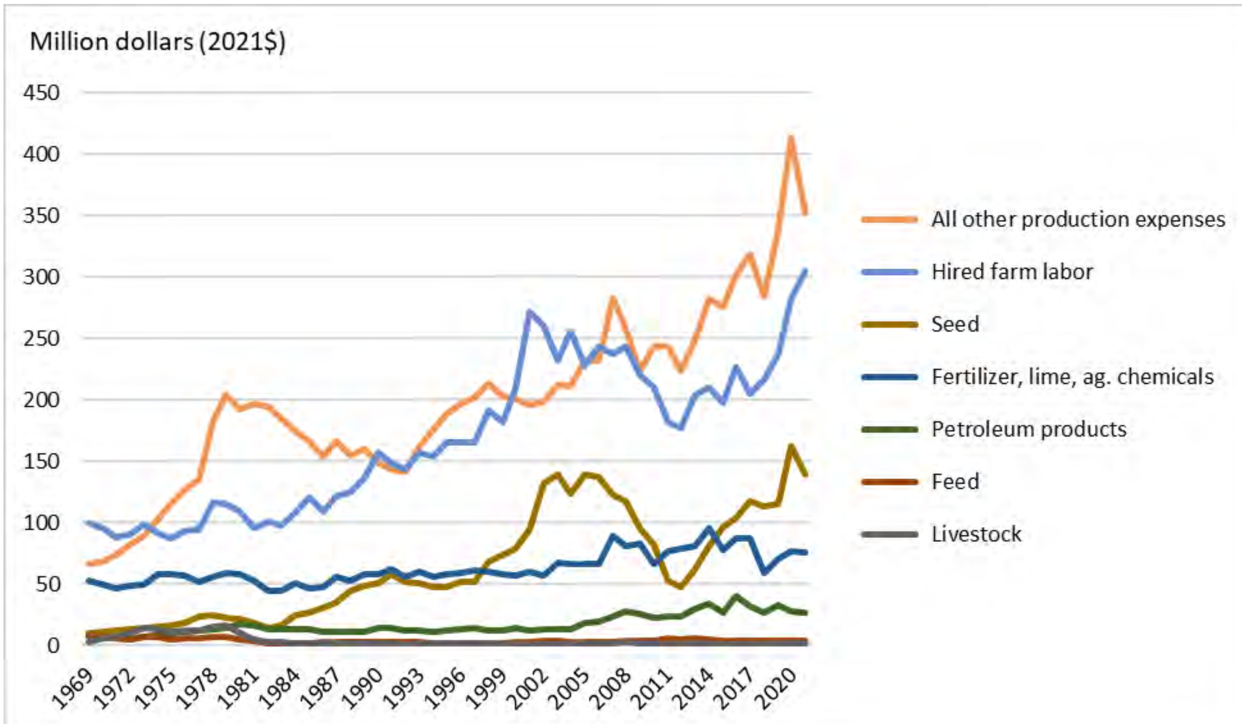
Source: USDA Agricultural Marketing Service. Note that data were not available for some years and commodities.

Increasing Production Costs

Assessment of trends in production costs is important to understanding the viability of the agricultural industry. Data from the U.S. Department of Commerce, Bureau of Economic Analysis (USDOC-BEA) farm income and expense statistics were analyzed for trends in farm production expenses in Miami-Dade County during 1969-2021. In 2021, farm production expenses were $905 million, including: farm labor ($305 million, 34% of total expenses); seed purchases ($139 million, 15%); fertilizer and chemicals ($76 million, 8%); petroleum products ($27 million, 3%); other expenses for machinery, depreciation, interest, rent, taxes, etc. ($353 million, 39%); and lesser amounts for animal feed and livestock ($5 million, <1%).

During the 1969-2021 period, farm expenses in the County were very volatile from year to year for labor, seed, and all other categories, with sharply increased costs during 2001-2008 (Figure 9.2). During the more recent 2001-2021 period, inflation-adjusted costs increased by 42 percent overall, including seed (48%), petroleum products (118%), all other expenses (80%), and fertilizer-chemicals (27%). Given these changes in production costs over the past 20 years, it is reasonable to expect that there may be similar cost increases in the next 20 to 30 years.

Figure 9.2. Trend in farm operating expenses in Miami-Dade County, 1969-2021



Data deflated using GDP Implicit price deflator.
Source: USDOC-Bureau of Economic Analysis and author's calculations.

Changes in farm production expenses directly affect profitability. The operating margin (ratio of net income to total income) for farms in the County has been extremely variable, ranging from 10 to 50 percent. Operating margin was inversely related to production expenses, with a correlation coefficient of -58 percent, confirming that production costs have a strong influence on profitability, somewhat more so than total income as a primary determinant.

More detailed information on recent changes in farm production expenses in Miami-Dade County from the USDA-NASS Census of Agriculture (2012, 2017) is shown in Table 9.1. According to USDA-NASS, total expenses increased from $503 million in 2012 to $696 million in 2017, in constant dollars. The largest expense items in 2017 were hired farm labor (32.2%), seeds and plants (14.4%), fertilizer (9.1%), repairs and maintenance (8.3%), chemicals (8.1%), and fuels and oils (6.5%). The change in total expenses represented a dramatic increase of 39 percent, or a +7.7 percent annual average over the five-year period. Among the largest expense categories, expenses increased significantly for hired labor (33%), seeds and plants (124%), fertilizer (33%), and repairs and maintenance (101%). The only expense items that decreased were feed (-22.5%) and land rent (-17%), which mainly reflected a decrease in the area farmed. Cropland farmed in the County declined from 64,904 acres in 2012 to 55,206 acres in 2017, according to the Census of Agriculture.

The increase in production costs combined with a decrease in acreage resulted in an increase in average production costs per acre rose from $7,745 to $12,609, an increase of 63 percent or +12.6 percent per year. The average annual rate of increase in farm production expenses in Miami-Dade County was far more rapid than general price inflation in the U.S. economy during this period (+7.7%) as measured by the GDP Implicit Price Deflator. Continued increases of this magnitude in farm operating costs will put further negative pressure on operating margins and return on investment, and likely cause increased business failures.

Table 9.2. Farm production expenses and expense per acre in Miami-Dade County in 2012 and 2017

Expense item	Expense (M$)*		Percent expense 2017	Percent change	Expense per acre cropland ($)*		Percent change expense per acre
	2017	2012			2017	2012	
Fertilizer, lime, and soil conditioners	63.09	47.51	9.1%	32.8%	1,143	732	56.1%
Chemicals purchased	56.33	53.73	8.1%	4.8%	1,020	828	23.3%
Seeds, plants, vines, and trees purchased	100.56	44.95	14.4%	123.7%	1,822	693	163.0%
Livestock and poultry purchased or leased	1.41	1.15	0.2%	22.6%	25	18	44.1%
Feed purchased	4.16	6.32	0.6%	-34.1%	75	97	-22.5%
Gasoline, fuels, and oils	45.54	29.55	6.5%	54.1%	825	455	81.2%
Utilities	25.82	12.85	3.7%	101.0%	468	198	136.3%
Repairs, supplies, and maintenance	57.73	39.82	8.3%	45.0%	1,046	613	70.4%
Hired farm labor	224.02	168.88	32.2%	32.6%	4,058	2,602	56.0%
Contract labor	34.45	31.51	4.9%	9.3%	624	485	28.5%
Custom work and custom hauling	21.88	5.87	3.1%	272.9%	396	90	338.4%
Cash rent for land, buildings, grazing fees	19.95	24.15	2.9%	-17.4%	361	372	-2.9%
Rent and lease expenses for machinery, equipment, vehicles	4.51	4.13	0.6%	9.3%	82	64	28.4%
Interest expense	19.51	15.52	2.8%	25.8%	353	239	47.9%
Property taxes paid	17.11	16.74	2.5%	2.2%	310	258	20.2%
Total (original data items do not sum to total)	696.08	502.67		38.5%	12,609	7,745	62.8%

*Values in 2022 dollars or million (M) dollars using the GDP Implicit Price Deflator (USDOC-BEA).
Source: USDA-NASS Census of Agriculture.

Invasive Pests and Diseases

Invasive pests and diseases are an important risk to the agricultural industry in Miami-Dade County because the tropical climate and year-round growing season create ideal conditions for the spread of invasive pests and diseases. In addition, the Port of Miami is a major gateway for imports of food and agricultural products to the U.S. from Latin America, with the potential for inadvertent introduction of pests and diseases. Two case studies are reported here as representative of the risks of invasive pests and diseases in Miami-Dade County: the Oriental Fruit Fly outbreak in 2015 (Alvarez et al., 2016) and Laurel Wilt Disease that was introduced to the U.S. in 2002 and rapidly spread to South Florida, causing mortality in avocado trees (Evans et al., 2010). These two major pest outbreaks within the past 15 years indicate the potential for ongoing disruption of the agricultural industry in the County as well as the resiliency of the industry to respond to these challenges.

Oriental Fruit Fly. The Oriental fruit fly (*Bactrocera dorsalis*) is a destructive pest to fruits and vegetables in Southeast Asia, the Pacific Islands, and Hawaii, and has been eradicated numerous times from California and Florida (Weems et al., 1999). It has over 400 potential hosts, including avocados, citrus, green peppers, papaya, and tomatoes (USDA). Gravid females puncture the fruit and lay eggs that hatch into larvae and feed on the pulp of the fruit, making it unfit for fresh consumption or processing. Infestation rates as high as 80 percent have been recorded in pear, peach, apricot, fig, and other fruits (Weems et al., 1999). The case of an outbreak of Oriental fruit fly in Miami-Dade County in 2015 was described by Alvarez et al., (2016). Oriental fruit flies were first detected in the Redland area of Miami-Dade County on August 26, 2015, which triggered an eradication program and establishment of a quarantine area of about 81 square miles of agricultural, residential, and commercial land (Steck, 2015), as authorized under Florida law. Growers and packers in the quarantine area were required to implement special procedures for harvesting, handling, and postharvest processing of agricultural products that might serve as hosts for any life cycle of the fruit fly. Host material in the quarantine area could only be harvested after a 30-day pre-harvest pesticide treatment or through a postharvest treatment. In addition, where female flies or larval stages of the fly were found, a 200-meter (656 feet) radius around the positive find was stripped of all host material, and the soil was treated with a pesticide to ensure fruit fly pupae were eliminated. Host products within a half-mile radius around positive female or larval finds could only be brought to market after a postharvest treatment was completed.

Lost agricultural sales resulted from both direct product damage or inability to sell perishable products, and from grower decisions to not plant or to stop planting due to the presence of the Oriental fruit fly and the associated eradication protocol. Expected annual gross revenues per acre for locally grown commodities were compiled from crop budgets. Over 3,600 acres of crops had pre-harvest treatments for Oriental fruit fly during 2015. Approximately 2 percent of the production area under quarantine was subjected to host material stripping. This acreage incurred total losses in production for a period of one or two years. An estimated 5 percent of the production area under quarantine was subjected to postharvest treatment. According to the assumptions used in the analysis, 98 percent of the quarantined area incurred a loss in production for a period of one year. Losses were calculated from annual revenues per acre for each specific crop.

Growers who decided not to plant did not receive the gross revenues they were expecting in the planting season and experienced a per acre loss equivalent to their expected gross margin (i.e., gross revenues minus variable costs, but still including fixed costs such as equipment, rent, etc.). The average gross margin of five annual crops (beans, squash, eggplant, pepper, tomato) in the non-core quarantine area was considered for avoided planting. There were also affected growers who had already started land preparations for planting and incurred some variable costs, depending on the timing of the outbreak in relation to planting seasons.

The Florida Department of Agriculture and Consumer Services (FDACS) is the main state agency establishing and enforcing pest quarantine and eradication programs. As part of the eradication effort, FDACS Division of Plant Industry and Office of Agricultural Law Enforcement personnel install and monitor fly traps in the area, establish a field operations center, and monitor the roadways to ensure that uncertified host material does not leave the quarantine area. In addition, FDACS covers the costs of stripping and disposal of host materials and the purchase of pesticides for treatment of quarantine areas. In the 2015 incident, the total costs for 79 days of quarantine were over $2 million. Additional costs were incurred by Miami-Dade County in leasing a helicopter to conduct aerial spraying.

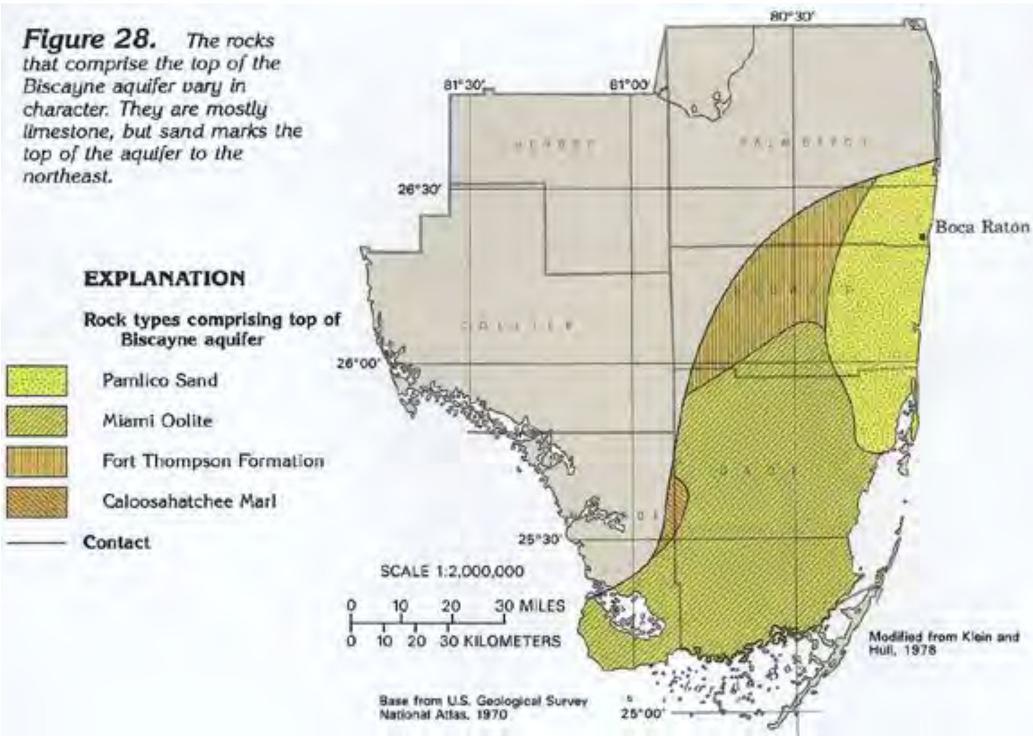
Growers in the production areas affected by the quarantine were estimated to have lost over $3 million. In addition, approximately $1 million was lost due to non-planting of vegetables. Some of these grower losses may have been mitigated by crop insurance payments; however, reliable information on the extent of insured losses is not available. The total regional impact was estimated at $10.2 million in lost output and loss of 124 jobs.

Laurel Wilt Disease. Laurel wilt disease is a fungal pathogen that infects plants in the Laurel plant family (Lauraceae), including native redbay trees (*Persea borbonia*) and avocado (*Persea americana*). The disease blocks water and nutrient transport in the sapwood, resulting in eventual death within a few weeks or months for over 90 percent of infected plants (Evans et al., 2010). The disease is vectored by the Redbay Ambrosia Beetle (*Xyleborus glabratus*), a non-native invasive species that was accidentally introduced to the U.S. in 2002 on wood packaging material at Port Wentworth near Savannah, Georgia. The disease spread rapidly throughout the southeast U.S., reaching Florida in 2005. Laurel Wilt Disease reached Miami-Dade County as early as 2011 and now threatens the avocado industry. In 2019, the County had about 10,000 acres of avocado production. The disease causes direct grower losses of seasonal fruit and kills trees, which require many years to bring to productive status. The value of an established avocado grove was about $80,000 per acre in 2010. The disease also imposes additional operating costs for control of the beetle with pesticides, removal of infected parts or trees, and disposal of infected plant parts and dead trees. Total labor, equipment, and chemical costs for preventative treatment in 2010 were estimated at $333 per acre. An economic study estimated that a 50 percent reduction in avocado production would result in a sales loss of $22.5 million, increased management costs of $4.53 million, and reduced property values of $245 million (Evans et al., 2010). The loss in production would further cause a loss of 273 jobs and $9.84 million in labor income, including regional multiplier effects.

Water Supply and Use

Potable water is an increasingly scarce resource throughout the United States and the world and will shape human development and settlement patterns into the next century. In general, the water supply situation in Florida is quite robust, with an average of about 50 inches of annual rainfall and extensive surface and underground sources. While water supplies have been challenged in some areas by rapid development and increasing withdrawals for consumptive use, including for agriculture, water consumption in Miami-Dade County has decreased in recent years. Water use in the County is supplied mainly by groundwater from the Biscayne aquifer, a shallow aquifer underlying Miami-Dade, Broward, and Palm Beach Counties that is highly vulnerable to contamination through porous surface layers (Figure 11.1).

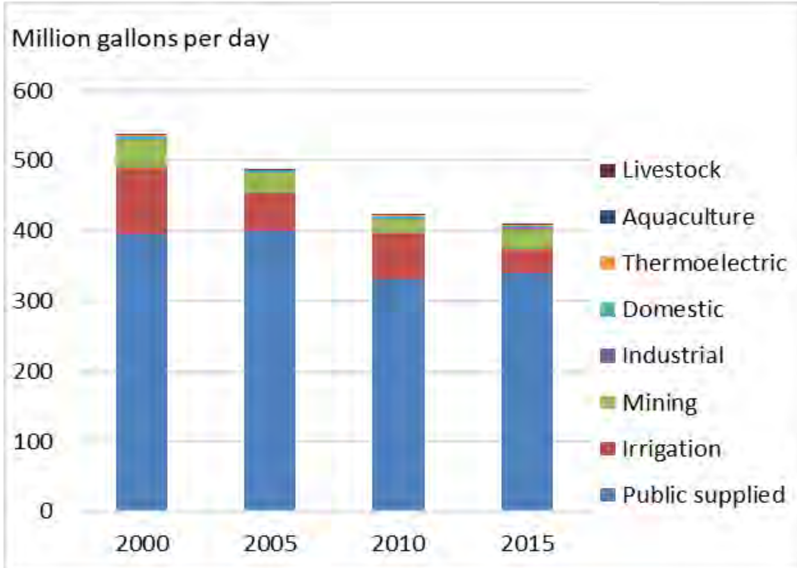
Figure 11.1. Map of the Biscayne aquifer in southeast Florida



Source: USGS, Groundwater atlas of the United States, Alabama, Florida, Georgia, South Carolina.

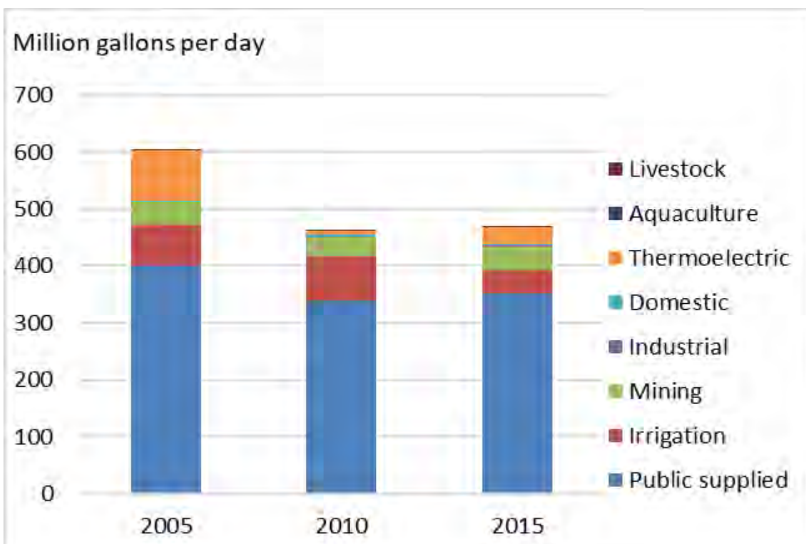
Trends in water withdrawals and use in Miami-Dade County are shown in Figures 11.2-11.5. Total withdrawals of fresh groundwater by all users in 2015 was 409 million gallons per day (MGD), with public supply representing 338.9 MGD or 82.8 percent of the total, followed by irrigation of agricultural crops and recreational facilities (34.6 MGD, 8.4%), mining (28.7 MGD, 7.0%), and various other minor uses (<7 MGD). During 2000-2015, fresh groundwater withdrawals from self-supplied sources declined from 537 to 409 MGD, representing a 24 percent decrease (Figure 11.2). Total water withdrawals from all sources (fresh and saline, ground and surface) were 468 MGD in 2015, including public supply (75.2%), irrigation (8.5%), mining (8.9%), and thermoelectric power plants (6.1%). Total water withdrawals from all sources declined 22 percent during 2005-2015 (Figure 11.3).

Figure 11.2. Fresh groundwater withdrawals by use in Miami-Dade County, 2000-2015



Source: USGS water use data for Florida.

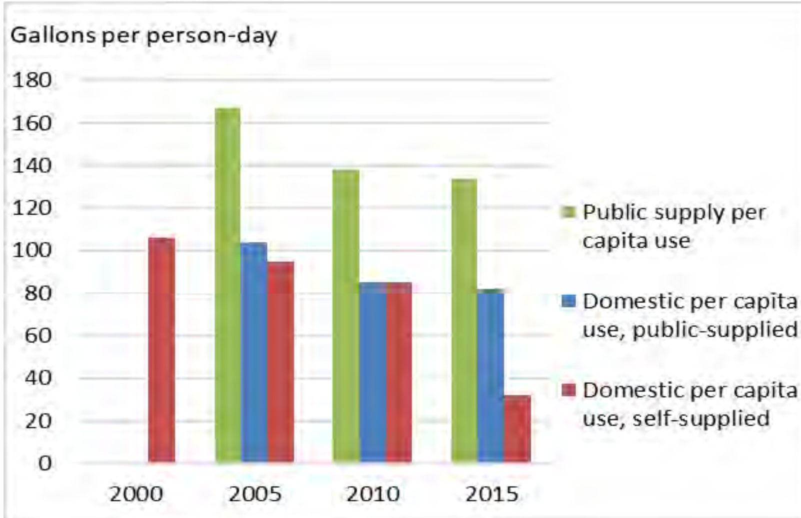
Figure 11.3. Total water withdrawals by use in Miami-Dade County, 2000-2015



Note, complete data not available for 2000. Source: USGS water use data for Florida.

While the County population and economy increased rapidly during this time, the decline in total water withdrawals was due to greater water use efficiency. Public-supplied water use per capita for all residential, industrial, and commercial users decreased by 20 percent during 2005-2015 from 167 to 134 gallons per person-day. Domestic self-supplied per capita use declined significantly from 106 to 32 gallons per person-day during 2000-2015, while domestic public-supplied use was generally higher and declined more slowly (Figure 11.4).

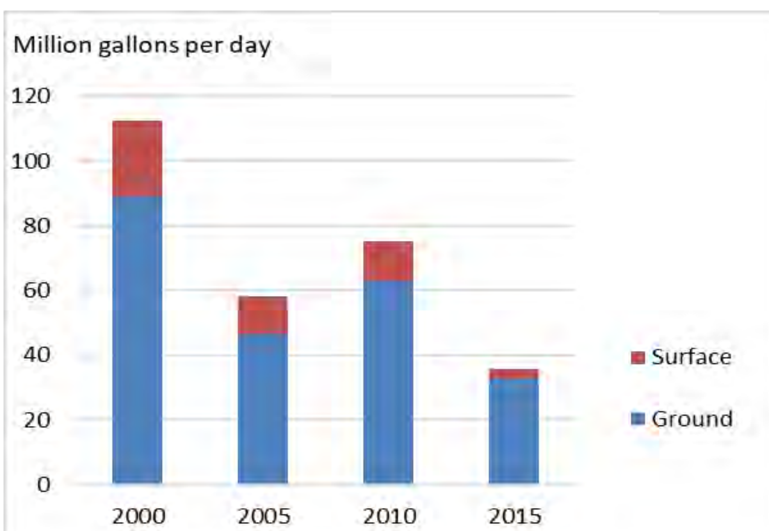
Figure 11.4. Water use efficiency in Miami-Dade County, 2000-2015



Source: USGS water use data for Florida. Complete data not available for the year 2000.

Water withdrawals for crop irrigation from both surface and groundwater sources in Miami-Dade County were 33 MGD in 2015, with groundwater representing over 91 percent. Withdrawals for irrigation declined 68 percent during 2000-2015, with surface water withdrawals declining more rapidly than groundwater (87% vs 63%) as shown in Figure 11.5. According to USGS, the total crop area under irrigation decreased from 67,000 to 48,000 acres. The decrease in water use for crop irrigation is driven by the decrease in irrigated area, particularly from surface sources, as well as the increasing efficiency of sprinkler and microirrigation systems, although the area under microirrigation declined.

Figure 11.5. Water withdrawals for crop irrigation in Miami-Dade County, 2000-2015



Source: USGS water use data for Florida.

A forecast of future agricultural water use under the Florida Statewide Agricultural Irrigation Demand (FSAID) program is shown in Table 11.1. These projections account for recent trends in land use, water use, irrigation technology, commodity market prices, and input costs. Irrigated crop acreage in Miami-Dade County was projected to decline from 37,729 acres in 2019 to 30,604 acres in 2045, representing a 19 percent decrease, including significant decreases for greenhouse/nursery (-26%), vegetables (-16%), and non-citrus fruit crops (-16%). Water use for agricultural irrigation in the County is projected to decrease from 71.4 million gallons per day (MGD) in 2019 to 57.6 MGD in 2045 for average-rainfall years, a decrease of 19 percent; however, water use in "dry" years expected every one out of ten years, was projected to be about 17 percent higher at 67.2 MGD in 2045. The projected decrease in water use is greater than expected for the decrease in irrigated area due to anticipated adoption of water-saving technology and improvements in water use efficiency.

Table 11.1. Agricultural water use in Miami-Dade County, 2019-2020 and projected for 2025-2045

Crop	2019	2020	2025	2030	2035	2040	2045	percent change
	Million Gallons per Day (average-rainfall years)							
Citrus	0.33	0.31	0.30	0.29	0.29	0.23	0.19	-42.4%
Fruit (Non-citrus)	22.74	22.57	21.73	20.70	20.44	19.88	19.06	-16.2%
Potatoes	0.69	0.67	0.67	0.68	0.68	0.61	0.61	-11.6%
Vegetables (Fresh Market)	20.89	20.72	19.95	19.43	18.51	18.12	17.76	-15.0%
Field Crops	0.03	0.03	0.03	0.02	0.02	0.02	0.02	-33.3%
Greenhouse/Nursery	26.17	25.98	24.99	23.83	22.39	20.87	19.47	-25.6%
Hay	0.13	0.13	0.11	0.11	0.11	0.11	0.10	-23.1%
Sod	0.22	0.22	0.21	0.22	0.22	0.21	0.17	-22.7%
Sugarcane	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.0%
Total	71.38	70.82	68.19	65.47	62.86	60.26	57.59	-19.3%

Source: FDACS-FSAID, Balmoral Group, 2022.

It appears that water scarcity and competition for water resources by various user groups in Miami-Dade County is becoming less severe, due to greater water use efficiency. If the rate of decline in public-supplied water uses per capita observed over the past 20 years continues into the future, it may largely offset the expected growth in population to stabilize overall water demand over the next 30 years to 2050. Therefore, water supply quantity may not be a serious constraint for the continued sustainability of agriculture in the County; however, climate change and sea level rise could pose threats to the groundwater supply from saltwater intrusion by adversely affecting groundwater quality. This issue is explored further in Appendix A: Climate and Hydrology Modeling for Miami-Dade County.

Workforce Availability

Workforce availability reflects a variety of factors, including compensation rates, population growth, migration, living standards, housing affordability, education, and training. Specialty crop agriculture in Miami-Dade County is highly labor intensive and requires a large workforce for planting, cultivation, and harvesting of annual crops, and ongoing maintenance activities for perennial or tree crops. Work in agriculture is typically physically demanding, under difficult environmental conditions, sometimes with long hours; irregular, part-time, or seasonal; and relatively low pay compared to other occupations. The workforce is generally young and unskilled, with low to moderate educational attainment (U.S. Department of Labor, Occupational Outlook, Agricultural Workers).

Immigrant Workers

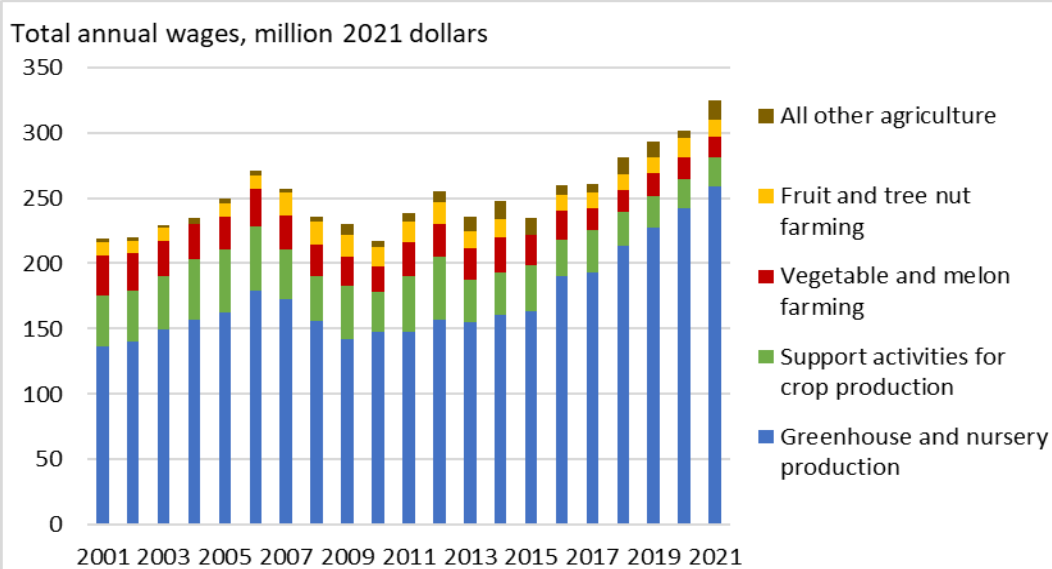
Many agricultural workers are undocumented immigrants who have few other job opportunities. According to the National Agricultural Workers Survey for 2019-20, 44 percent of agricultural workers in the U.S. were undocumented (Gold et al., 2022), and the State of Florida had 7 percent of the undocumented worker population (Rosenbloom, 2022).

Increasingly, foreign workers are being employed under the H-2A Temporary Agricultural Workers visa program, whereby agricultural operators commit to hire workers for up to a year, with a guaranteed wage rate and provided housing and transportation. Over the last decade, the number of agricultural jobs in the U.S. under the H-2A visa program increased from 75,000 in 2010 to 275,000 in 2020 (Castillo et al., 2022). Florida was the leading state for H-2A agricultural workers in 2020, with 39,064 jobs certified at 1,134 farms, mostly for vegetable or fruit harvesting or crop support, and representing about 27 percent of the overall agricultural workforce in Florida. However, there were reportedly less than 500 H-2A workers in Miami-Dade County. The Adverse Effect Wage Rate that Florida H-2A employers are required to pay in 2023 is $14.33 per hour.

Wage Rates

Annual wages paid in the agriculture, forestry, fisheries, and support services sectors in the County were $325 million in 2021, including $259 million for nursery/greenhouse, $15 million for vegetable/melon farming, $14 million for fruit farming, and $22 million for crop production support services (Figure 12.1). During 2001-2021, total wages increased by 48 percent in inflation-adjusted terms, including increases for nursery/greenhouse (90%), fruit farms (43%), and aquaculture (140%), but decreased for vegetables (-44%), other animal production (-34%), and farm support services (-44%). Wages in most agriculture sectors have steadily grown since 2015, after recovering from the recession in 2007-2009 and following a period of low growth. For comparison, total wages for all workers in the County grew by 47 percent during 2001-2021, slightly lower than for agriculture/forestry/fisheries/support services sectors.

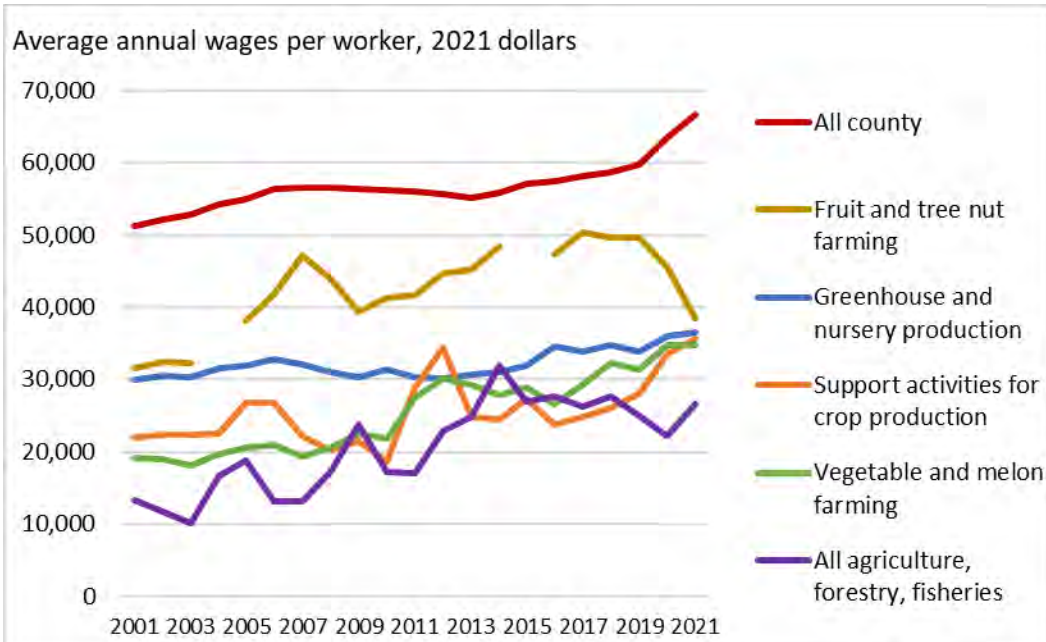
Figure 12.1. Wages paid for agriculture/forestry/fisheries/support services sectors in Miami-Dade County, 2001-2021



Wages adjusted for inflation with the GDP Implicit Price Deflator (USDOC-BEA).
Source: U.S. Department of Commerce, Bureau of Labor Statistics, Quarterly Census of Employment and Wages (BLS-QCEW).

Trends in average annual wages per worker in Miami-Dade County are shown in Figure 12.2. The average annual compensation per worker in the agriculture-forestry-fisheries sector was $26,534 in 2021. The average for the entire County workforce was $66,685. Wages were somewhat higher in the sectors of fruit farming ($38,468), greenhouse/nursery ($36,614), and crop production support services ($35,677), which tend to be more full-time or year-round activities. Annual wages were significantly higher in aquaculture ($62,422), other animal production ($44,342), and animal production support services ($42,939), although these are small sectors in the County (not shown in Figure 12.2). Wages increased more for vegetable farming (81%), and crop production support activities (62%), but less so for fruit farming (22%) and greenhouse/nursery work (22%). The increase in average wages per worker in the agricultural sector is a favorable sign for the industry; however, wages still remain well below the average for the County, so it is challenging to retain employees or recruit new employees.

Figure 12.2. Average annual wages per worker in agriculture-related sectors and all sectors in Miami-Dade County, 2001-2021

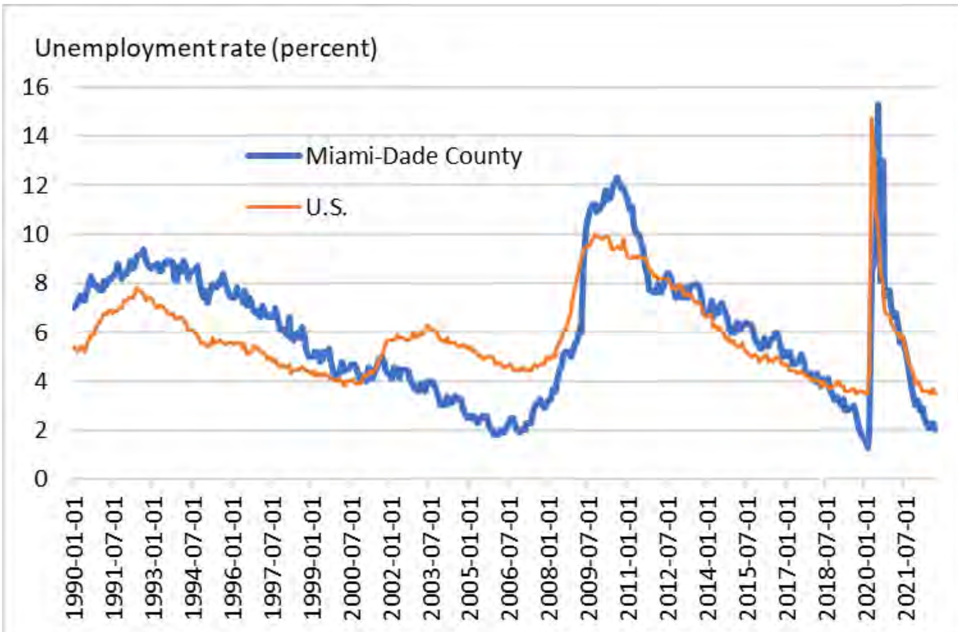


Wages adjusted for inflation with the GDP Implicit Price Deflator (USDOC-BEA). Data for some sectors not available in some years. Source: U.S. Department of Commerce, Bureau of Labor Statistics, Quarterly Census of Employment and Wages (BLS-QCEW).

Unemployment, Poverty, and Cost of Living

Other indicators of social and economic well-being in Miami-Dade County that affect the quality of life and availability of agricultural workers include unemployment rates, poverty rates, cost of living, and County net migration. The unemployment rate in the County over the period 1990-2022 averaged 6.0 percent and ranged from a low of 1.3 percent in February 2020 to a high of 15.3 percent in July 2020 as a result of the COVID-19 pandemic (Figure 12.3). High unemployment rates indicate a lack of employment opportunities and a surplus of workers for available jobs, putting downward pressure on wage rates, which is favorable to reduce labor costs for employers, but leads to reduced earnings and employee welfare. Unemployment rates in the County were generally higher than for the U.S. in 1990-2002 and 2010-2018 (except for a few months), but were lower in 2018-2020 into the early months of the COVID-19 pandemic. The unemployment rate in the County was well below the U.S. average during 2001-2009, leading up to the 2007-2009 recession, and again fell below average since mid-2021 to present.

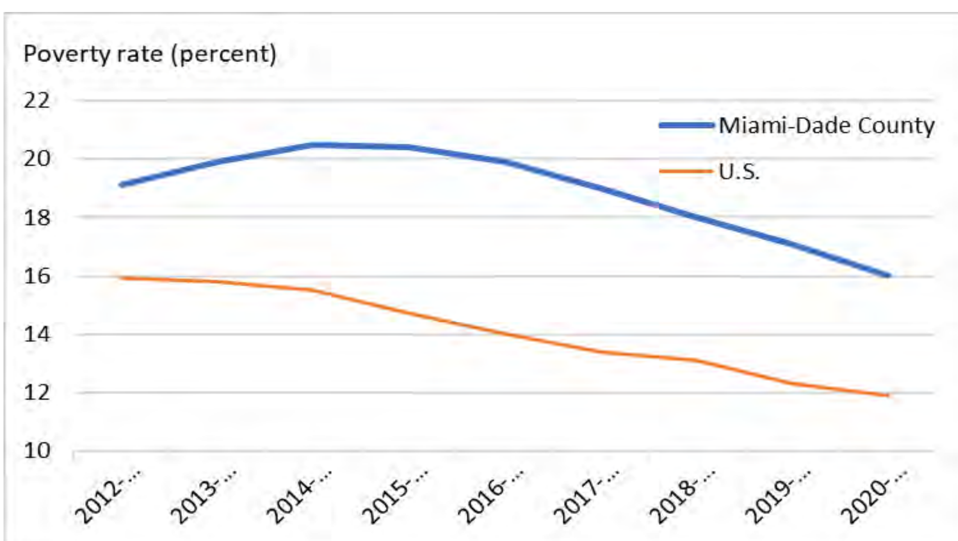
Figure 12.3. Unemployment rate in Miami-Dade County and the U.S., monthly 1990-2022



Source: Bureau of Labor Statistics, Current Population Survey, via Federal Reserve Bank of St. Louis.
Data through September 2022.

The poverty rate in Miami-Dade County averaged 18.9 percent in 2012-2020, which was higher than the U.S. average of 14.1 percent, although poverty rates have generally declined since 2014 at both the national and County levels, according to five-year averages from the American Community Survey (Figure 12.4). Higher poverty rates indicate a low standard of living and greater needs for public assistance. Poverty rates reported for other major metropolitan counties, such as Los Angeles County, California, Harris County (Dallas), Texas, and Cook County (Chicago), Illinois, were generally lower than Miami-Dade County, averaging 16.8, 15.9, and 17.2 percent, respectively, during 2012-2020.

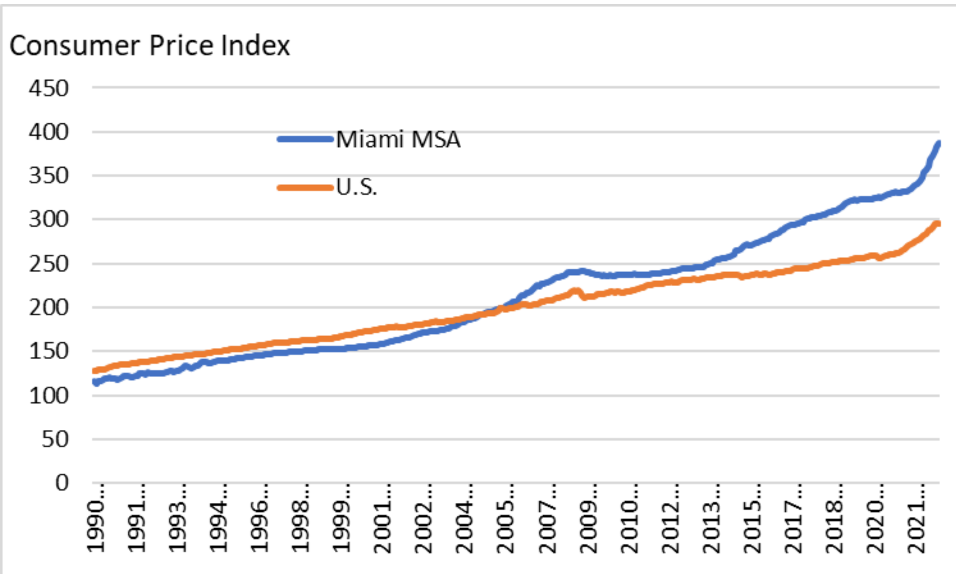
Figure 12.4. Poverty rate in Miami-Dade County and the U.S., 2012-2020



Source: U.S. Census Bureau, American Community Survey, five-year averages, via Federal Reserve Bank of St. Louis.

The Consumer Price Index (CPI) in the Miami-Ft. Lauderdale-West Palm Beach Metropolitan Statistical Area (Miami-Dade, Broward, Palm Beach Counties) was higher than the U.S. average since 2005 and accelerated rapidly due to very high inflation during 2021-2022 (Figure 12.5). A rising CPI reflects increased costs of living for food, clothing, transportation, energy, and housing. Without commensurate increases in income, an increasing CPI results in lower consumer purchasing power.

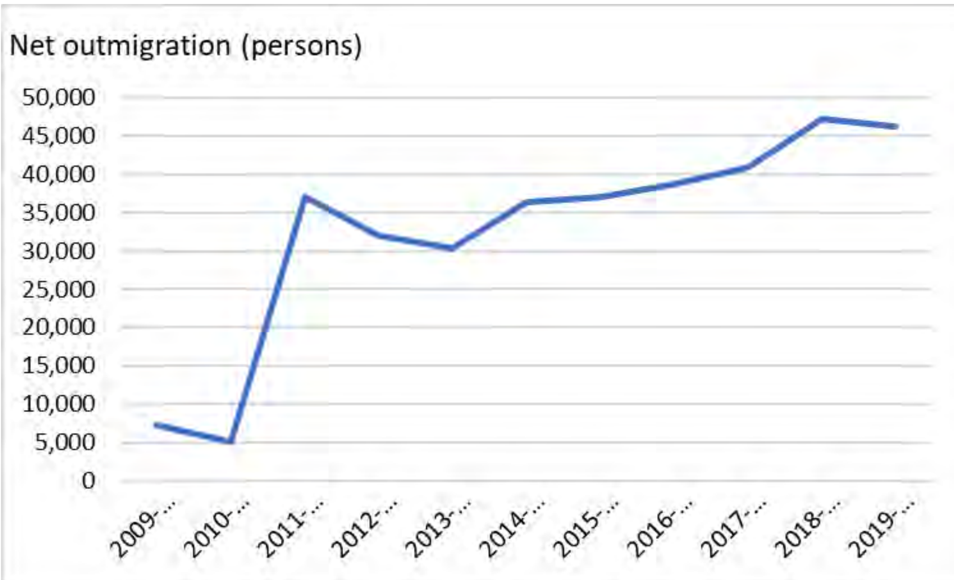
Figure 12.5. Consumer Price Index in the Miami Metropolitan Statistical Area and the U.S., monthly 1990-2022



Data through September 2022. Source: U.S. Bureau of Labor Statistics, via Federal Reserve Bank of St. Louis. Indexed 1982-1984=100, seasonally adjusted.

Net out-migration from Miami-Dade County to other U.S. counties (i.e., the difference between in-migration and out-migration) increased from less than 10,000 people annually during 2009-2010 to over 30,000 during 2011-2016, and over 40,000 during 2017-2019 (Figure 12.6). The increasing rate of outmigration suggests that the social and economic attractiveness of the County is lessening, such that people are compelled to leave to find better opportunities elsewhere.

Figure 12.6. Net out-migration from Miami-Dade County to other counties, 2009-2019



Source: U.S. Census Bureau, American Community Survey, five-year averages, via Federal Reserve Bank of St. Louis.

In conclusion, social indicators for Miami-Dade County showing higher poverty rates and higher inflation since 2005 compared to the U.S., together with increasing out-migration from the County since 2013, suggest significant challenges for worker availability in the County agriculture sector.

Urban Development

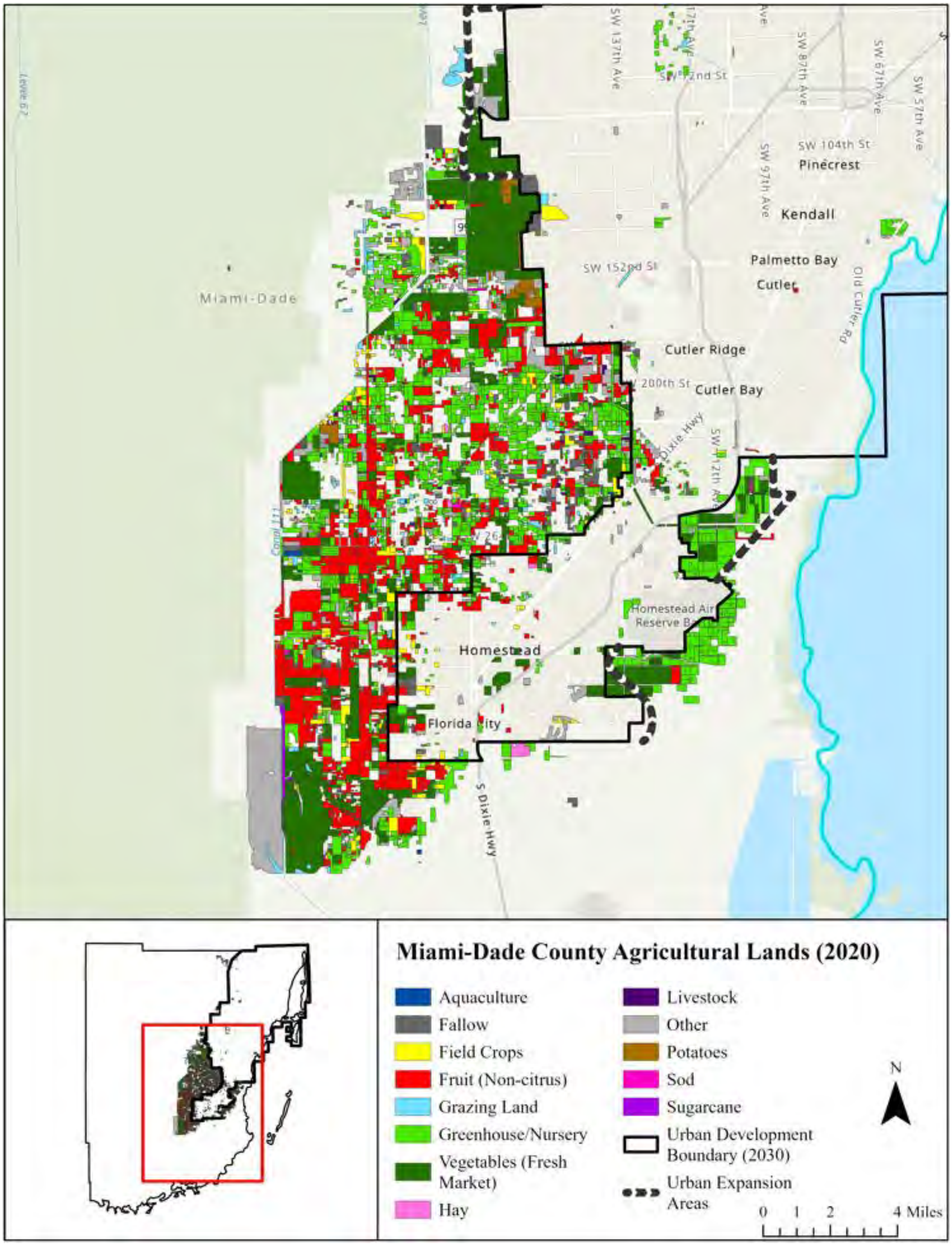
Miami-Dade County has historically been rapidly growing, and the recent decline in population growth during 2017-21 is probably an anomaly. A population forecast for the County projects the resident population of 2.662 million in 2021 to grow to 3.286 million in the year 2050, representing a 21.0 percent increase (Miami-Dade County Department of Regulatory and Economic Resources). The County is rather densely developed, with a population density of 1,422 people per square mile in 2020, which is more than three times higher than the State of Florida (U.S. Census Bureau). Because well over half of the County is in water reserve areas and Everglades National Park, developed areas are much denser than stated here.

The County Comprehensive Development Master Plan (CDMP) has long maintained a policy of directing urban development inside the Urban Development Boundary (UDB), which encompasses urban Miami in the northern part of the County and extends along U.S. Highway 1 to include Homestead and Florida City in the southern part of the County. Agricultural lands are mostly outside of the boundary, as shown in Figure 13.1. The policy is intended to limit urban sprawl, to provide urban services more efficiently, and to maintain space for population growth and continued commercial agriculture and environmental lands. The County has a long history as one of only a few climate zones in the U.S. able to produce tropical crops and fruits and vegetables for the wintertime market.

Implementation of the UDB has geographically contained development in the County by concentrating it at higher densities through taller buildings in some areas, infill development of vacant properties within existing urban areas, and contiguous development for newer areas. The population density inside the UDB is over 6,000 per square mile, or roughly four times greater than outside the UDB, and similar to densities found in other metropolitan counties in large urban areas. This has resulted in intense competition for new land for residential and commercial development, for uses such as retail stores, office space, warehouses, and utilities such as solar farms. Some developers prefer to work with large, open properties while other developers are successful at developing desirable and affordable projects on infill sites. There is also demand for large residential properties, up to five acres, that often have rural amenities like open space, gardens, pastures, and space for domestic animals. Several areas inside the UDB accommodate these types of properties.

Recognizing the desire for additional land for urban development, County government identified four areas totaling 6,718 acres (10.5 square miles) that are designated as Urban Expansion Areas (UEAs), shown by the bold dashed lines on Figure 13.1, planned for future development when warranted after the year 2030 (Miami-Dade County, 2021). The UEAs are located adjacent to the existing UDB boundary, such that new development, if these areas are used, would be contiguous to urban areas, and would cause less severe disruption to the agricultural area outside the UDB.

Figure 13.1. Map of agricultural lands and the Urban Development Boundary in Miami-Dade County.



Source: Florida Department of Agriculture and Consumer Services, Agricultural Land Geodatabase.
Map produced by UF/IFAS Food and Resource Economics Department.

Property Sales Prices

Property sales in the County during 2021-2022 are summarized in Table 13.1. A total of 133,304 parcels were sold during this period, including 543 agricultural parcels, and 132,761 parcels classified non-agricultural use, but excluding sales with multiple parcels that would duplicate the acreage numbers. The "just value" represents the current market value of properties, including all buildings and other improvements, while the "land value" represents only the value of bare land, excluding improvements, based on market assessments by the County Property Appraiser. About 3,606 acres of agricultural property were sold at a total price of $289 million, or an average of $80,151 per acre, while a total of 20,436 acres of non-agricultural property were sold at a price of $81.17 billion, or an average of $3.97 million per acre. When adjusted to represent only the land value as a share of total market value, the average sale price was $11,167 per acre for agricultural land and $1.29 million per acre for non-agricultural land, or 115 times higher than for agricultural land. Average sale prices per acre of land value for agricultural land ranged as high as $22,123 per acre for the "improved agricultural" classification, and $17,425 per acre for "ornamentals/miscellaneous agricultural." These data clearly show that prices for agricultural land are much lower than for non-agricultural land in the County, presumably due to the limits on land use in agriculture-zoned areas outside the UDB, as well as other market factors.

Table 13.1. Summary of agricultural and other property sales in Miami-Dade County, 2021-2022.

Land use classification	Number parcels sold	Just value (M$)	Land value (M$)	Sale price (M$)	Acres	Average price per acre	Average price per acre land value
Improved agricultural	300	$235.33	$45.93	$163.72	1,444.3	$113,359	$22,123
Cropland soil capability Class III	64	$35.47	$4.15	$30.33	652.5	$46,492	$5,434
Grazing land soil capability Class II	3	$111.65	$0.93	$0.51	189.0	$2,673	$22
Orchard Groves, citrus, etc.	88	$43.47	$6.08	$40.54	745.4	$54,384	$7,607
Ornamentals, miscellaneous agricultural	88	$48.70	$9.04	$53.94	575.0	$93,811	$17,425
Subtotal agricultural	543	$474.61	$66.13	$289.04	3,606.1	$80,151	$11,167
Subtotal all non-agricultural	132,761	$80,142.36	$25,960.27	$81,172.73	20,435.5	$3,972,134	$1,286,681
Total all properties	133,304	$80,616.97	$26,026.39	$81,461.76	24,041.7	$3,388,357	$1,093,898

Data excludes muti-parcel sales. Aggregate values are in million dollars.
Source: Florida Department of Revenue, Miami-Dade County Property Appraiser, and author's calculations.

Land Cash Rents

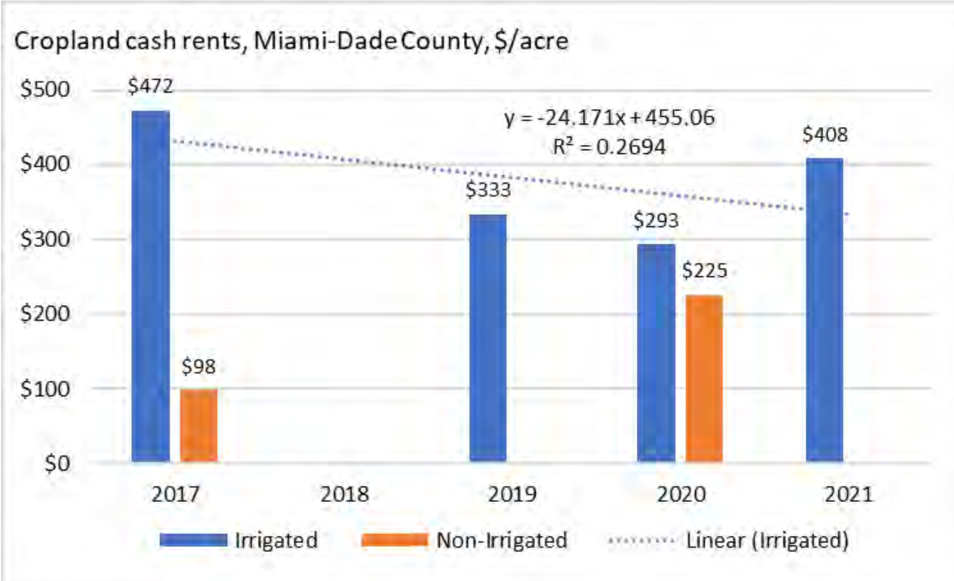
Another indicator of the market for agricultural land in Miami-Dade County is presented in Table 13.2: information on cropland cash rents from USDA-NASS Census of Agriculture. During 2017-2022, cropland rents in Miami-Dade County averaged $377 per acre for irrigated land and $161 per acre for non-irrigated land, which was higher than for the south Florida region ($332 and $57, respectively) and the State of Florida ($246 and $56, respectively). Cropland cash rents for irrigated land in the County fluctuated over time, from a high of $472 per acre in 2017 to a low of $293 per acre in 2020 (Figure 13.2). Linear regression analysis of the irrigated-land cash rents over time indicate a slight downward trend of about $24 per year (dotted line in Figure 13.2), although the correlation coefficient for this trend is quite low (27%) due to the high level of year-to-year variability in the data. Average cash rents for irrigated land during this period in the County were 14 percent higher than the region and 53 percent higher than the State. Farmland rental rates may vary widely across the County depending upon location, soil type, parcel size, length of lease, and other terms, and level and quality of improvements. Taken together, these data suggest that competition for land among tenant farmers is not increasing. According to County staff, a significant amount of farmland in the County is owned by developers who rent the land to farmers, although their long-term intentions for this land may be to develop it.

Table 13.2. Summary of cropland cash rents for irrigated and non-irrigated farmland in Miami-Dade County, South Florida region, and the State of Florida, 2017-2022.

	Miami-Dade County		South Florida Region		State of Florida	
Year	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated
			dollars per acre			
2017	$472.0	$97.5	$366.0	$27.0	$259.0	$50.0
2018						
2019	$333.0		$306.0	$68.5	$216.0	$58.0
2020	$293.0	$225.0	$323.0	$75.0	$263.0	$62.5
2021	$408.0				$245.0	$54.0
2022					$248.0	$57.0
Average	$376.5	$161.3	$331.7	$56.8	$246.2	$56.3

Note: data not available for some years and regions due to insufficient observations for statistical reliability.
Nominal values not adjusted for inflation. Data is for bare land only; land with buildings is excluded from the survey.
Source: USDA-NASS, annual cash rents for cropland, Florida County estimates.

Figure 13.2. Trend in cropland rents for irrigated and non-irrigated land in Miami-Dade County, 2017-2021.



Note: data not available for some years due to insufficient observations for statistical reliability.
Nominal values not adjusted for inflation.
Source: USDA-NASS, annual cash rents for cropland, Florida County estimates.

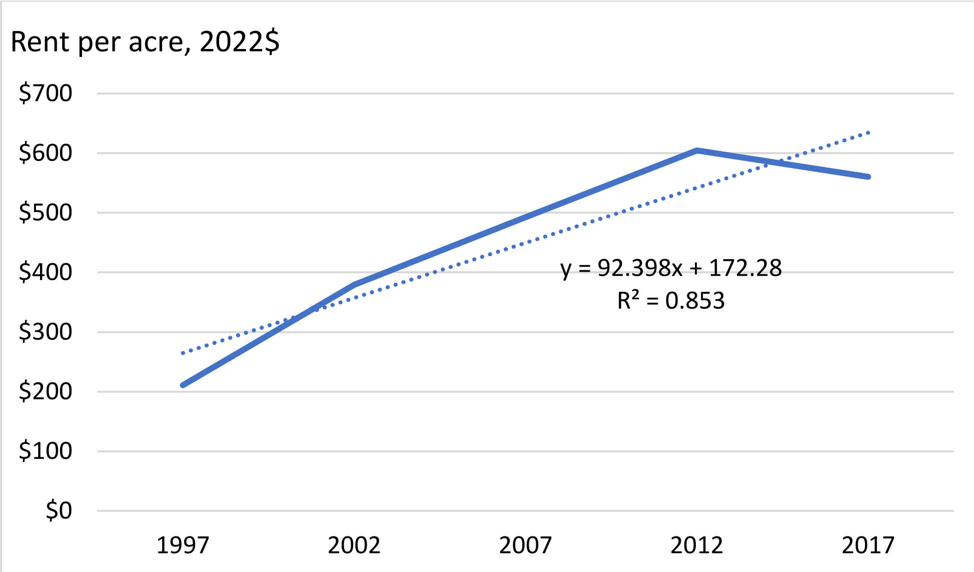
Additional information on long term trends in farmland rental expenses and rates per acre in the County was compiled from the USDA-NASS Census of Agriculture, as shown in Table 13.3. Total expenses for land and buildings rental increased from under $10 million in 1997 to over $24 million in 2012, then declined to under $20 million in 2017, in constant dollar terms. Land rent represented less than 3 percent of total farm production expenses in Miami-Dade County in 2017. The number of operations with rent expense also increased over time, while the total acres rented generally declined, although it varied widely: over 45,000 acres in 1997, under 30,000 acres in 2007, nearly 40,000 acres in 2012, and 35,628 acres in 2017. Average rent expense per acre generally increased during this period, peaking at $605 per acre in 2012, then declined slightly to $560 per acre in 2017. Rents per acre increased 2.7 times or +8.3 percent per year over the 20-year period. Linear regression analysis of these data indicated an increase of about $92 per acre over each five-year period, or an average annual rate of +$18 per acre (Figure 13.3). This information confirms that land rental rates in the County have significantly increased over the long run, although they have recently stabilized, consistent with the data for 2017-2021 shown above.

Table 13.3. Estimated land rental expense and expense per acre for farmland in Miami-Dade County, 1997-2017

	1997	2002	2007	2012	2017
Rent expense for land and buildings (Million 2022$)	$9.69	$12.93	$13.60	$24.15	$19.95
Operations with rent expense	231	243	261	312	322
Acres rented	45,885	34,085	27,600	39,950	35,628
Average rent expense per acre (2022$)	$211	$379	$493	$605	$560

Sources: USDA-NASS Census of Agriculture; USDOC-BEA, GDP Implicit Price Deflator.

Figure 13.3. Trend in land rental rates per acres for farmland in Miami-Dade County, 1997-2017



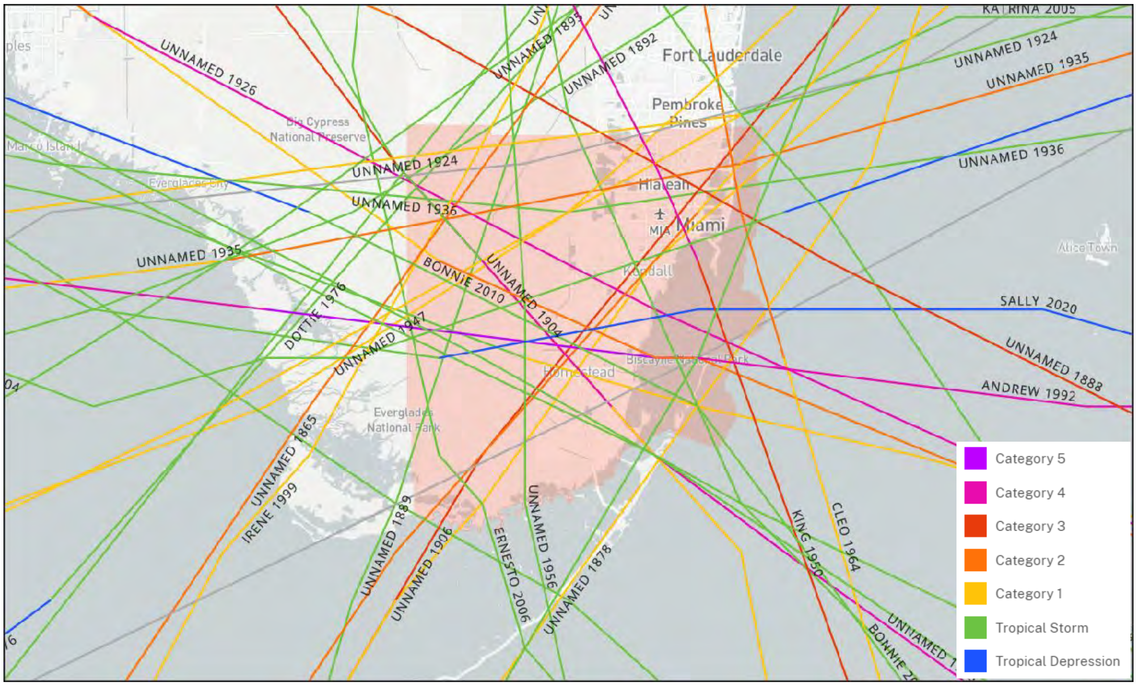
Sources: USDA-NASS Census of Agriculture; USDOC-BEA, GDP Implicit Price Deflator.

Weather Hazards

Historical Tropical Cyclones in Miami-Dade County

With strong wind, heavy rainfall, and flooding, tropical cyclones (tropical storms and hurricanes) can cause considerable damages and losses to agriculture, such as production loss of crops and livestock, destruction of farm assets and infrastructure, damages to stored supplies and products, loss or movement of agricultural labor, loss of worker housing, etc. Availability of agricultural labor can be an issue after major storms, particularly when other areas in the South Atlantic or Gulf region contemporaneously experience severe storms. The annual losses from tropical cyclones in the United States are estimated to average about $10 billion (Pielke et al. 2008). The National Hurricane Center (NHC) of the National Oceanic and Atmospheric Administration (NOAA) publishes the geospatial data of historical hurricane tracks. From 1851 to 2022, there were 37 hurricanes or tropical storms with the central path passing over Miami-Dade County, as shown in Figure 14.1. An average of 2.06 tropical cyclones traversed Miami-Dade County every 10 years. Figure 14.2 shows the number of tropical cyclones of different intensity levels passing over the County every 10 years, and Figure 14.3 summarizes the intensity distribution of tropical cyclones in the County. Six of the tropical cyclones were major hurricanes (Category 3-5), including one Category 3 storm, four Category 4 storms, and one Category 5 storm (Andrew 1992). Tropical cyclones mostly happened during August to October, except one tropical storm that happened in February 1952, and all the major hurricanes happened during August to October (Figure 14.4).

Figure 14.1. Tropical cyclones with central path passing over Miami-Dade County, 1851-2021.



Source: NOAA Historical Hurricane Tracks, [https://coast.noaa.gov/hurricanes.](https://coast.noaa.gov/hurricanes)

Figure 14.2. Number of tropical cyclones passing over Miami-Dade County by decade, 1851-2022.

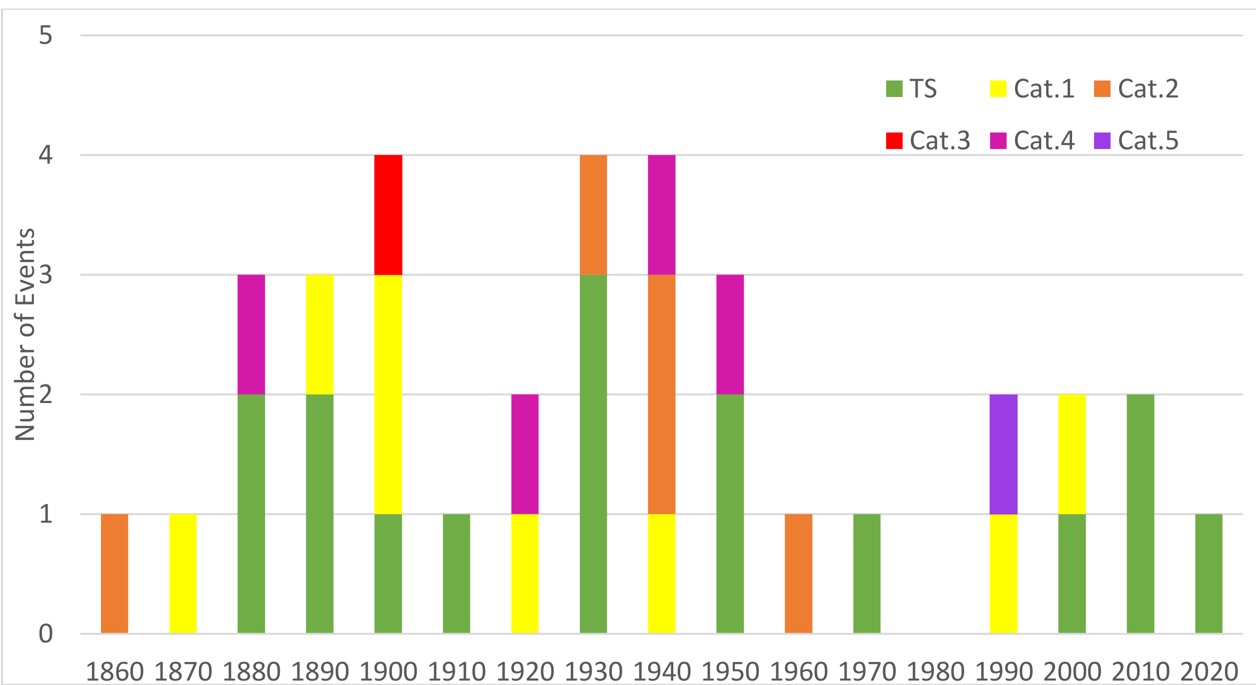


Figure 14.3. Intensity distribution of tropical cyclones passing over Miami-Dade County, 1851-2022.

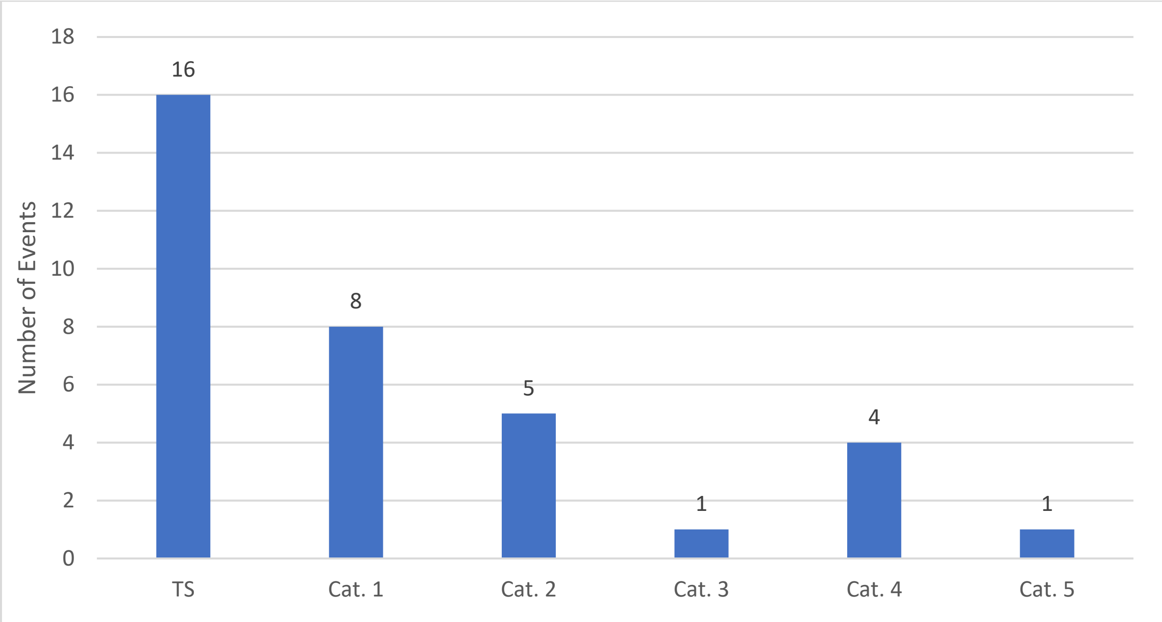
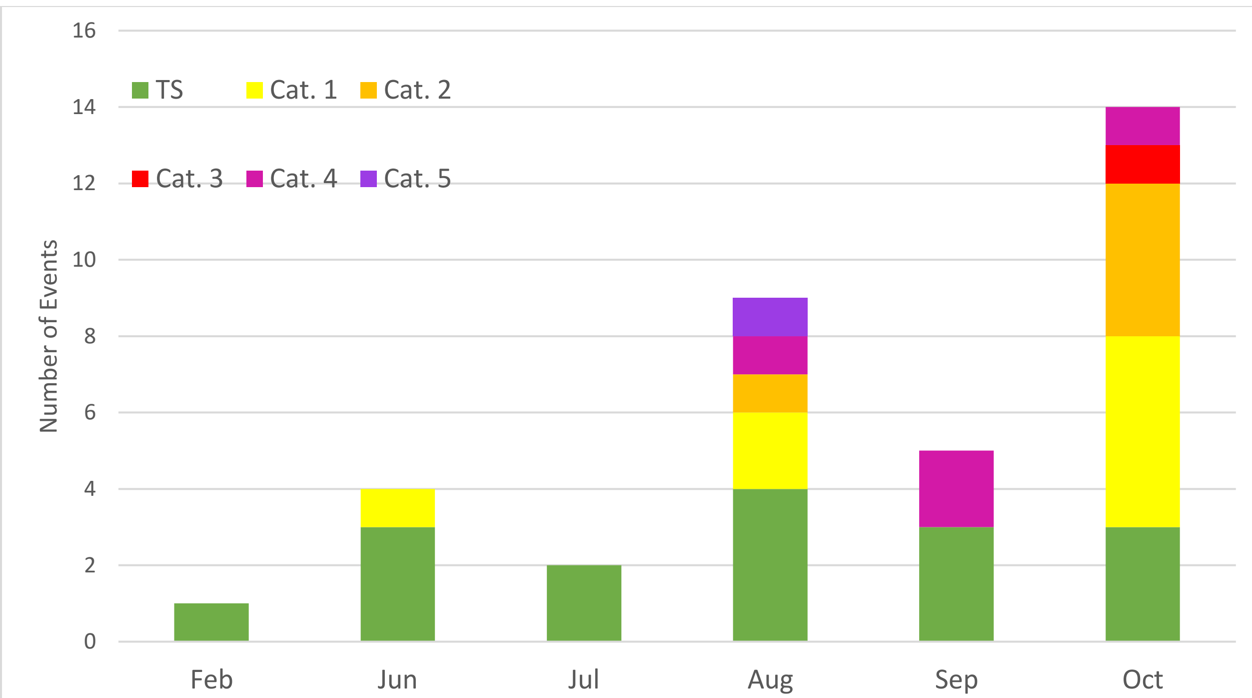


Figure 14.4. Monthly distribution of tropical cyclones passing over Miami-Dade County, 1851-2022.

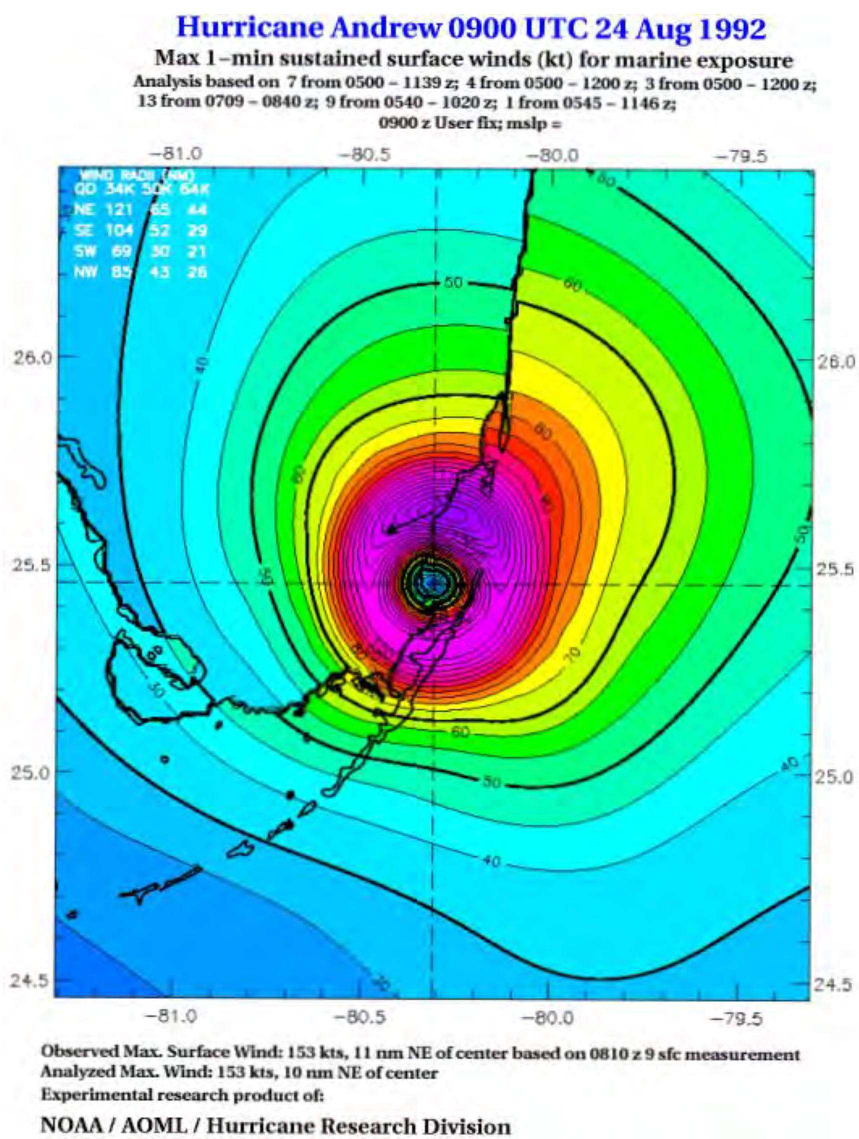


Scenario Analysis – Category Five Hurricane

Hurricane Andrew (August 16-28, 1992) was one of the most destructive hurricanes on record in the United States, causing 61 deaths and an estimated $25 billion in damages with over 125,000 homes destroyed or damaged. It is an example of the potential impacts of a Category 5 hurricane on agriculture in Miami-Dade County because it predominantly affected the southern parts of the County around Homestead and the Redland. Andrew began as a tropical depression in the eastern Atlantic Ocean on August 16, then rapidly intensified into a Category 5 hurricane as it moved westward towards the Bahamas on August 23, and made landfall in Florida on Elliott Key and Homestead on August 24. After several hour, the hurricane emerged over the Gulf of Mexico at Category 4 strength, then turned northwestward and made a second landfall near Morgan City, Louisiana, as a Category 3 storm.

The NHC only provides geospatial data of wind swaths for events after 2008. The reanalyzed wind swath map of Hurricane Andrews at the point of landfall on August 24 was produced by NOAA Hurricane Research Division (Landsea et al. 2004), as shown in Figure 14.5. In this section, we performed a scenario analysis to provide an estimate on the agricultural production losses of Miami-Dade County that would occur if a "Hurricane Andrew" happened again with the current mix of agricultural systems in place.

Figure 14.5. Hurricane Andrew wind swath analysis.



Source: NOAA Hurricane Research Division, https://www.aoml.noaa.gov/hrd/hurdat/hwind.html

Using geographic information systems (GIS) software (ArcGIS Pro), we extracted the hurricane wind swath of hurricane Andrew from Figure 14.3 as a shapefile. We assumed that the same windspeed intensity was maintained across the County and created the wind swath intensity of hurricane Andrew shown in Figure 14.6. The wind swath shapefile was overlaid on the agricultural land geospatial data of Miami-Dade County to identify the impacted agricultural lands, as well as the wind intensity that each parcel of affected agricultural land experienced. The agricultural lands geospatial data are from the Florida Statewide Agricultural Irrigation Demand (FSAID) Agricultural Lands Geodatabase (ALG) developed by the Florida Department of Agriculture and Consumer Services (FDACS 2023). Figure 14.6 shows the wind swath intensity of hurricane Andrew and impacted agricultural lands using the Saffir-Simpson Hurricane Wind Scale as indicated in Table 14.1.

Figure 14.6. Estimated wind swath of Hurricane Andrew (1992).

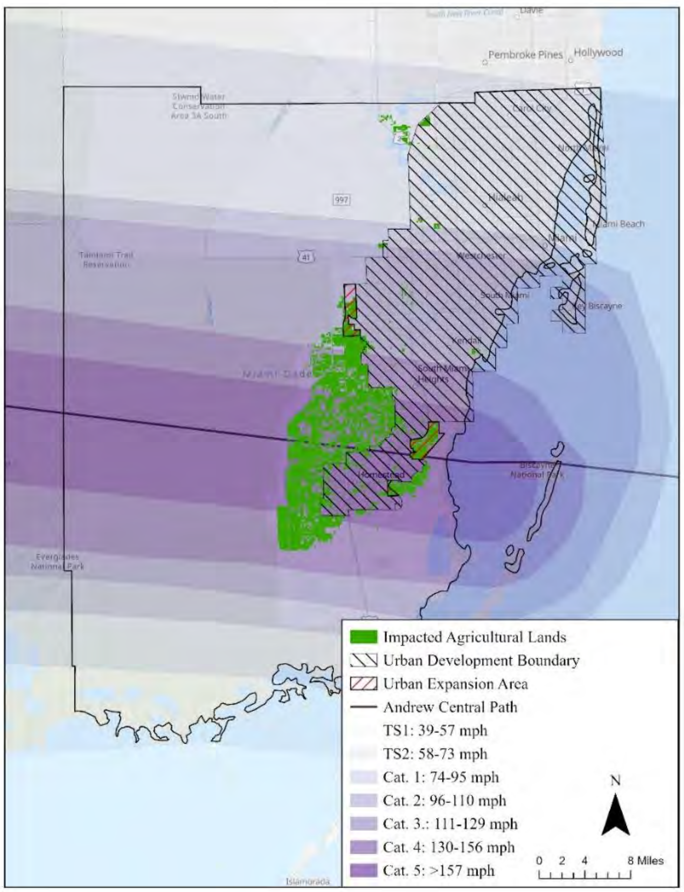


Table 14.1. Saffir-Simpson hurricane wind scale.

Category	Sustained Winds (mph)
Tropical Storm I (TS1)	39-57
Tropical Storm II (TS2)	58-73
Category 1	74-95
Category 2	96-110
Category 3	111-129
Category 4	130-156
Category 5	157 or higher

The estimated agricultural acreage impacted for different commodity groups by hurricane intensity level is summarized in Table 14.2. A total of 42,562 acres of agricultural land would be affected, with 98 percent of agricultural lands experiencing major hurricane force winds (Category 3-5). The most affected commodity group in terms of acreage would be vegetables (15,348 acres), followed by greenhouse/nursery (10,991 acres) and fruit (10,925 acres).

Table 14.3 shows the estimated annual value of production on affected acreage by commodity group. Data published by the USDA-NASS Census of Agriculture on price and yield were used to estimate value per acre in Florida for individual crops within commodity groups for the years 2017-2021. Where not available at the County level, value per acre was estimated using commodity average price and yield at the national level or using the average value per acre of the relevant commodity group. The resulting five-year average of value per acre was used to estimate the value of production at risk on affected acreage by commodity group and hurricane level. Due to lack of data for greenhouse/nursery, the five-year average sales revenue of 2017-2021 from IMPLAN (in 2022 dollars) was used to estimate the value of impacted acreage**.** In summary, a repeat of Hurricane Andrew in the current era would impact agricultural lands that produce over $774 million dollars of agricultural products throughout a calendar or marketing year, with 89 percent of that value in the greenhouse/nursery sector ($688 million).

Table 14.2. Estimated area impacted in Miami-Dade County under simulation of a Category 5 hurricane, 2022

Commodity Group	Hurricane Intensity						
	TS2	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Total
Fruit (Non-citrus)		18		67	2,454	8,396	10,925
Greenhouse/Nursery	1	37		249	1,728	8,975	10,991
Vegetable				3,225	5,786	6,336	15,348
Other		778	37	723	1,306	2,455	5,299
Total	1	833	37	4,265	11,275	26,152	42,562
Percent of total ag. area	0.0%	2.0%	0.1%	10.0%	26.5%	61.4%	100%

Table 14.3. Estimated value of annual production impacted under simulation of a Category 5 hurricane, 2022

Commodity Group	Value of Annual Production (million 2022$)						
	TS2	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Total
Fruit (Non-citrus)		$0.05		$0.19	$6.56	$22.49	$29.27
Greenhouse/nursery	$0.06	$2.31		$15.60	$108.14	$561.59	$687.69
Vegetables				$5.98	$25.06	$26.49	$57.53
Total	$0.06	$2.35		$21.76	$139.76	$610.55	$774.48

The production losses were calculated using the estimated value of annual production for each commodity group and the percentages of production lost. The production loss percentages vary for different hurricane levels and crop types, along with the growth stage of crops when the hurricane strikes. Although hurricanes can negatively impact crops at all stages of growth, harvestable crops result in the most economic losses and are of the greatest concern. We collected information on planting and harvesting months of the crops grown in Miami-Dade County from the UF/IFAS Extension vegetable crop production handbook, USDA reports, and online articles. At the time of Hurricane Andrew in late August, most fruit crops are in harvest or ready for harvest, such as avocado, carambola, mango, etc. For vegetables, most crops grown in Miami-Dade County are either out of season or in planting. We excluded the out-of-season crops from the analysis. Based on our experience working with previous tropical cyclones events in Florida (Irma 2017, Michael 2018, Ian 2022), we assume the annual production loss percentage of different commodity groups by hurricane intensity as shown in Table 14.4. Vegetables show lower loss percentages since most crops are in planting or out of season, and the losses can be reduced by replanting after the event.

Table 14.4. Assumed annual production loss by windspeed level and agricultural commodity under simulation of a Category 5 hurricane, 2022.

Commodity Group	TS2	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5
Fruit Crops	10%	20%	30%	40%	50%	60%
Greenhouse/nursery	10%	20%	40%	50%	60%	80%
Vegetable (Fresh Market)	5%	10%	15%	20%	25%	30%

The estimated production losses for agricultural production resulting from an event like Hurricane Andrew would be $554.69 million dollars, as shown in Table 14.5. The most affected commodity group in terms of production losses is the greenhouse/nursery sector, with $522.42 million dollars or around 94 percent of total agricultural losses. The losses represented 29.8 percent of estimated potential agricultural production value in 2022.

Table 14.5. Estimated value of annual production loss under simulation of a Category 5 hurricane, 2022.

Commodity Group	Million 2022$
Fruit (Non-citrus)	$16.86
Greenhouse/Nursery	$522.42
Vegetable (Fresh Market)	$15.41
Grand Total	$554.69

Information on buildings in Florida was obtained from the USA Structures geospatial database maintained by the Department of Homeland Security (DHS), Federal Insurance and Mitigation Administration (FIMA), Federal Emergency Management Agency (FEMA) Response Geospatial Office, Oak Ridge National Laboratory, and the U.S. Geological Survey (USGS) (2022). The geospatial data contains the footprints for all structures greater than 450 square feet in the United States, with information on building area, occupancy, and primary occupancy type (e.g., Residential, Agricultural, Industrial), as well as height classifications. For Miami-Dade

County, the database contains approximately 521,500 different polygons, each representing a building, of which 2,250 are identified as agriculture buildings. This geospatial data allows us to identify the potential buildings at risk within a given disaster area. The USA Structures data has no information about the number of floors or other attributes in relation to building values, thus it is challenging to estimate the value of agricultural buildings in Florida due to the lack of reliable and detailed information.

Using ArcGIS Pro, the agricultural buildings in the County were extracted from the USA Structures data and overlaid with the hurricane wind swath shapefile to determine the wind intensity that each agricultural building might experience. Table 14.6 shows the number and area of impacted agricultural buildings by hurricane level in the simulated scenario of Hurricane Andrew. We can see there would be 2,251 agricultural buildings affected, including 2,172 buildings (96%) experiencing Category 3-5 winds, and an overall building footprint area of 10.12 million square feet or 232 acres. Note that these data may not include nursery/greenhouse structures.

Table 14.6. Number and area of agricultural buildings impacted for simulation of a Category 5 hurricane, 2022.

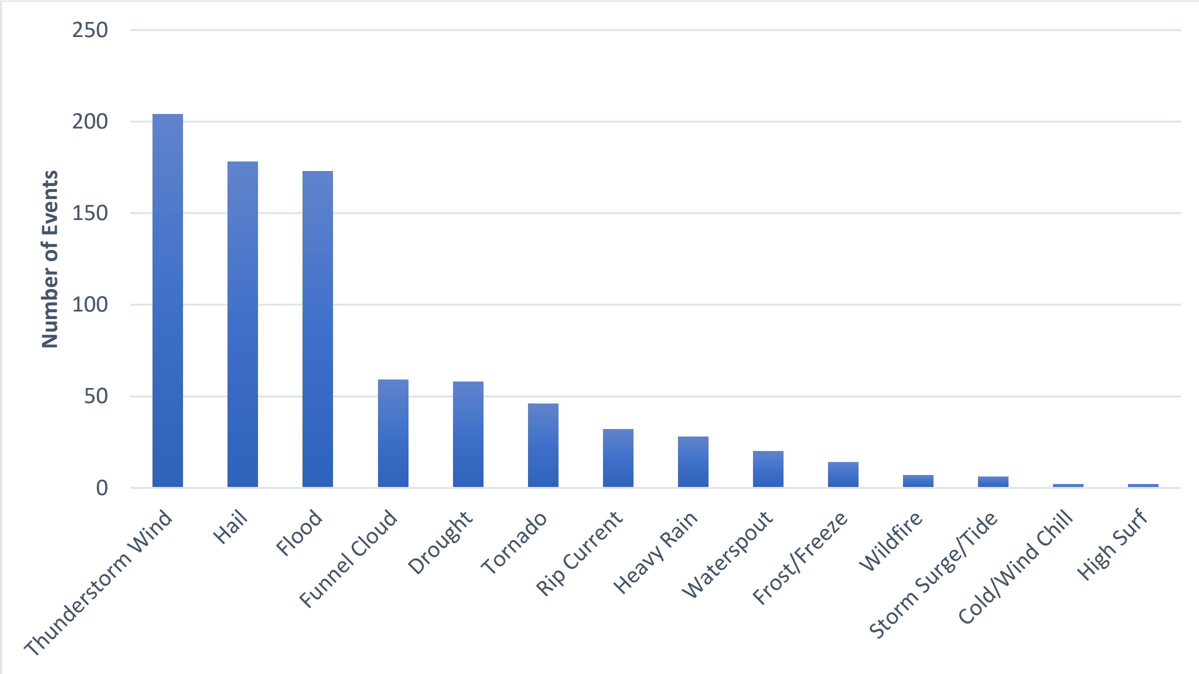
Hurricane Level	Number of Buildings	Total Area (1,000 sq ft)
TS	5	53
Cat. 1	74	228
Cat. 3	199	524
Cat. 4	586	1,185
Cat. 5	1,387	8,133
Total	2,251	10,123

Other Weather Hazards

Global climate change causes more extreme weather events such as coastal floods and storm surges with higher intensity. The NOAA Storm Events Database (2023) provides comprehensive records of significant weather events in the U.S., including those causing loss of life, injuries, major property damage, or disruption to commerce, i.e., rare or unusual weather that generates media attention. A total of 942 hazardous weather events were recorded in the County during 2000 to 2022, as shown in Figure 14.7. On average, there were 41 hazardous weather events annually in Miami-Dade County, with the most frequent weather being thunderstorm winds (204 events), hail (178 events), and flooding (173 events), including inland floods, flash floods, and coastal floods.

These three most frequent weather hazards are all major threats to agriculture and can cause significant damage and economic losses. Thunderstorm winds can break plants, remove leaves, cause fruit drop, etc. Hail can cause damage to leaves, flowers, and fruits, reducing yield or destroying plants. Flooded fields can lead to crop loss, contamination, equipment loss, debris deposition, and the spread of invasive species.

Figure 14.7. Number of hazardous weather events in Miami-Dade County during 2000-2022.

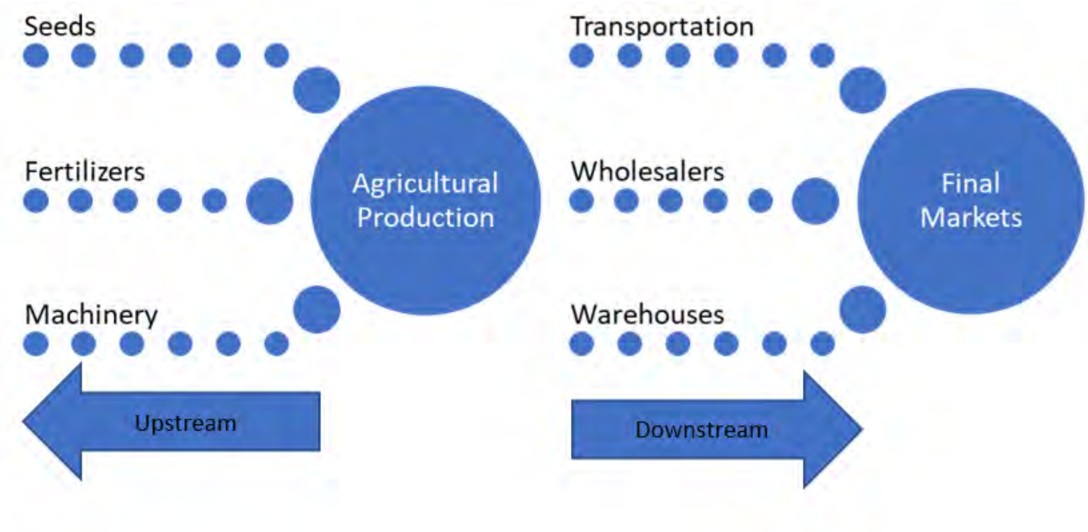


Source: NOAA Storm Events Database

Market Disruptions

Market disruptions are events or circumstances that interrupt the normal functioning of a market and cause a significant shift in supply or demand, which may lead to fluctuations in prices and economic activity. The events that can contribute to a market disruption include natural disasters, technological advancements, changes in consumer behavior, economic changes, and political instability. In the case of agriculture, and particularly in the case of agricultural commodities like the ones produced in Miami-Dade County, most of the examples that can be found in the literature refer to the supply side. Such disruptions can be caused by various factors that affect a specific product/commodity or activities upstream or downstream of that product/commodity. In the case of agriculture, disruptions upstream of agricultural production can affect the provision of inputs such as fertilizer, seeds, or other supplies or equipment. Examples of downstream events include a shortage in warehousing or transportation services that affect how a particular product can be distributed to wholesalers or consumers. In addition to upstream and downstream events causing market disruptions, other events such as weather can directly affect the ability of farmers to produce. The value chain of agricultural production is illustrated in Figure 15.1.

Figure 15.1. Value chain of agricultural production.



Market disruptions can lead to significant losses for businesses involved in a specific commodity market and may ultimately benefit competitors or goods that might act as a substitute. Some common examples of these events in the agricultural industry include weather events (e.g., drought conditions, extreme heat, freezing, or flooding), pest infestations, labor shortages, economic and political factors, and transportation disruptions. Of course, the significance and negative impacts associated with a specific disruption will depend on the severity and duration of the event, but also on the specific way that a given industry is exposed to its competitors, the way it can access alternative suppliers, and the resilience of the logistic networks that allow the industry to reach markets.

IMPLAN (Implan Group, LLC) is a regional economic modeling software system that serves as resource to understand the inputs that support agricultural production. In Miami-Dade County, the predominant agricultural industries are greenhouse/nursery/floriculture production, vegetable/melon farming, and fruit farming. The data from IMPLAN shown in Table 15.1 indicates the share of industry production costs for different inputs in the County agricultural sectors. These inputs reflect the upstream linkages of the value chain represented in Figure 15.1. The numbers in Table 15.1 indicate the importance of each type of input to total costs; however, even inputs representing a small share of total costs can critically impact the production or productivity of a given crop.

Table 15.1. Selected input consumption as a share of total output for specialty crop industries in Miami-Dade County.

Greenhouse/Nursery/Floriculture production		Vegetables/Melon farming		Fruit farming	
Greenhouse, nursery, and floriculture products	11.9%	Support activities for agriculture	10.9%	Support activities for agriculture and forestry	16.0%
Support activities for agriculture	5.4%	Vegetable/melon products	4.7%	Pesticides and other agricultural chemicals	4.4%
Nitrogenous and phosphatic fertilizer	2.7%	Pesticides and other agricultural chemicals	4.6%	Nitrogenous and phosphatic fertilizer	2.1%
Refined petroleum products	2.4%	Nitrogenous and phosphatic fertilizer	3.3%	Water, sewage, and other systems	0.9%
Truck transportation services	1.8%	Refined petroleum products	1.2%	Refined petroleum products	0.9%
Pesticides and other agricultural chemicals	1.7%	Water, sewage, and other systems	1.0%	Fruit products	0.6%
Labor Compensation	29.6%	Labor Compensation	15.5%	Labor Compensation	14.7%

Source: IMPLAN model for Miami-Dade County (Implan Group, LLC).

Labor is a major input for specialty crops, representing a large part of the cost structure, and it is critical to sustaining agricultural production. Labor compensation represents a higher share of costs for the greenhouse/nursery/floriculture industry (29.6%) than it does for vegetables (15.5%) or fruit farming (14.7%). Vegetable/melon and fruit production rely more on support activities such as hired labor contractors or custom farming services for planting, harvesting, or caretaking activities, which also represents mostly labor. This implies that the labor compensation shown in the last row of Table 15.1 is an underrepresentation of the total input of labor costs, and to account for direct and indirect labor we must also consider those that are employed by the industry of "support activities for agriculture and industry."

Fertilizers and pesticides also play a critical role in specialty crop farming. In Miami-Dade County, "vegetable/melon farming" (mostly vegetables) has a higher dependency in cost terms than other sectors on fertilizers and pesticides to maintain crop growth and protect against pests and diseases. Other inputs, like seeds, do not represent a large share of the cost structure of specialty crop sectors in Miami-Dade County, although their availability is still vital for production. Seeds have a crucial role in agriculture as a means of propagating crops and maintaining and transmitting genetic improvements made by plant breeders (Delouche and Potts, 1983).

Disruption of Inputs

Labor. While labor shortages occur in most industries, they tend to occur more frequently in industries where the work is seasonal and or area-specific, such as agriculture (Alwang and Siegel, 1999). Labor shortages can also be more frequent and intense where industries rely on workers living abroad (Levine, 2005). Labor shortages in other agricultural areas in the U.S. can also affect markets for competing specialty crops in Florida. A 2013 survey of specialty crop growers in Florida found that undocumented workers accounted for

90 percent of the workforce (Guan et al., 2015). In 2017, Florida had the highest number of certified H-2A visa guestworkers in the U.S., mainly in fruits (48%) and vegetables (24%, Luckstead and Devadoss, 2019). Only 20 percent of respondents who reported hiring workers through the H-2A visa program did not have labor shortage issues during that specific harvesting season (Biswas et al., 2018). A report by Rutledge et al. (2019) concluded that despite rising wages and increasing benefits, California farmers still had trouble finding enough workers to harvest crops. Some farmers offset this labor shortage by changing to less labor-intensive crops and adding automation.

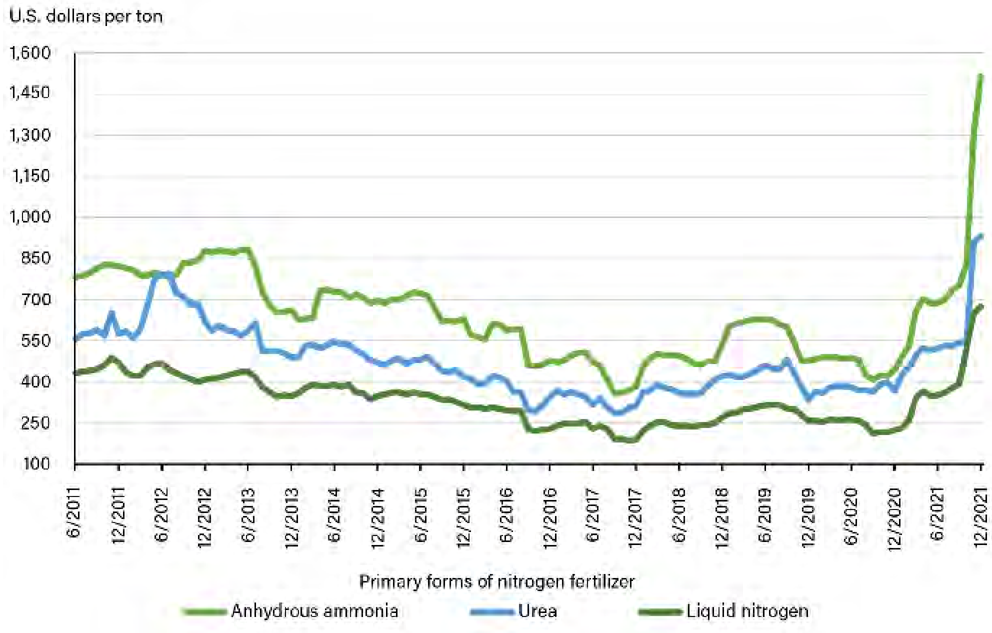
Because much of agriculture relies on migrant or visiting workers, particularly in Florida and other states that have significant specialty crop production (e.g., California), the introduction of more restrictive immigration policies or less capacity to attract new agricultural workers can create labor shortages that affect production in Miami-Dade County.

Seeds and plants. Seeds and starter plants are essential to agricultural crop production, especially when farmers shift to new products or expand acreage. Seed and plant shortages are not everyday events but can substantially limit crop acreage in a given area. One example is boniato (sweet potato cultivar), a significant root crop in Miami-Dade County for which propagation relies on cuttings from active vines. In 2010, multiple freezes wiped out about 60 percent of the boniato crop and production took three years to completely recover due to the absence of starter plants (Ozores-Hampton et al., 2010). Due to a major drought last year in the Western U.S., a low crop seed supply is expected in 2023 (GoSeed, 2022). Some specialty crops in Miami-Dade County agricultural production rely heavily on the availability of seeds and starter plants. Although the costs of seeds and starter plants may not represent a large share of the total agriculture costs, they are a critical element of agricultural production.

Pesticides and fertilizer. Pesticides and fertilizers are critical to all types of crop farming. In the wake of the COVID-19 pandemic and the 2022 invasion of Ukraine by Russia, the price of fertilizers skyrocketed, with this market facing a high level of uncertainty. Based on USDA data, Figure 15.2 shows the changes in the price of fertilizers in the Midwestern U.S. Given that fertilizer production is highly concentrated, with prices set in global markets, fertilizer prices in South Florida are expected to follow a similar trend. Anecdotally, fertilizer prices in Florida have dramatically increased over the past two years, with acute shortages reported in some areas.

Given that fertilizer prices are spiking, many farmers in the U.S. and worldwide are replacing high-fertilizer-requiring crops with low-fertilizer-requiring ones (Ben Hassen and El Bilali, 2022). In the U.S., higher costs for fertilizers translate to financial pressure on farmers, as well as higher costs for the food industry, grocery stores, restaurants, and consumers (Business Insider, 2022).

Figure 15.2. Monthly average fertilizer prices in the U.S., 2011-2021.



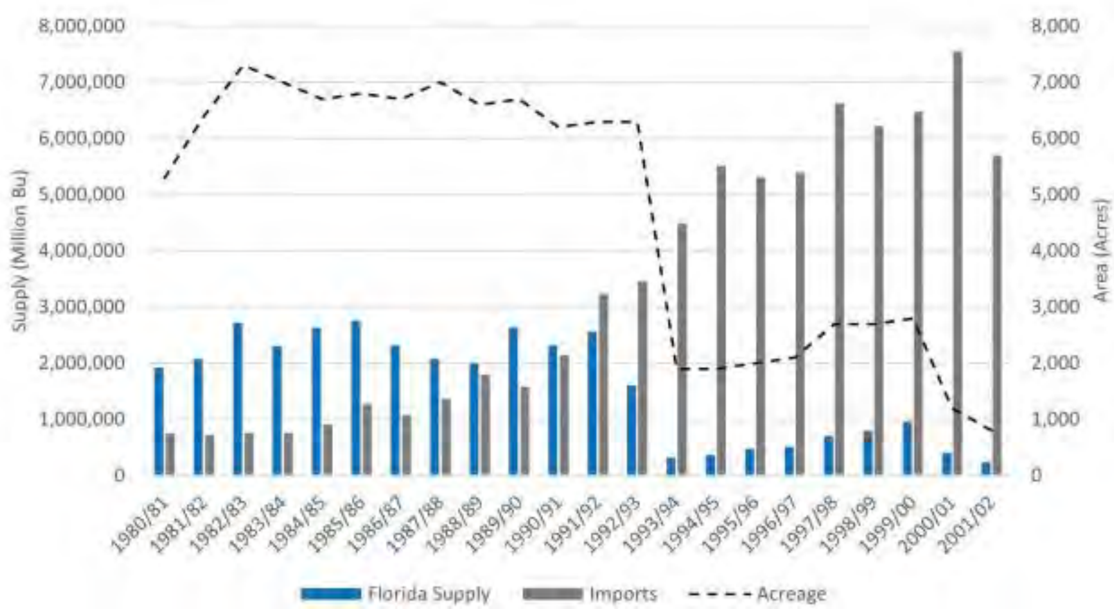
Source: USDA Economic Research Service and USDA Agricultural Marketing Service, 2022.

Regarding pesticides, U.S. farmers have cut back on using common herbicides, sought substitutes to popular fungicides, and changed planting practices due to persistent shortages of agricultural chemicals (Reuters, 2022). Farmers who try to use fewer herbicides/pesticides or turn to cheaper-yet-less-effective fungicides may increase their risk of loss to weeds, pests and diseases. As shown previously in Table 15.1, fertilizers and pesticides are a critical input for agricultural production in Miami-Dade County's specialty crop industries. Changes in the fertilizer and pesticide market are unpredictable and will challenge the resilience and capacity of agricultural producers to adapt.

Disruptive Events Affecting Production in Florida

Another form of market disruption is associated with hazardous weather events. Hurricanes, tornados, and other events can significantly reduce agricultural production. Some crops will tend to recover faster than others. Production of perennial tree crops and large nursery plants may be affected for multiple years. For example, production of Tahiti Lime declined in Southern Florida after Hurricane Andrew hit in 1992 (Blare et al., 2022). The decline was noticed during the 1993-94 season as production fell to only 14 percent of the average production in the previous decade (Figure 15.3). In this case, the effects persisted over time because the hurricane was particularly damaging to perennial tree crops, and Tahiti lime production never recovered. It is important to have in mind that agriculture production that relies on trees will always need more years to recover than those based on temporary crops, because tree need to be replanted and nurtured for several years until becoming commercially viable.

Figure 15.3. U.S. Tahiti lime supply and acreage 1980/1981 to 2001/2002.



Source: Blare et al., 2022.

Another recent example of a market disruption associated with weather conditions happened in Florida after Hurricane Ian hit in September 2022. According to a UF/IFAS assessment, the storm affected around 4.7 million acres of agricultural land and caused $1.03 billion in losses of crops and livestock (Court et al., 2023). Citrus production was severely affected, with a large part of seasonal production being destroyed. Besides this event, significant losses in Florida were reported for other weather events such as hurricanes Katrina, Wilma, and Irma, a 2015 flood, and a 2010 freeze.

Weather events also affect other regions competing with Florida producers. Although some of these events can occur thousands of miles from Florida, they can shape the market for agricultural commodities here. California – the state that directly competes in production with most agricultural commodities produced in Miami-Dade County – recently had to deal with severe floods after years of severe drought. Of the 220,000 acres of irrigated land in Monterey County, home to the fertile Salinas Valley, an estimated 20,000 acres were affected by flooding, with strawberries being the main crop affected for an estimated $40 million in losses (Vegetables Grower News, 2023). Another report points to a similar level of losses in Ventura County, where many strawberries and specialty crops were lost (Los Angeles Times, 2023). Approximately 12,000 agricultural jobs had been previously lost in Ventura County when California's irrigated farmland shrank by 752,000 acres or nearly 10 percent due to drought and water use restrictions. Finally, the 2023 Atmospheric River event in California affected prices and availability of some commodities for Florida and other U.S. growers. If some competitors are affected by extreme weather events, the market share for Miami-Dade County products will expand. On the other hand, if a production disruption occurs in Miami-Dade County, farmers may face additional barriers to compete, and market share may temporarily decline.

Disruptions Limiting Market Access

Border, logistic, and transportation network disruptions can limit access to markets. One recent example was the disruption of containerized agricultural exports from California ports. In this case, port congestion and container shortages reduced agricultural exports by 22 percent from May to November 2021, leading to an estimated loss of $3.2 billion (Carter et al., 2022). This disruption was linked to other disruptions that affected several markets during the COVID-19 pandemic. Disruptions between 2000 and 2022 due to introduction of new international trade barriers reduced commercial air cargo trade capacity worldwide (Xu et al., 2022). According to the U.S. Department of Transportation-Transportation Security Administration, passenger flights in 2021 fell by 95 percent compared to the year before, and 50-60 percent of all airfreight cargo is transported in passenger planes (Levin, 2020). Measures like the ones adopted during the COVID-19 pandemic have repeatedly happened in other periods of political unrest or instability in international trade.

Another factor constraining transportation networks and logistic chains during the COVID-19 pandemic is the introduction of export and import restrictions. For example, export restrictions imposed by India, France, Germany, and the U.S. on medicines, medical equipment, and raw materials delayed transactions, increased prices, and caused shortages (Xu et al., 2022). In the case of agricultural production, scarcity of nursery plant containers and other plastics were reported during this period. In addition, the need for more truck drivers, additional inspection measures, and quarantine periods delayed freight delivery. Border closures can create instability and price changes in countries with more fragile institutions. In August 2019, Rwanda closed its border for less than one day, but the news caused a panic among those who cross the border to trade and work, and the price of fruit and vegetables surged in border towns (Brenton and Chemutai, 2020). This type of event can increase commodity prices in the U.S. and/or in Florida.

Many of these disruptive events affect international trade, but on the domestic front, there are concerns about the extreme dependence of domestic trade on the trucking industry, and a shortage of truck drivers (Gurtu, 2023). Demographic, socioeconomic, regulatory, and psychographic factors are involved in the shortage of truck drivers. The situation is described as “the younger generation avoiding the truck driving profession due to the laborious nature of the job involving long working hours, time away from family, and an expectation of a higher salary” (Mittal et al., 2018). Since Miami-Dade agricultural production satisfies demand in other states, there is a possibility that truck driver shortages could impact access to U.S. markets. Infrastructure may also be a concern. Most commodities from Miami-Dade County are transported by truck using three specific roads: Interstate-75, Interstate-95, and the Florida Turnpike. A report from the U.S. Department of Transportation (2019) classified Florida interstate traffic as the third busiest of all fifty states. Accidents and construction activity on these roads can generate delays and increase transportation costs that are partly borne by local producers and wholesalers.

Miami-Dade County has the 15th highest number of airport passengers and 5th largest cargo port in the U.S. (Stratos, 2023; Statista, 2023). Disruptions in international transportation can affect commercial exchanges for many local industries. As the world becomes more interdependent, disruptions in international markets will happen more often. The transportation system needs to be more resilient, and the creation of redundant infrastructures or alternative shipping schemes can become vital to overcome temporary shutdowns or sudden changes in logistic supply chains.

Global Market Disruptions

Abrupt changes in the performance of specific markets, political contexts, or regulations adopted in times of uncertainty and instability can cause disruptions that no model or forecast can anticipate. If companies or governments could predict the exact moment of disruptions and fully anticipate their consequences, most of the effects could be avoided, the impacts reduced, and the disruption minimized.

The most relevant domestic competitors for South Florida in the winter vegetable market from November through April are California, south Texas, and Arizona. Internationally, Mexico, Brazil, Chile, and Argentina represent major competition for vegetable producers in Miami-Dade County. Competition in fruits comes mainly from California, Mexico, Costa Rica, and the Caribbean. Finally, given the restrictions on imported soilborne plants, competition in nursery/greenhouse products tends to be mainly from California and other southern states of Texas, Georgia, Alabama, and North Carolina. As mentioned before, California faces a particular set of threats that can disrupt the stability of certain agricultural commodities. After years of wildfires and droughts, California faced flooding in early 2023. Increased minimum and maximum temperatures, highly variable and shifting precipitation patterns, reduced snowpack in the Sierra Nevada mountains, and increased frequency and intensity of weather extremes such as heat waves and drought are examples of events that negatively impact California's highly productive agricultural industry (Pathak et al., 2018). Environmental impacts and extreme weather conditions also happen in other U.S. states that compete with Florida and depending if the extreme weather events happen in spring or fall, the impacts might be entirely different.

As we have seen, different market disruptions have distinct geographical impacts. Disruptions can affect all competitors in a given market or can be more localized. Additional awareness and more resilient and diverse markets will reduce the damage caused by international supply disruptions. This distinction was clear during the COVID-19 pandemic. Many issues affecting agricultural markets impacted producers worldwide during this period, while other impacts were more localized. Political unrest is challenging to predict in the international political arena, and how that will imply changes in trade policies. For example, the relationship between Cuba and the U.S. could change, increasing competition in the U.S. market. Other countries with fragile democracies or autocratic governments can rapidly shift resources to increase or reduce their participation in the U.S. market.

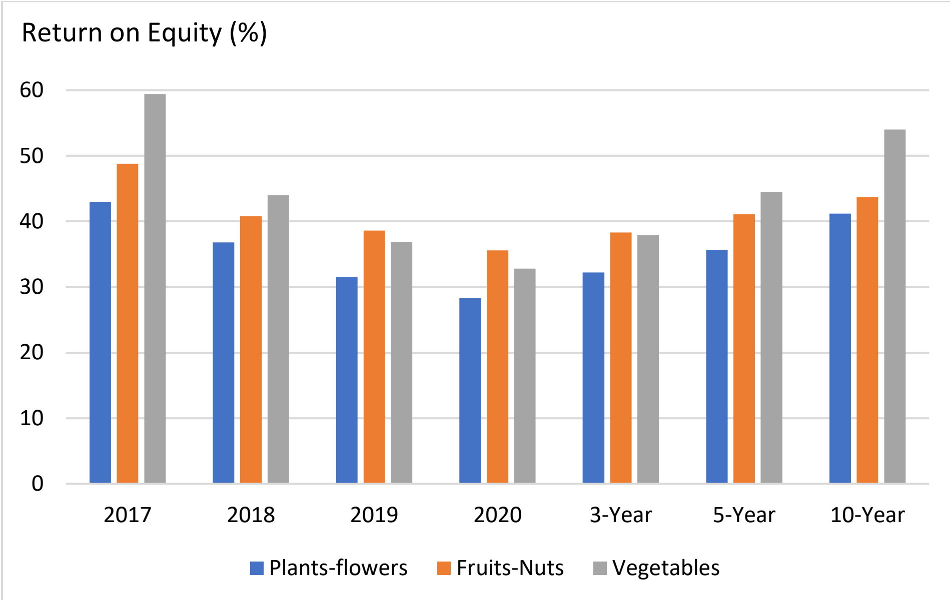
Financial Risk

Farming businesses in the U.S. often rely on external funding to support their operations, including debt financing, although the amount of debt greatly varies among farms. Farmers involved in vegetable production in Miami-Dade County either own a portion of the land they cultivate or maintain an extended partnership with the property owner. Along with volatility of income, debt is one of the largest sources of risk in any business. Operators that are averse to risk tend to have lower debt but may not have sufficient resources to expand their business or make needed capital improvements, and typically have lower rates of return on equity. Long-term debt has a positive effect on productivity growth and intermediate debt is positively related with farm technical efficiency as well as scale efficiency; however, short-term debt has a negative impact on technical efficiency (Mugera and Nyambane, 2015). If they borrow money to purchase assets or to finance farm operations, producers will face financial risk because of uncertain interest rates, lending relationships, and changes in asset values. For example, following the 2008 real estate crash, many farms had their lines of credit significantly reduced or were required to pay down debt immediately due to asset devaluation; some went out of business as a result.

Financial ratios such as return on equity (ROE) and return on assets (ROA) have long been used to investigate the relationship between assets, liabilities, and profitability. ROE is a measure of profitability based on net income from the income statement, and equity or total assets minus total liabilities from the statement of financial position. ROE thus expresses net income earned by the owners as a percentage of equity in the business. ROA is another useful measure of profitability, calculated as net income plus interest expense divided by total assets. ROE is always greater than or equal to ROA. ROE can be likened to the possible earnings if the money was invested elsewhere: if the ROE is less than prevailing interest rates, or if the earnings are less than the cost of borrowing, then the business is performing poorly.

Information was not specifically available on financial risk for agricultural businesses in Miami-Dade County; however, information for the relevant agricultural sectors at the U.S. level was available from IBISWorld industry research reports for the specialty crop industries of plant-flower growing, fruit-nut farming, and vegetable farming (Rose, 2022; Madigan, 2022; Curtis, 2022). As shown in Figures 16.1 and 16.2, during 2017-2020 these industries generally had a ROE of 30 to 45 percent and a ROA of 10 to 20 percent, which is considered competitive with most other agricultural industries. Profitability of these industries was projected to increase slightly over the next 3 to 10 years compared to 2020.

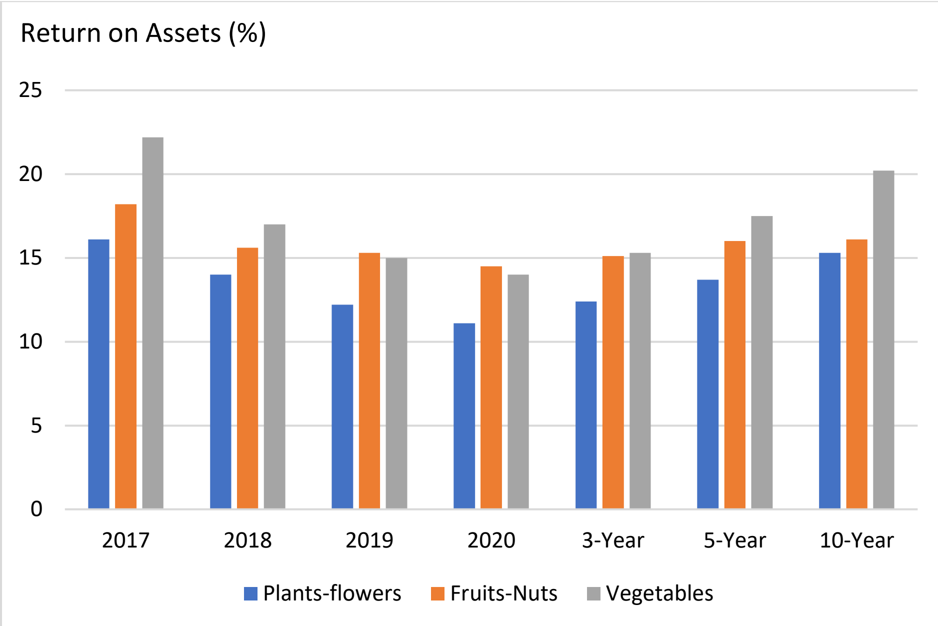
Figure 16.1. Rate of return on equity for plants-flowers, fruits-nuts, and vegetable farming in the U.S., 2017-2020 and 3-10 year projections



Source: IBIS World industry reports.

In the U.S., farmland represents an attractive, long-term investment while providing significant capital preservation and wealth over generations, and consistently beats other asset investment classes over time (Henneman, 2022). High land values can have a unique localized effects on the ROA of specialty crop farming industries in several ways. High land values increase the cost of farmland, which makes it more difficult for farmers to start or expand their operations, limits the supply of land available for farming, and lowers ROA for farmers who have to pay higher prices for their land. In addition, as the value of the land increases, so does the property tax burden, which can further reduce ROA for farmers. High land values can be a significant cost for farmers who own or lease large tracts of land. Finally, investment in farmland by commercial and residential developers can lead to the conversion of farmland into non-agricultural uses, limiting the supply of farmland and driving up prices, making it more difficult for farmers to make a profit. Some of these impacts would be seen in Miami-Dade County if the Urban Development Boundary did not exist.

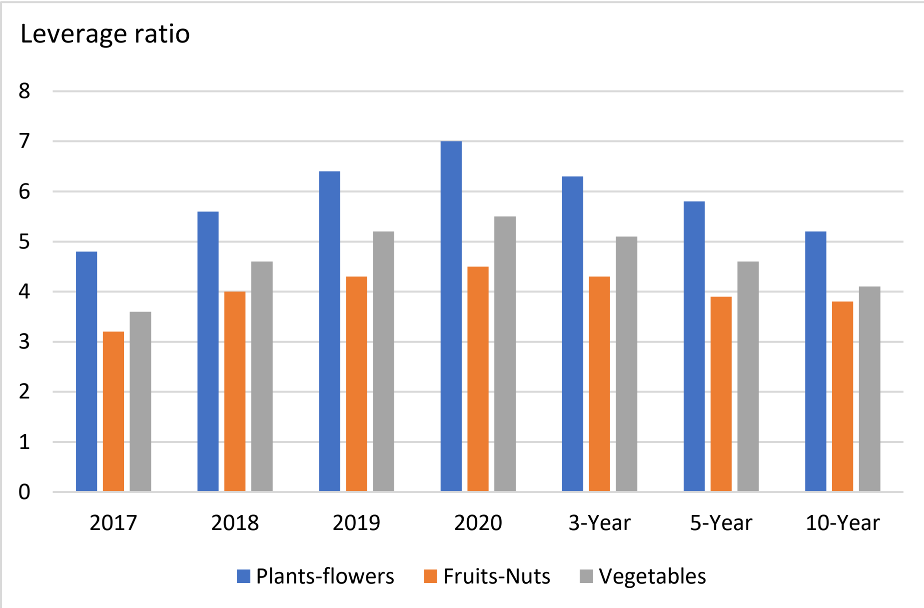
Figure 16.2. Return on assets for plants-flowers, fruits-nuts, and vegetable farming in the U.S., 2017-2020 and 3-10 year projections



Source: IBIS World industry reports.

Leverage is a measure of long-term financial risk, calculated as total assets divided by equity or net worth. The specialty crop industries in the U.S. have a rather high leverage ratio, exceeding 4 and as high as 7 during 2017-2020, as shown in Figure 16.3. A leverage ratio of 2, implying total assets two times the net worth, is generally considered a safe financial position. Similar to the U.S. generally, it is expected that specialty crop growers in Miami-Dade County have a highly leveraged financial position due to the long-term higher cost of land, operating costs, and capital requirements as compared to growers of commodity crops. The County's specialty crop growers also have a smaller operation scale than commodity crop growers in the region. Over the years, the specialty crop industry in Miami-Dade County has faced various challenges, such as land-use pressures, disease outbreaks, and increased competition from imports (Wang et al., 2014). The leveraged financial position of specialty crop growers makes it more difficult for growers to obtain financing or attract investment, as lenders and investors may view the industry as riskier or less profitable than in the past.

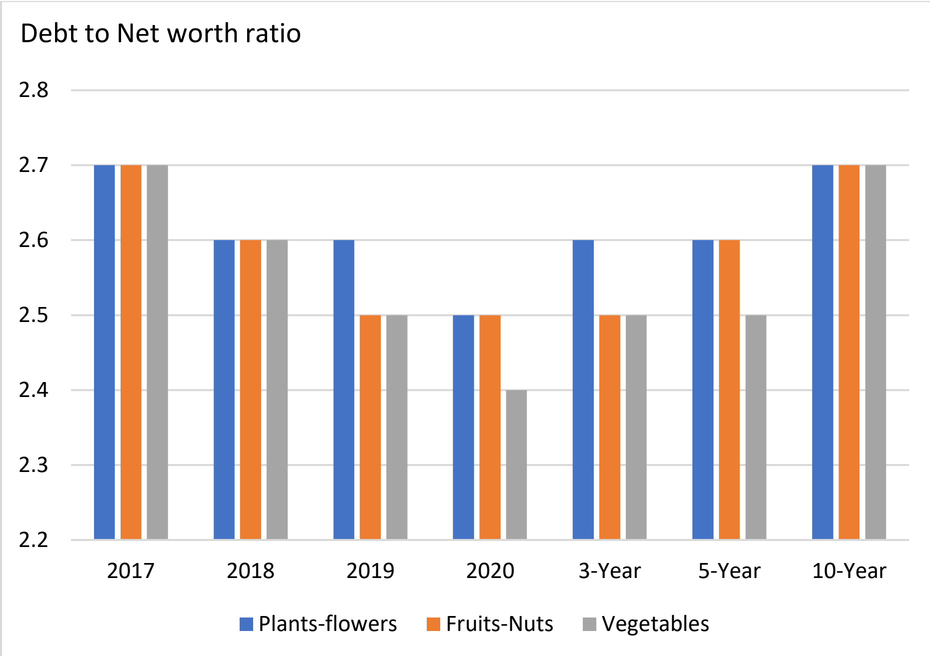
Figure 16.3. Leverage ratio for plants-flowers, fruits-tree nuts, and vegetable farming in the U.S., 2017-2020 and 3-10 year projections



Source: IBIS World industry reports.

The debt to net worth ratio is another measure of long-term financial risk, calculated as total liabilities divided by net worth or owner equity. Generally, a ratio of less than 0.25 is considered very strong, 0.25 to 0.40 is satisfactory, and more than 0.40 is weak. The debt to net worth ratios of specialty crop industries in the U.S. were 2.4 to 2.7 during the period from 2017 to 2020 and were projected to be 2.5 or higher over the next 3 to 10 years (Figure 16.4). This indicates that these industries have a higher percentage of financing by debt, which means higher financial risk. Specialty crop sectors in Miami-Dade County, like other agricultural sectors in the U.S, often require significant upfront investments in land, equipment, and labor. These investments can take years to pay off, and the unpredictable nature of farming means that there is always a risk of crop failure, weather-related disasters, market disruptions, and other unforeseen circumstances that can negatively impact the financial viability of a farming operation. As a result, many farmers normally take on debt to finance these upfront investments and to help manage financial risks. This debt can include loans for land, equipment, and operating expenses, as well as lines of credit to cover cash-flow shortfalls during lean times. Thus, it is expected that the specialty crop sectors in Miami-Dade County would typically have high debt to net worth ratios similar to these U.S. averages.

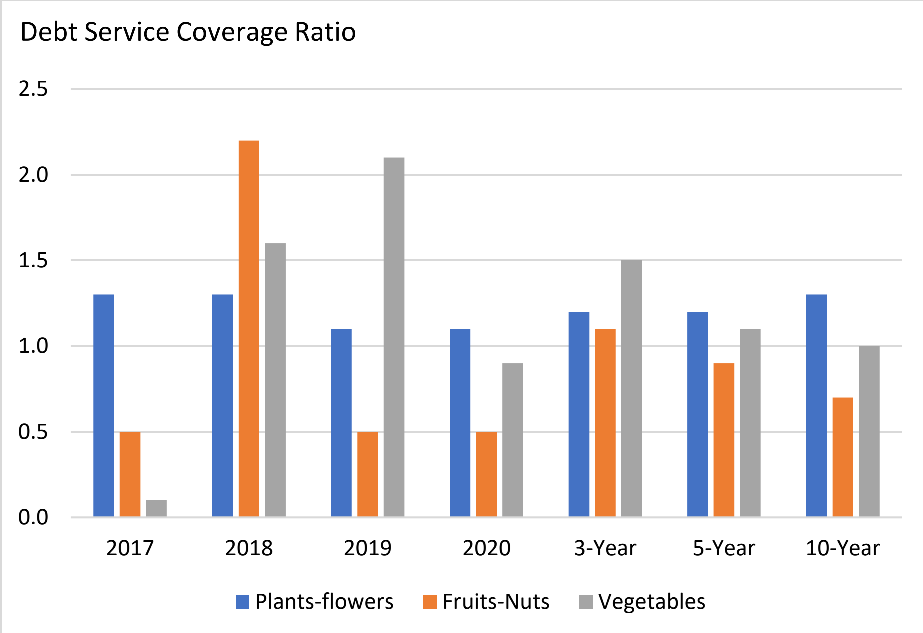
Figure 16.4. Debt to net worth ratio for plants-flowers, fruits-tree nuts, and vegetable farming in the U.S., 2017-2020 and 3-10 year projections



Source: IBIS World industry reports.

The debt service coverage ratio (DSCR) is an indicator of short-term financial risk, reflecting the ability to meet regularly scheduled debt payments and maintain cash flow of the business. It is calculated as annual operating income divided by payments for interest and principal on loans and mortgages. If the DSCR is too low, a farm may find it hard to make payments on what is owed using only revenues; however, a very high DSCR may not be optimal either. While a high DSCR can reflect an operation that doesn't need debt to generate revenue, it may also point to inability to exploit market opportunities. Generally, a DSCR value greater than 1.75 is considered strong, between 1.25 to 1.75 is considered in the caution range, and less than 1.25 is considered vulnerable. As shown in Figure 16.5, the DSCR of the U.S. crop industries has fluctuated significantly over the 2017-2020 period. The DSCR for plants/flowers has been consistently above one, while it was below one for fruits/tree nuts in three of four years, and below one in two of four years for vegetable farming. These results suggest that long-term and short-term financial risks are rather high for specialty crop growers.

Figure 16.5. Debt service coverage ratio for plants-flowers, fruits-tree nuts, and vegetable farming in the U.S., 2017-2020 and 3-10 year prediction



Source: IBIS World industry reports.

Agricultural capital investments include land purchases, improvements, farm buildings, and agricultural machinery and equipment. In the U.S, capital expenditures in the vegetable farming industry are close to the average of other farming industries. The plant/flower growing industry in the U.S. has relatively low capital intensity, with average capital spending of $0.12 per dollar of farm labor during 2017-2022. The level of capital intensity for plant/flower growing is predicted to rise in the future, although to a small degree. Over time, the industry has become more reliant on machines and technology instead of workers. Capital intensity of U.S. fruit farming varies among different segments in the industry. Fruit farms employ varying levels of capital equipment. Fruit grown for the fresh market is mostly picked by teams of harvesters to avoid damage. These farms still use labor to hand pick, even if machinery can improve harvesting efficiency. Higher dependency on equipment leads to more wear and tear, which increases depreciation costs.

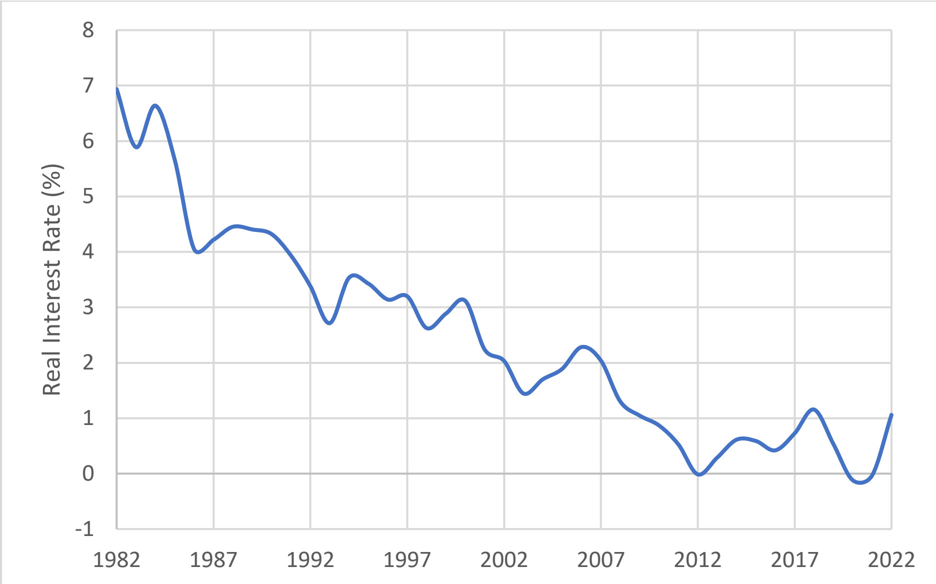
It is expected that the specialty crop farming industries in Miami-Dade County will make significant new investments in labor-saving technology in order to compete with low-cost producers in other regions and countries. This is because labor is a significant cost for many specialty crop farmers, particularly in Miami-Dade County where wages tend to be higher than in other regions. By investing in precision agriculture technology, farmers can reduce their labor costs and improve efficiency, which can help them remain competitive with low-cost producers. Moreover, technology can also help farmers to optimize their crop yields and quality by monitoring crop health and more efficiently managing resources such as water and fertilizer. This can result in higher crop yields, better quality produce, and lower input costs, which can improve profitability and competitiveness.

Interest rates have a significant impact on farms and other businesses, affecting the cost of loans, investment decisions, and farmland values. Farms generally purchase machinery, land, and buildings with debt, so high interest rates lead to greater expenses. A change in interest rates directly affects the profitability of farming and indirectly impacts competitiveness in global markets. As shown in Figure 16.6, during the 40-year window of 1982-2022, the average real (inflation-adjusted) interest rate in the U.S. decreased significantly, from around 7 percent to under one percent, although with considerable fluctuations. The interest rate has remained below 1 percent since 2010, except for a brief rise in 2018. Changes in interest rates are partly driven by the federal funds rate, set by the Federal Reserve, along with markets for loans, mortgages, and treasury bonds. Changes in agricultural lending rates have long term impacts on farmland values, as it takes at least a decade for the full effects of an interest rate change to be capitalized in farmland values (Basha et al., 2021).

Interest rates can have a significant impact on Miami-Dade County's specialty crop industries in several ways. High interest rates can make it more difficult for farmers to access capital, which can limit their ability to expand production, invest in new technologies, or purchase new equipment. Interest rates can also impact the cost of inputs, such as fertilizer and fuel, which are essential for specialty crop production. Interest rates can also impact the value of land, which is a critical resource for specialty crop production. High interest rates can reduce demand for farmland, leading to lower land prices. This can be beneficial for farmers looking to purchase land, but can also reduce the value of their existing land holdings. Overall, interest rates are an important economic factor that can impact the profitability and competitiveness of Miami-Dade County's specialty crop industries. Understanding these impacts can help farmers and policymakers make informed decisions about investments and policy choices to support the long-term growth and sustainability of the industry.

If interest rates were to increase again to historic levels, interest costs would be commensurately increased for agricultural industries in Miami-Dade County. Growers in Miami-Dade County can apply for the reduced rate financing that USDA provides to assist with the increases in rates.

Figure 16.6. Average real interest rate in the U.S., 1982-2022



Source: Federal Reserve Bank of St. Louis, Economic Research Division.

Government Policies and Regulations Affecting Agriculture in Miami-Dade County

This section discusses local, state, and federal government policies that affect the viability of agriculture in Miami-Dade County. A summary of each policy is followed by a discussion of the potential effect: plus (+) or minus (-) signs indicate a positive or negative effect, double plus (++) or double minus (--) indicate a strong positive or negative effect, while plus and minus (+/-) indicates that a policy has both positive and negative effects. The section provides an overview of major policies that affect agriculture in the County and is not an exhaustive list.

County Policies

Agriculture Designated Areas and Urban Development Boundary. The Land Use Element of the Comprehensive Development Master Plan (CDMP) for Miami-Dade County (2017c) states that "in order to protect the agricultural industry, uses incompatible with agriculture, and uses and facilities that support or encourage urban development are not allowed" in areas designated as Agriculture (AU) on the CDMP Land Use Plan (LUP) map. "Residential development that occurs in this area is allowed at a density of no more than one unit per five acres. Creation of new parcels smaller than five acres for residential use may be approved in the Agriculture land use designation only if the immediate area surrounding the subject parcel on three or more contiguous sides is predominantly and lawfully parcelized in a similar manner, and if a division of the subject parcel would not precipitate additional land division in the area."

In addition, the CDMP states that "No new commercial agricultural use of property may be established within the Urban Development Boundary (UDB), except on property designated Agriculture on the LUP map or zoned AU (Agricultural) or GU (Interim). All property within the UDB not designated Agriculture or zoned AU or GU shall not be permitted to be used for the establishment of any new commercial agricultural use, with the exception that land in utility easements or rights-of-way or airport or other large government-owned properties may be approved for new commercial agricultural uses where the use would be compatible with the surrounding area. Commercial agricultural uses include, without limitation, all uses of property associated with commercial horticulture; floriculture; viticulture; forestry; dairy; livestock; poultry; apiculture; aquaculture for production of tropical fish; all forms of farm production; and all other such uses, except retail nurseries and retail greenhouses." (I.69)

Impact: ++ The benefits to the viability of agriculture in Miami-Dade County are twofold. First, limiting the uses on land designated as "Agriculture" to agriculture or those directly supportive of agriculture and farm residences reduces development pressure on these areas. Second, the minimum parcel size of five acres prevents land from being subdivided to the extent that it becomes unviable for agricultural production. Prohibiting commercial agriculture on land not designated AU or GU within the UDB incentivizes development to be concentrated in urban areas, and probably has minimal consequences for viability of agriculture.

<u>Cluster Development (LU-1U)</u>. The CDMP states that the County "should study the feasibility of allowing cluster development in the area designated Agriculture on the CDMP Land Use Plan map by 2027 to promote the conservation of agricultural land. Cluster development allows for the concentration of allowable residential units on lots that are smaller than would otherwise be permitted in the Agriculture land use designation with the remainder of the property being conserved for agricultural uses. The study should include consideration of potential land use conflicts between residential and agricultural uses, an analysis of similar programs, identify the advantages and disadvantages of such a program, and provide recommendations on whether a cluster development program should be implemented in the County." (I.4)

Impact: +/- Clustered development may allow for sustainable development in agricultural areas but may also take substantial land out of production. The net effect on the viability of agriculture will depend on the nuances of implementation, such as the ratio of agricultural to developable land and the type of development (residential, commercial, etc.) allowed. Generally, a higher ratio of agricultural land to developable land is better for agriculture, provided that the conserved land is large enough for the existing agricultural activity to be viable. Factors for consideration include whether a proposed cluster development would displace existing agriculture and how many acres the development would permanently remove from agricultural production. Unintended consequences, such as conflicts between farmers and new residents over agricultural practices (e.g., manure application, use of biocides) and slow-moving farm equipment on roads, will need to be anticipated and mitigated. Additionally, infrastructure (e.g., roads, water lines, waste transfer stations) will need to be extended or improved to serve the cluster development. An example of clustered development can be found in Palm Beach County, which has density restrictions within the

Agricultural Reserve Tier and requires development to be clustered within designated areas (Palm Beach County, 2022). In 2019, The Board of County Commissioners considered a proposal to amend the CDMP to permit cluster development in a manner that would preserve 80 percent of a development site for farmland, but it elected not to adopt that policy.

Transfer of Development Rights (LU-1R). The CDMP states that the County “shall adopt and implement a transfer of developments rights…program to preserve sufficient agricultural land to maintain a viable agricultural industry that will be supplemented by a purchase of development rights program to preserve agricultural land and environmentally sensitive property.”

Impact: + The transfer or purchase of development rights protects the agricultural viability of land by creating an easement that limits nonagricultural uses in perpetuity. To date, 805 acres have been protected by the purchase of development rights program. A transfer of development rights (TDR) program has not yet been implemented. Neighboring Collier County has three TDR programs, the most recent of which had 7,347 acres under development rights restrictions as of 2019, is an example of the challenges and successes possible from such a program (Collier County, 2019). Factors common to successful TDR programs include customized receiving areas, strict sending areas, few alternatives to TDR, and market incentives (Pruetz and Standridge, 2009).

Urban Services (LU-2B). The CDMP states that "Urban services and facilities which support or encourage urban development in Agriculture and Open Land areas shall be avoided, except for those improvements necessary to protect public health and safety and which service the localized needs of these non-urban areas.”

Impact: +/- Limiting certain urban services and facilities outside of the UDB may reduce the incentive to develop agricultural lands for nonagricultural purposes. However, the lack of services or inadequate provision of services in rural areas may adversely impact agriculture.

Aquifer Recharge (CON-4A). The Conservation, Aquifer Recharge, and Drainage Element of the CDMP for Miami-Dade County (2017b) states that "The aquifer-recharge values of undeveloped land and the water storage values of wetland areas shall be maintained and, where feasible, enhanced or restored. There shall be no further positive drainage of wetlands to accommodate urban development or agricultural uses.” (IV.6)

Impact: +/- Maintaining the aquifer recharge values in undeveloped land and the water storage values of wetland areas helps ensure there is sufficient water for agriculture and mitigates flooding. Preventing drainage of wetlands for agricultural uses may limit the scope of viable agricultural practices on existing land and prevent new land from being used for agriculture; however, given the benefits, the policy is unlikely to be controversial among agricultural producers.

Farm-to-School (CHD-4E). The Community Health and Design Element of the CDMP for Miami-Dade County (2017a) states the County shall "Encourage the establishment of farm-to-school initiatives and community supported agriculture programs" under the objective to "promote local food production and improve access to healthy food products for all residents."

Impact: + Farm-to-school initiatives may improve the viability of agriculture by incentivizing schools to purchase directly from local farmers. According to the most recent USDA Farm to School Census, 100 percent of schools within the School Food Authority for Miami-Dade County Public Schools participated in some farm-to-school activity during the 2018-2019 school year, accounting for approximately $60,960,000 in food costs (USDA Food and Nutrition Service, 2021). Schools prefer products that are already washed, pre-chopped, and packaged, requiring minimal preparation before serving, which may pose barriers for small farms to participate in the program.

Florida Statutes

Agricultural Use Value (F.S. 193.461). Florida statute states that, in years in which proper application for agricultural assessment has been made and granted, the assessment of land classified as agriculture by the appraiser be based solely on its agricultural use.

Impact: ++ Taxing land designated as agriculture based solely on its agricultural use, rather than for residential or commercial purposes, helps avoid premature conversion of agricultural land to other purposes by maintaining lower taxes for farmland.

Water Restricted Allocation Areas (F.S. 373.037). Florida statutes allows the South Florida Water Management District to define restricted allocation areas (RAAs). These are defined geographic areas where new or increased consumptive use allocations (permits for use that reduces the availability of water from the source that it is drawn from, such as pumping for irrigation) are restricted due to concerns regarding water availability. RAAs are adopted where there is insufficient water to meet the projected needs of a region and to protect water for natural systems and future restoration projects (e.g., Comprehensive Everglades Restoration Plan projects) as part of Minimum Flows and Levels recovery or prevention strategies.

Impact: +/- Restricting new or increased consumptive use allocations limits the viability of existing agricultural producers and may discourage new operations from entering the industry. However, water scarcity is generally not an issue in Miami-Dade County and the denial or reduction of a consumptive use permit is unlikely.

Minimum Flows and Levels (F.S. 373.042). Florida statutes require the Water Management Districts or the Florida Department of Environmental Protection to establish Minimum Flows and Levels (MFLs). Rivers, streams, estuaries, and springs require minimum flows, while minimum levels are developed for lakes, wetlands, and aquifers. MFLs are defined as the minimum flows or water levels "at which further withdrawals would be significantly harmful to the water resources or ecology of the area" (§ 373.042, Fla. Stat., 2022). MFLs apply to decisions affecting permit applications, declarations of water shortages, and assessments of water supply sources. Water uses cannot be permitted that cause any MFL to be violated.

Impact: +/- Restricting withdrawals during water shortages will have an immediate negative effect on commercial agriculture, but as with other policies protecting water quality, the long-term viability of agriculture depends on the sustainable use of water resources.

<u>Water Reserves (F.S. 373.223)</u>. Florida statutes grant the water management districts the power to establish water reserves "for the protection of fish and wildlife or public health and safety" (§ F.S. 373.223, Fla. Stat., 2022). Water reserves prevent the use of reserved water for consumptive uses but protect existing legal uses unless they are contrary to public health. Consideration of water reserves are required for Comprehensive Everglades Restoration Plan projects and may be used as MFL recovery or prevention strategies. Reserved water includes all surface water contained within Nearshore Central Biscayne Bay and all surface water flowing into Nearshore Central Biscayne Bay.

Impact: +/- The establishment of water reserves will likely have a negative impact on commercial agriculture. However, as with other policies protecting water quality, the long-term viability of agriculture depends on the sustainable use of water resources.

<u>Environmental Liability (F.S. 403.182)</u>. Florida statutes state that "the Florida Secretary of Environmental Protection has exclusive jurisdiction in setting standards or procedures for evaluating environmental conditions and assessing potential liability for the presence of contaminants on land that is classified as agricultural land…and being converted to a nonagricultural use." Additionally, "the secretary may not delegate the authority to set standards or procedures for evaluating environmental conditions and assessing potential liability…to a county, a municipality, or another unit of local government through a local pollution control program" (§ F.S. 403.182, Fla. Stat., 2022).

Impact: +/- This policy ensures that a consistent procedure is used statewide when assessing potential liability for the presence of contaminants on agricultural land before being converted to a nonagricultural use. This policy benefits agricultural landowners seeking to use part of their land for nonagricultural use (e.g., housing for seasonal workers) by ensuring a consistent and predictable process for assessment, but also may reduce costs converting agricultural to nonagricultural uses, thereby increasing conversion rates.

<u>Right to Farm (F.S. 823.14)</u>. The Florida Right to Farm Act protects "reasonable agricultural and complementary agritourism activities conducted on farmland from private and public nuisance suits and other similar lawsuits" (§ F.S. 823.14, Fla. Stat., 2022). The Act also limits a local government's ability to regulate agriculture if the state of Florida already regulates that activity.

Impact: + The Florida Right to Farm Act provides a defense for farmers when a nuisance suit is brought against them for reasonable agricultural or agritourism activities (e.g., fertilizer application) and they are compliant with state regulations (Caracciolo et al., 2021).

Federal Policies

H2-A Temporary Agricultural Workers (87 F.R. 61660). The Department of Labor clarified that H-2A Temporary Agricultural Workers visa program employers must pay at least the highest of the following applicable wage rates: the Adverse Effect Wage Rate, the state prevailing minimum wage, the state prevailing hourly wage, or the federal or state minimum wage. The Immigration and Nationality Act permits only agricultural labor or services of a temporary or seasonal nature to be performed under the H-2A Temporary Agricultural Workers visa category.

Impact: - Under this rule, Florida H-2A employers are required to pay $14.33/hour as opposed to the state's current minimum wage of $11.00/hour, increasing labor costs.

Farmland Protection. The Farmland Protection Policy Act (7 U.S.C. 4201) discourages Federal activities that would convert farmland to nonagricultural purposes. It assures that, to the extent possible, federal programs are administered to be compatible with state and local governments, and private programs and policies to protect farmland.

Impact: + The Farmland Protection Policy Act requires federal agencies to examine the impact of their programs and projects receiving federal funding that would potentially convert farmland designated as being of unique importance to another use. Notably, Miami-Dade County has a substantial area of farmland currently designated as being of unique importance.

Conservation Easements (16 U.S.C. 3865). The Agricultural Conservation Easement Program, part of the federal Farm Bill, protects the current agricultural use, future agricultural viability, and related conservation values of eligible land by limiting nonagricultural uses which negatively affect agricultural uses and conservation values, protecting grazing uses and related conservation values by restoring or conserving eligible grazing land, and protecting and restoring and enhancing wetlands on eligible land. The program specifically helps private and tribal landowners, land trusts, and other entities, such as state and local governments, protect croplands and grasslands on working farms and ranches by limiting nonagricultural uses of the land through conservation easements.

Impact: + The Agricultural Conservation Easement Program is designed to support local level efforts to conserve agricultural land through the establishment of conservation easements, such as through transfer or purchase of development rights programs. Miami-Dade County has received approximately $7.4 million in grant funds through this program.

Stakeholder Interviews and Focus Groups

Interviews and focus groups with agricultural industry stakeholders in Miami-Dade County were conducted as part of this project. Input was obtained from a total of 74 individuals, through personal interviews and four focus groups with the following stakeholder groups the County:

- Row Crop/Vegetable Growers
- Nursery and Floriculture
- Tropical Fruit Growers
- Allied Suppliers and Associated Industries
- Banking and Financial Services
- Related Agriculture: Agritourism, Beekeeping, Vertical Farming
- Developers (conducted by Miami-Dade County)

Participants were recruited through local contacts with UF/IFAS Extension, UF-IFAS-TREC, and the Miami-Dade County Agricultural Manager's Office. The makeup of participants by gender was 78 percent male, 22 percent female, and by race was 85 percent White, 12 percent Asian, and 4 percent Black/African American, with 25 percent of Hispanic/Latino ethnicity.

Protocols for the interviews and focus groups were approved by the University of Florida Institutional Review Board for compliance with human subjects research requirements. Participants were asked to sign an informed consent statement agreeing to participate voluntarily and without compensation. The sessions followed a script with a uniform set of instructions and questions that were asked of all participants. Questions covered topics such as strengths and weaknesses of the industry, threats over the next 10 to 30 years, recommendations for programs and policies to support economic viability and sustainability, and personal visions or aspirations for the future. Sessions were conducted in-person, by telephone or online (Zoom) meeting, and were recorded and transcribed.

In addition, the Miami-Dade County Department of Regulatory and Economic Resources (RER) conducted a focus group with five local development companies; although not part of the UF/IFAS research for this project, a summary of the discussion from this focus group is included in in this report.

Summary of Findings

Key findings of the interviews and focus groups are summarized in the following points, and specific observations for different stakeholder groups are discussed in the sections below, highlighted by selected quotes from participants.

- There was a strong belief among all participants that the agricultural sector in Miami-Dade County will continue to evolve and hopefully will remain a critical component of the County's economy.

- Free trade agreements have allowed increased foreign competition (perceived by growers to be unfair because of subsidies that foreign growers receive from their governments), which has caused a steep decline in row crop acreage in the County.
- The specialty vegetable crop industry has had much success, particularly for vegetables popular in Asian culture, but increasing foreign competition may inhibit future growth.
- Nursery and ornamental plant growers have been especially successful in the last few years and have expectations to continue to be profitable; however, concerns about higher interest rates, inflation, and a potential recession raise concerns that they may not be as profitable as they were during the COVID-19 pandemic.
- Tropical fruit growers have been able to access niche and high value markets, allowing them to remain profitable; however, foreign competition remains a concern and has, in some instances, reduced profitability.
- Several other related industries that have not traditionally been part of the agricultural sector of Miami-Dade County, such as agritourism, aquaculture, vertical agriculture, and honey production, have grown over the last few years with expectations of continued success.
- Access to labor continues to be a challenge for all growers. Housing regulations make options to accommodate H-2A visiting workers very difficult. Small-scale growers face particular administrative and logistical difficulties to participate in the H-2A program.
- Very high land prices have limited the expansion of existing businesses and the ability of younger people and other interested individuals to enter the industry.
- Growers feel that individuals should have the freedom to sell or use their land as they wish. However, several organizations suggested that purchasing conservation easements may be a viable solution to preserving crop land and natural areas in the County.
- Growers feel that County policies often do not consider the perspectives or concerns of the agricultural sector.
- Almost all growers agree that harmonization is needed in regulation and inspections between federal, state, and County agencies. Education programs would help growers better understand what regulations apply to them and how to comply with regulations from various governmental entities.
- Visions about the future of agriculture in Miami-Dade County vary, with some believing that large scale production agriculture will continue, especially for ornamental plants, while others expect small scale farming will become increasingly important, with larger numbers of growers dedicated to high value specialty crops and the agritourism industry.

Row Crop/Vegetable Growers

Responses from this group of growers were consistently pessimistic. Rapidly increasing competition from Mexico under the 1994 North American Free Trade Agreement (NAFTA) and its successor trade agreement, the 2020 USMCA (United States-Mexico-Canada Agreement) has been undercutting prices for years, making it extremely difficult for Miami-Dade County growers to sell their produce at a profit. Many interviewees reported that Mexico was subsidizing its growers, which has been documented by separate UF/IFAS research (Wu et al., 2021; Guan et al., 2018). County fresh vegetable production has been in a steady decline since the mid-1990s, shortly after NAFTA went into effect. County tomato acreage in the 1980s peaked at over 13,400 acres, but tomato acreage in the current season is estimated to be less than 600 acres. While there likely were other factors contributing to the decline of row crop/vegetable acreage, local growers attributed the declines entirely to the impacts of the NAFTA, and lamented that the USMCA, which was supposed to revise and update the NAFTA, did nothing to alleviate the competitive pressures which they face.

<u>Participant Quotes</u>

"It used to be like seventy percent of the production in the wintertime came from Florida, thirty from Mexico."

"If NAFTA were to change, or anything would change to make row crop farming profitable, I would be back into it."

Some smaller scale growers have success selling vegetables directly to consumers in local farmers' markets, community supported agriculture (CSA) programs, roadside stands, and U-pick enterprises. These growers sell mostly organic vegetables, while sales of specialized produce in some ethnic markets have also been expanding. Several South and Eastern Asian communities have had success since the early 2000s selling in specialty ethnic markets with many growers moving to the area within the last five years. However, all the growers that participate in these markets expressed concern with competition from produce from Mexico and Central America starting to enter the U.S. market. An example of this competition that was mentioned by a grower is bitter melon that is now being produced in Honduras and entering U.S. markets.

<u>Participant Quotes</u>

"They [small scale specialty vegetable growers] do very well with five acres…I don't even know what all they grow, but I know they do very well on small properties…You can't over produce because the market is so small."

"I know you can make a profit on five or ten acres if you grow the right crops."

Another significant challenge cited includes rapidly increasing land prices, both for sale and rent. Many growers interviewed both owned farmland as well as leased acreage. However, development in the area results in growers who lease land having to find new land to lease on a consistent basis. Rental/lease rates were also reported to be high, as they have to compete with developers as well as nurseries and other growers for rental/leased land, making it difficult to find land to lease at a reasonable price. High land prices also make it difficult for young farmers to start new farms. As is the case globally, rapidly increasing input prices also present another significant challenge as farmers are not able to increase their prices enough to cover the input price increases.

<u>Participant Quotes</u>

"It's crazy. It's crazy, the increase in costs of all the inputs. I mean, even boxes..."

"Some buyers are willing to offer you a fortune to build houses."

Labor shortages were another challenge that was consistently identified. A notable proportion of the traditional migrant labor force reportedly has moved into better paying jobs in construction, creating a critical absence of available labor for agriculture. Three growers with larger operations mentioned shifting to using H-2A workers recently, and they were generally pleased with this arrangement except that it is very expensive given the increase in the Adverse Effect Wage Rates (AEWR) in Florida to $14.33 per hour in 2023, in addition to the need to provide for housing and transportation. The smaller scale growers mentioned that the program was too cumbersome to be a feasible option for them. A consistent complaint was that Miami-Dade County has extra building permit regulations in place that go beyond the state regulations, which make it exorbitantly expensive for farmers to create their own worker housing. Examples include the requirement to hold public hearings before the approval to construct temporary or permanent housing for farm labor (Code of Miami-Dade County § 33-279, 2023) and changes to regulations following hurricane Andrew that prevent the use of trailers for temporary farm worker housing.

<u>Participant Quotes</u>

"There's much hand labor involved in tomatoes, pepper, squash, and beans to a degree, but they can mechanically pick [beans], so that takes some pressure off. I'm thinking it's what we pay [for labor compared to in Mexico]. I started to cut back on tomatoes."

The most obvious policy remedy suggested was to "fix" the trade problems created by the NAFTA, (which growers believe are now being flagrantly violated by Mexico); the USMCA did nothing to address the problems faced by Florida winter fresh vegetable growers which need to be addressed. Some speculated that it is too late to save the winter fresh vegetable industry in Miami-Dade County while others thought there was still hope, although significant changes would need to be made quickly. Otherwise, the decline in County winter vegetable production will continue until it disappears altogether in a relatively few years, and the United States becomes totally reliant on Mexico to supply U.S. winter fresh vegetable demand. There is some hope that negotiations for the new Farm Bill, which are ongoing in Washington, DC, may address the issues of what Miami-Dade County growers believe to be unfair competition from Mexico, as discussed previously. To counteract the effect of these imports, four growers suggested that more can be done to raise the awareness of products grown in Miami-Dade County such as educating consumers in urban Miami about what is grown in the County, and where to purchase these products. Better enforcement of Country-of-Origin Labeling (COOL) in retail outlets also would allow consumers to distinguish between local and foreign products.

Participant Quotes

"You would be surprised at the people who live in Miami, but don't even know that we [growers] are here."

"I would like to go in the grocery store and point out [to consumers] which tomatoes are from here, and I'm sure that customers would be happy to pay a few more cents a pound for our tomatoes."

Nursery and Floriculture Industry

Both segments of the nursery industry (foliage and floriculture growers; and woody ornamental and landscape growers) reported generally similar observations. Prior to the COVID-19 outbreak growth had been steady yet relatively slow. However, during COVID, sales increased for most nursery growers and exploded for many growers. Generally, growers reported that business slowed somewhat in 2022 vis-à-vis 2021, and there is concern on the part of some growers about the continued softening of demand in 2023. Large profits from the abnormally strong demand due to the COVID-19 pandemic are likely to normalize. The industry is particularly susceptible to recessions, as much of the landscaping demand accompanies development. The exploding increase in the cost of inputs is a major concern for growers for the future as they reported that they are not able to increase prices proportionally. Other concerns include high land values limiting their ability to expand, rising interest rates are increasing their cost of working capital, and the impact of recent inflationary trends may impact consumer demand for their products. Even with all these challenges, individual growers felt that they would like to expand their nurseries. However, the high costs of land, in particular, and difficulty in getting labor have made expansion of their business in Miami-Dade County difficult in many cases. This was a sentiment shared by three growers of different sized operations in individual interviews as well as in the focus group. Two growers mentioned having to expand in central Florida. Two growers also mentioned having nurseries located in different parts of the County so that if they felt the need to sell out due to developers they could expand in their second location.

Participant Quote

"Coming off of the pandemic, I think it's been very strong. Where we're going to 2023, I have a little bit different feelings."

Growers also feel that the County does not adequately take their concerns and problems into consideration in terms of regulatory issues. The focus group pointed out that growers felt there were too many inspections from County (i.e., building code enforcement and health), state, and federal agencies. They explained that they dedicate much of their time to receiving inspectors rather than running their business. There was confusion on the inspectors that came from the different governmental agencies at the County, state, and federal levels. Three Miami-Dade County foliage growers mentioned how they face additional inspections, as the County exports a significant number of ornamental plants to the Caribbean; they expect to see this market grow, as long as the regulatory and inspection processes are not too cumbersome.

Participant Quotes

"The County expresses its support for agriculture. However, they pass rules that make it more complicated for us to do business in the County."

"Code enforcement tends to be inconsistent and sometimes irrational."

"I am very unhappy with the County in this area [regulations]...The number of inspections and the amount of oversight that we have makes me not even want to do business in this County anymore...I would like to possibly think about expanding here, but I'm not anymore because I don't know when the County is going to come down so hard...I don't want to be any bigger because I would have to leave."

"I would like for him [the inspector] to come in and consult and ahead of time and tell us how to fix a problem. You really don't want someone to get injured or you don't want something to happen."

"Don't be arrogant and fine us. Teach us. Let us know how to do it right because we are trying to do everything the right way."

Two growers mentioned the challenges in getting permits, especially the need to travel to downtown Miami to get building permits. One particular concern for the landscape industry was the effect that new bans on fertilizer use during the summer, which have been considered by the County, would have on their businesses. Larger businesses expressed similar concerns as the vegetable growers on County requirements for worker housing and worker protection. Overall, there was agreement that there could be better coordination in regulation across the different entities and clarity in inspections as one inspector may have different standards than another in the same agency. On a federal level, they pointed out that, as long as current Quarantine 37 trade regulations prohibiting the import of plants in soil (to prevent the import of invasive soil-borne pests and diseases) remain in place, they are hopeful that will continue to be profitable, even if they face challenges during future recessions.

Tropical Fruit Growers

There was some optimism for the prospects for tropical fruits, including small specialty fruits, in Miami-Dade County. However, all the growers recognized that overproduction and imports are driving prices so low that they could not be profitable, in particular for dragon fruit and Thai guava. Several growers believe that the future for agricultural production in Miami-Dade County will be small specialty crop farms, which produce high value products which can be more profitable than row crop production. The focus group of organic growers agreed that small scale growers could earn a living on five or ten well-managed acres as is currently allowed by zoning laws in the Redland.

Participant Quotes

"Agriculture has always been a part of Miami-Dade County, and it will continue to be a part of its future. It just will adapt. We don't have the same make up of crops we had thirty years ago. We won't have the same crop mix thirty years from now. Agriculture will still be here. It will just continue to evolve."

"I came here forty-two years ago, and all these farmers said, 'Look around next year, year after that, two, three years this is all going to be gone because we're all losing money so badly.' Well, it's forty-two years later, and there's still plenty of farming going on here. I grant you the biggest bean farmer went out of business here. Thousands of acres are gone...Here's my vision, big crops go away, smaller farms come in and fill in the spaces with specialty crops of all kinds, mostly tropical fruits. And then, of course, the nursery

business is big. Here we have tropical fish farms, and this is one of the biggest orchid growing regions in the whole world – right here in Redland. We all know that's a huge economic generator."

Like the row crop growers, some tropical fruit growers expressed concerns about competing with imports, which have greatly increased following NAFTA. Yet competition continues to increase from regions other than Mexico, and a specific example included grove expansion for avocados in the Dominican Republic. The Dominican Republic grows a number of different varieties of avocados, including the same variety of green skin avocados as those grown in the County; thus, the Dominican Republic directly competes with Miami-Dade County growers. The growers in the focus group mentioned their frustration with U.S. government (USDA and USAID) programs supporting avocado production in the Dominican Republic. However, the authors were not able to find evidence or documentation for any U.S. government support programs for avocado production in the Dominican Republic. Just like the specialty vegetable growers, the growers in the tropical fruit focus group mentioned that as soon as they developed a new specialty crop that had little to no foreign competition, growers in Mexico and Central America quickly discover this market and flood it with produce, depressing the prices. They also mentioned growing import competition for lychee and langoustine from Mexican growers.

<u>Participant Quotes</u>

"We're getting all these imports in from Mexico, South America. Aren't many of the farms in in Mexico funded by the American people?"

"There is no way I can complete with the many imports. They're paying sixty cents an hour. They're going to the market right now. I can't pay sixty cents an hour, so I know my days are numbered."

While the growers in this focus group mentioned that they could remain profitable on smaller acreages, extremely high land values limit the ability of young growers to enter the industry, as well the ability of established growers to pass on their farms to the next generation.

<u>Participant Quotes</u>

"If it is going to make sense [to start a farm], a new grower needs nine hundred thousand dollars."

"And again, we already have a lot of these regulations on the books. The one house for five acres seems to be doing good. That would allow for somebody to, if they could afford the land in the first place, to supplement another income."

Several growers mentioned that they are challenged in finding reliable labor. As they are mostly small scale, H-2A workers are not a viable option for them because the administrative costs per employee that the private company has to charge are too high when arranging to provide small numbers of H-2A for small growers.

<u>Participant Quotes</u>

"I don't know if you have any idea what's going on with the labor market in South Florida. You got people digging ditches, making twenty dollars an hour..."

"You have to work all year to get, if you're lucky, four thousand dollars out of an acre. If I had to pay eighteen dollars an hour, I wouldn't be in business."

There was a consensus that the County, state, and federal governments have been unresponsive to the concerns of the tropical fruit industry, which growers feel is unique compared to other commodities. One particular concern raised in the focus group of tropical fruit growers is that the Florida Department of Agriculture and Consumer Services (FDACS) no longer has an advisory group for tropical fruits.

Participant Quote

"What happened to the tropical farm advisory board that reports to the Agricultural Commissioner? That council is needed during emergencies to tell the state what the tropical fruit industry needs."

Similar to the suggestion from the vegetable growers, the tropical fruit growers in the focus group suggested that the County should do more to promote south Miami-Dade County agriculture and locally grown agricultural products to urban consumers. With growing consumer awareness for local products, growers feel there is an opportunity to better market their products within the County. Several growers feel that organic production is a profitable niche that could be exploited.

Participant Quotes

"What we can do is create an image that voters are willing to protect for the products that we produce."

"There is not good enough information in the overall system regarding what it is that we do here."

"We're saying that we hope that the County would be more supportive of the efforts that we're trying to do and try to assist us in getting out the message about food to table, more sustainability."

Allied Suppliers and Associated Industries

Allied industries expressed differing levels of concern about the current situation and prospects for agriculture in south Miami-Dade County.

Participant Quotes

"In the back of mind, I keep wondering how long agriculture will hold out here."

"If they [growers] can survive they will stay in farming."

Those who sold equipment, agrichemicals, and other services to row crop growers expressed that they have been feeling the impact of declining row crop acreage since at least the early 2000s. Others, including irrigation companies, greenhouse builders, and suppliers of nursery products were encouraged by the growth in and strength of the nursery industry, and the perceived profitability of tropical fruit production and agritourism. They are changing strategies and offering different products to maintain profitability with the evolving composition of the agricultural sector in Miami-Dade County.

Participant Quote

"I am extremely surprised with how well the Asian growers are doing."

"Down here we have to roll with the times."

However, this change can require significant investment. Agrichemical dealers in particular mentioned how the EPA has been slow in authorizing the use of certain products on the multitude of specialty crops grown in Miami-Dade County, especially as new crops are being grown commercially. The input suppliers have been particularly squeezed by supply chain issues and rising costs, and their ability to pass those costs on to growers, who also have tight profit margins. While these pressures have become increasingly problematic since the disruptions caused by COVID, cost/price pressures are expected to continue in the years ahead, particularly if the agricultural acreage in south Miami-Dade County continues to shrink.

Banking and Financial Services

Representatives from the banking and financial services sector expressed concern about the future of agriculture in south Miami-Dade County. Of particular concern was the situation for row crop growers who have experienced substantial contraction in their acreage and profitability. Interviewees consistently reported this as being the result of subsidized foreign fresh fruit and vegetable imports. One interviewee suggested that if foreign competition isn't controlled, row crop growers need subsidies like other agricultural commodities; these could be in the form of input subsidies, labor subsidies or price supports. Another option might be to reduce regulatory costs. Regardless, something needs to be done not just to help growers survive, but to also aid with succession. They explained that the children of row crop farmers aren't going to want to stay in the business if there isn't a profit to be made, which would lead to an even more rapid decline in Miami-Dade County agriculture.

There was less concern about other commodity sectors in Miami-Dade County as they were variously viewed as being "OK" to "strong" in terms of profitability and future viability, although a reduction in regulations and related costs would benefit these sectors as well.

Strengths were perceived to be the diversified nature of Miami-Dade County agriculture, while weaknesses identified included foreign competition and urban sprawl, and some concern was expressed over the issue of sea-level rise and saltwater intrusion, and how they would affect Miami-Dade County agriculture.

One of the frustrations that interviewees report hearing from growers and agritourism industry participants is that elected and appointed officials in the County discuss how much they value agriculture and agritourism, but many ordinances conflict with that message. The general perception seems to be that government officials do not fully appreciate the economic importance of the agricultural sector for the region. Moreover, County offices were reported to be providing conflicting information.

Participant Quote

"With respect to inspections from different County offices the right hand doesn't seem to know what the left hand is doing."

The apparent lack of proper coordination and uniformity leads to confusion and frustration, with farms and agritourism venues being charged fines and penalties without clearly knowing what the correct regulations are. With respect to policy options, it was suggested that increased use of conservation easements, deed restrictions, and transferrable development rights might be helpful, as is being done in Palm Beach County.

Concerns were expressed about the impact that a recession could have on various commodity sectors in south Miami-Dade County. Concern was also expressed about the impact of increasing interest rates on the financial viability of agricultural operations. Development pressures are expected to continue over the next 10, 20 and 30 years.

<u>Participant Quote</u>

"Lots of people want to move to south Florida and that isn't likely to change."

Infrastructure problems were another issue mentioned. Rural roads in the area were not designed to accommodate traffic from large and heavy construction vehicles for building homes and other non-agricultural buildings, on top of regular traffic and farm traffic. Some government officials believe that the requirements for developers to provide infrastructure improvements solve all the problems, but they don't realize that developers simply improve the entrances to their developments and the immediate surrounding area. They do not do anything to help improve roads beyond that.

<u>Participant Quote</u>

"When the time changed and I had to drive home in the dark, I had to think carefully about what route to take because I didn't want to hit one of the many large potholes on some streets that I couldn't see in the dark and get a flat tire."

There was discussion that new agricultural technologies could potentially improve yields and productivity, but growers cannot afford to invest if they aren't making money to begin with.

<u>Participant Quote</u>

"I would love to see substantial increases in agricultural technology, but that requires capital investment which is difficult for growers to justify if they aren't making money."

All interviewees in this segment mentioned that the continuation of agriculture in South Miami-Dade County is important. It helps satisfy food needs, and purchasing of local food is important. At the same time, they highlighted that economic diversity is important and there needs to be a balance among nature and industry along with the need for growth.

Agritourism

Agritourism and event venues have been expanding rapidly in the County over the past few years, especially as Florida legislation has supported this industry in protection from liability claims. Agriculture areas near urban areas and on the route to many tourist destinations like the Everglades, Biscayne National Parks, and the Keys complement the area's beauty, and increase interest for many urban residents and tourists visiting the region. Agritourism activities provide an additional income source for established farms as well as an option for new entrepreneurs.

<u>Participant Quotes</u>

"Miami is now the winter wedding capitol of the United States."

"There are more than 40 agritourism venues now in south Miami-Dade County, and the industry is beginning to get better organized."

One of their initiatives is to try to compile data on the economic impact of the sector which operators believe to be substantial given the linkages between events and other businesses like florists, food, hotels, etc. The Economic Development Council of South Miami-Dade and the South Dade Chamber of Commerce have been actively discussing ways to support and promote the development of the agritourism sector.

Growers in the tropical fruit and nursery focus groups expressed concern about County food safety and health regulations that have not been adequately updated to meet the particular situation for agritourism businesses that serve food.

There were also reports about conflicts and tensions between agritourism venues and neighbors, as the venues can cause traffic problems during their events. It was suggested that it would be helpful to implement policies and educational programs to help inform new residents moving to south Miami-Dade County about the economic, environmental, and social benefits of agriculture and agritourism in the region. Providing information on the real, science-based benefits of agriculture and agritourism will help people to better appreciate their contribution, as opposed to allowing rumors to flourish about what happens on agricultural land. If residents do not understand agriculture, they won't want to interact with it or live near it.

Beekeeping

Beekeepers were generally optimistic about future prospects, both for hives for pollination, and honey production for sale. However, they did express concern about County regulations that some believe contradict state policies that are impacting and, in some cases, restricting their ability to operate. They are concerned about the loss of crop land and natural spaces limiting their bees' access to food and ability to serve as pollinators for the tropical fruit growers and other crops. They believe that residents need to be better informed about the need for bees, natural spaces, and agricultural areas to maintain a healthy ecosystem. They shared concerns that nearly all the growers expressed about the challenges for young people to be involved in the agricultural sector due to the high start-up costs, lack of access to land, declining profit margins, labor shortages, etc.

<u>Participant Quotes</u>

"The County Commission needs to know what else [like beekeeping] is going on down here [in south Dade]."

"I feel like we can grow anything, pretty much anything down here."

Vertical/Controlled Environment/Indoor Farming

Those involved in the vertical agricultural sector in the County, mostly concentrated in the urban areas of Miami-Dade County, reported that this sector has grown substantially in the last few years to meet growing demand, especially in Miami's growing restaurant scene. They have been quite profitable. The owners of these startups expressed optimism about their future. However, they have yet to prove their longevity and economic sustainability, as many were established in the last few years, and a few have gone out of business. They were clear in expressing that they would not exist without the agricultural sector in south Miami-Dade, as their specialty herbs and greens complement this production. The growing demand in the urban areas of the County for tropical fruits and specialty vegetables has provided an opportunity for vertical agriculture to provide complementary products to provide a more diverse offering in local markets, with the expectation that demand will continue to increase for both traditional growers and the vertical farms. However, they also struggled establishing their business due to a confusing regulatory regime that has not been updated to be applicable for this industry.

<u>Participant Quotes</u>

"So, I think of it [vertical farming] as a complement to what does grow in Homestead. That's a good way to think about it, you know, mixing things together."

"Getting a certificate of occupancy has been so hard...It was like there was no code for what we're doing. There was no like category for us."

"It was just very confusing. We don't know where to put you. You are like a lot of different things…Are you technology or you agriculture? But we're both. The needs are unique, and also, you know, just getting support for the resources that are available to the rest of the agriculture."

Builders and Developers

A separate focus group with builders and developers was conducted by Miami-Dade County, Department of Regulatory and Economic Resources to get their input and perspectives on the issues being examined as part of the research being conducted by UF/IFAS for the project. This focus group was <u>not</u> a part of the UF/IFAS study covered by UF Institutional Review Board approved protocols, but the authors felt that it would be helpful to include information obtained from this group in this report. Some observations from this session are summarized as follows.

Builders acknowledged that year-round growing conditions and good soils are a strength of agriculture in the County. They recognized that nurseries have been expanding, and that there seems to be some expansion in Asian/specialty tropical fruits as well.

The developers recognized the difficulty that growers are having competing with imports due to lower labor costs faced by foreign producers. They suggested that protective tariffs would help the growers. One developer observed that large row crop growers have moved to Mexico and were benefitting from Mexican government subsidies. The observation was made that food security is important and that there needs to be a balance of domestic versus imported food. They also observed that nurseries don't face the same competition from foreign producers.

Some argued that the next generation of farmers are reluctant to go into farming, while others recognized that high land prices make it basically impossible for a new, young grower to start a new farm.

There was some discussion of agricultural leases, which are typically annual leases except for nurseries which tend to be longer term because nursery growers have to spend more money on infrastructure.

There appears to be more interest in smaller, 5-to-10-acre properties now for agriculture as opposed to larger (100 acre+) properties. The question is if smaller operations have the economies of scale to be competitive.

Some discussion on agritourism was raised. There has been some growth in agritourism although not all ventures are successful – a failed brewery in the Redlands was mentioned. Agritourism operations often are not growing produce. One strategy might be to concentrate event venues in specific areas to preserve more agricultural land. Venues can be very crowded on the weekends, causing significant traffic problems.

Significant challenges for County agriculture include labor availability. Cost and availability of housing for visiting agricultural workers are important issues.

There were comments that indicated an appreciation for the economic role of agriculture in Miami-Dade County. Yet at the same time, some observations were made which suggested a lack of developer understanding of the role and importance of agriculture in Miami-Dade County.

Participant Quotes

"Most growers are just doing agriculture for tax benefits"

"The County subsidizes ag land with low property tax rates"

"There is no shortage of land, but there is a shortage of good agricultural practices."

There was discussion of how the building industry can help fund infrastructure for agriculture. Also, there was discussion of how development could perhaps help consolidate agricultural land.

One participant stated that protective covenants, Transfer of Development Rights and Purchase of Development Rights do not help farmers in the long run, since these are one-time payouts.

There was considerable discussion about the Urban Development Boundary (UDB). Greenfield developers who participated stated that they need large tracts of land rather than small parcels, whether they are developing warehouses, or houses or apartments /condos. Such parcels are very difficult to find within the UDB, and if they are available, they are extremely expensive. All of this makes infill development difficult, though it is the readily available option. Infill is a specialty type of development, but it is a more 'finicky' type of process. There are developers who specialize in infill development, and smaller builders who do smaller projects at infill sites throughout the County. Industrial development needs a larger footprint area (20 acres or more). Land costs typically represent about one-third of the cost of development. Outside the UDB, developers can sometimes afford to purchase and then lease the land in the short term which helps to promote more phased development. Clustered development could help outside UDB. Regulatory barriers are more significant outside the UDB. Some advocated allowing builders to use the Urban Expansion Area immediately, rather than waiting until 2030.

A recommendation was made to update the agricultural land study every 5 years.

Figure 18.1. Photo of sign for residential development in South Miami-Dade County.

Source: Photo by William Messina.

Conclusions

Concerns expressed across all stakeholder groups in interviews and focus groups were quite consistent. Participants mostly agreed that the agricultural sector in Miami-Dade County has evolved for over a century and will continue to evolve. While some sectors have being doing very well, such as the nursery and landscaping industry, agritourism, and certain tropical fruit crops, the row crop sector has been challenged in recent years, which is nearly all blamed on foreign competition. There are concerns that other sectors (i.e., tropical fruits and nursery) could follow the same fate if fair trade practices are not followed.

Stakeholders were frustrated that urban residents in Miami-Dade County are generally unaware of the agricultural sector, the diversity of products produced in the County, and where they can purchase local products.

Many participants were concerned that their perspective was not considered when the County makes regulations that affected them and an overall lack of willingness at various levels of government to address grower problems and concerns.

Participants generally agreed that agricultural land prices are too high, which limits the ability for the next generation to be involved in the agricultural sector and current businesses to expand. However, many stated that they felt that no restrictions should be placed on property owners' rights to sell their land.

The majority of participants mentioned that more residents and government officials should be aware of the importance of the environmental services (i.e., improved air quality, water recharge zone, habitat for native animal species and plants) provided by the agricultural sector.

Both growers and allied industries expressed concern about finding sufficient labor. Many are seeking options to use the H-2A visa program, which is difficult for smaller operations. Current County regulations substantially constrain the ability to provide the necessary worker housing.

Nearly all the stakeholders were concerned about increasing input costs shrinking their profit margins.

A majority of participants expressed a need to educate those who move to south Miami-Dade about how agricultural enterprises operate (e.g., having slow moving tractors on the road, the sound of irrigation pumps), so that they will be aware of and can live in harmony with nearby agricultural activities.

A significant number of participants are concerned about enough law enforcement presence in south Miami-Dade to combat illegal dumping, trespassing, and theft of fruit and equipment.

<u>Participant Quote</u>

"Agriculture in Miami-Dade County is valuable but vulnerable."

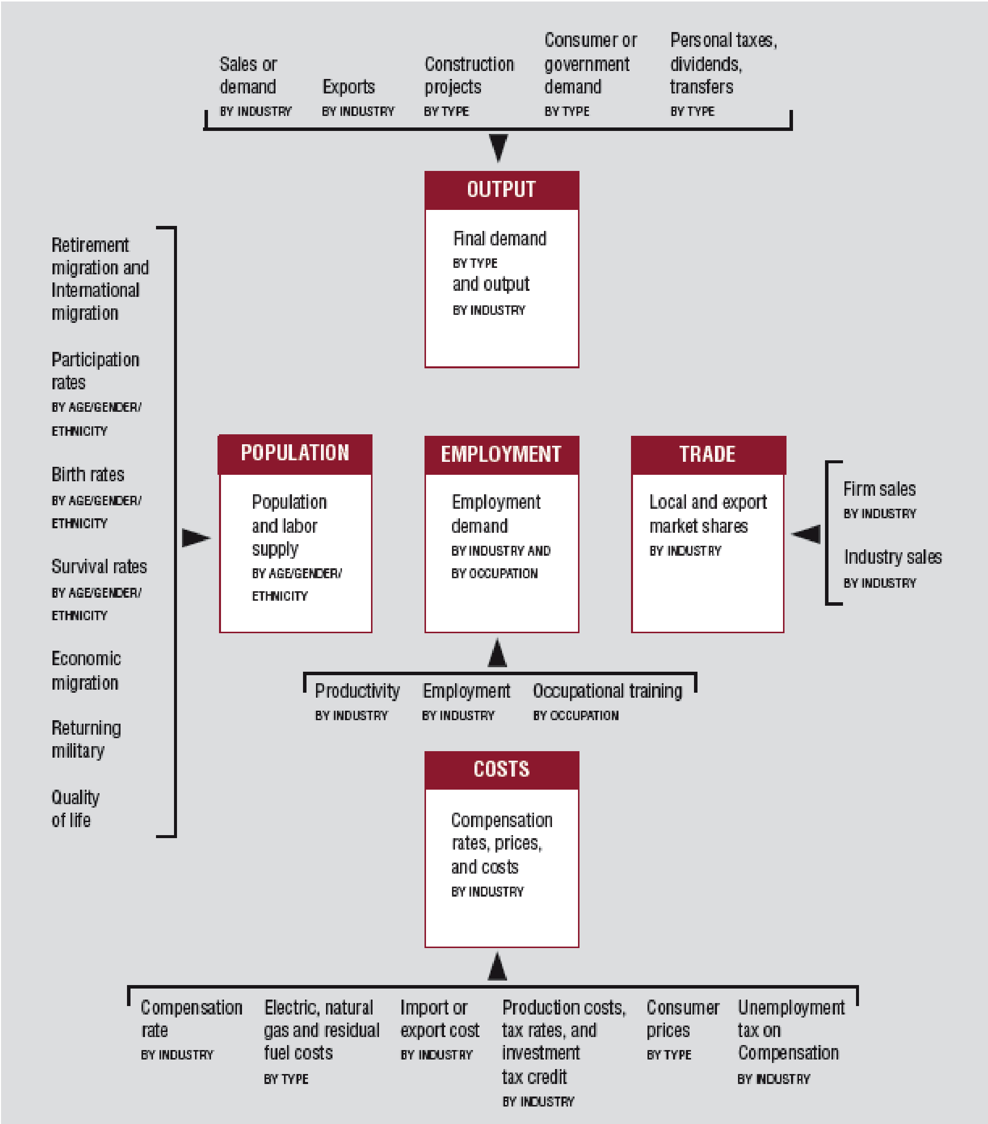
Scenario Analysis for Agriculture in Miami-Dade County

Scenarios were developed for long term economic forecasts of the agricultural sector in Miami-Dade County using a model from Regional Economic Models, Inc. (REMI©) Policy Insight software licensed to Miami-Dade County's Department of Regulatory and Economic Resources. REMI is an industry input-output/social accounting matrix coupled to a computable general equilibrium (CGE) modeling system, which accounts for changes in prices, labor intensity, technology, consumption patterns, and displacement effects, to support long-term economic forecasts for a variety of policy variables. The model consists of thousands of simultaneous equations that are solved and projected forward in one-year time steps.

The original version of the regional economic model was developed in 1977, and REMI was founded in 1980 to provide regional economic models for all states and counties in the U.S. Further refinements to the model during the 1980s and 1990s added features for capital stock adjustment, migration and demographic structure, consumption, labor force participation, multi-regional analysis, central bank monetary policy, and new economic geography theory (REMI, 2017). The current version of the model incorporates data for 2020.

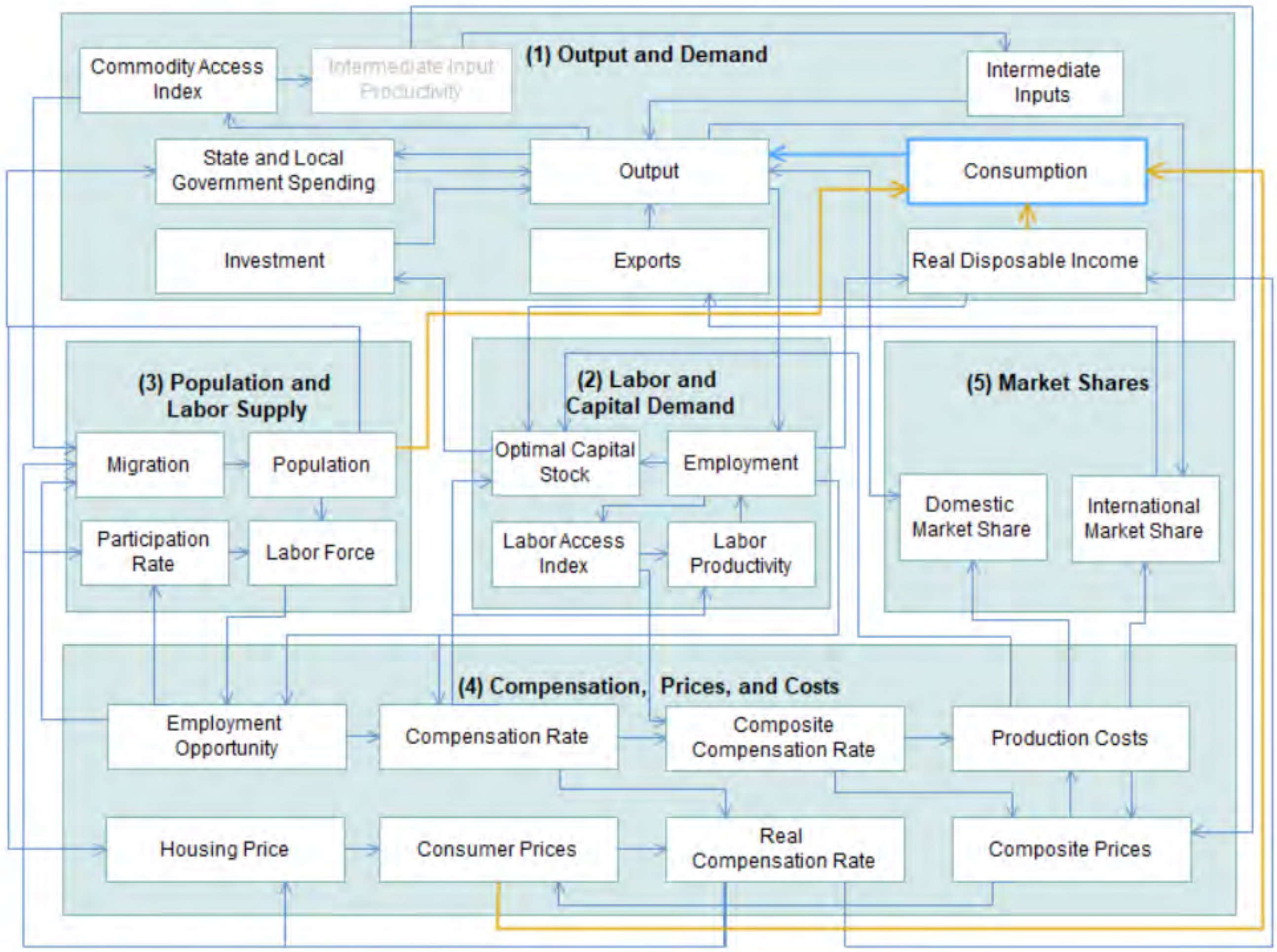
Multi-regional models contain linkages for trade flows of goods, services, capital, worker commuting, human migration, and many other factors. The REMI model has separate modules and policy variables for industry output, population/labor supply, employment, trade and costs, as shown in Figure 19.1. The extensive technical linkages between components of the REMI model that are described by model equations are shown in Figure 19.2 (REMI, 2017). The model has 67 industry sectors corresponding to the 3-digit level of classification under the North American Industry Classification System (NAICS). General equilibrium models such as REMI typically estimate smaller economic impacts of specified changes in output or employment than standard input-output models such as IMPLAN (Implan Group, LLC) or RIMSII (USDOC-BEA), because of price changes and displacement effects. The industry sectors in REMI are more aggregated because of greater computational requirements and costs for calibration of the model. Note that an important limitation of REMI for agricultural sector analysis is that the farm sector is not fully integrated within the general equilibrium model, due to limitations of underlying National Accounts data, meaning that farm output and employment do not respond to changes in demand or prices for farm products in other sectors of the local economy.

Figure 19.1. REMI model modules and policy (input) variables.



Source: Regional Economic Models, Inc.

Figure 19.2. REMI model component linkages.



Source: Regional Economic Models, Inc.

Farm and related agriculture/natural resource industry sectors in the REMI model are shown in Table 1. The most important farm industry sectors in Miami-Dade County are greenhouse/nursery/floriculture production (NAICS 1114), vegetable/melon farming (NAICS 1112), fruit/tree nut farming (NAICS 1113), and animal production/except cattle and poultry (NAICS 1129), although other farm sectors also exist at low levels. In addition, related agricultural and natural resource sectors include forestry/logging/fishing/hunting/trapping (NAICS 113/114), and support activities for agriculture and forestry (NAICS 115), which comprises activities such as custom farming services and farm labor contractors. For most model variables, crop and livestock production sectors are aggregated together under farms (NAICS 111/112). The agritourism/local food scenario also used the sectors for food services and drinking places (NAICS 722) and amusement and recreation industries (NAICS 713).

Table 19.1. Industry sectors for farms and related agricultural and natural resource industries in the REMI model.

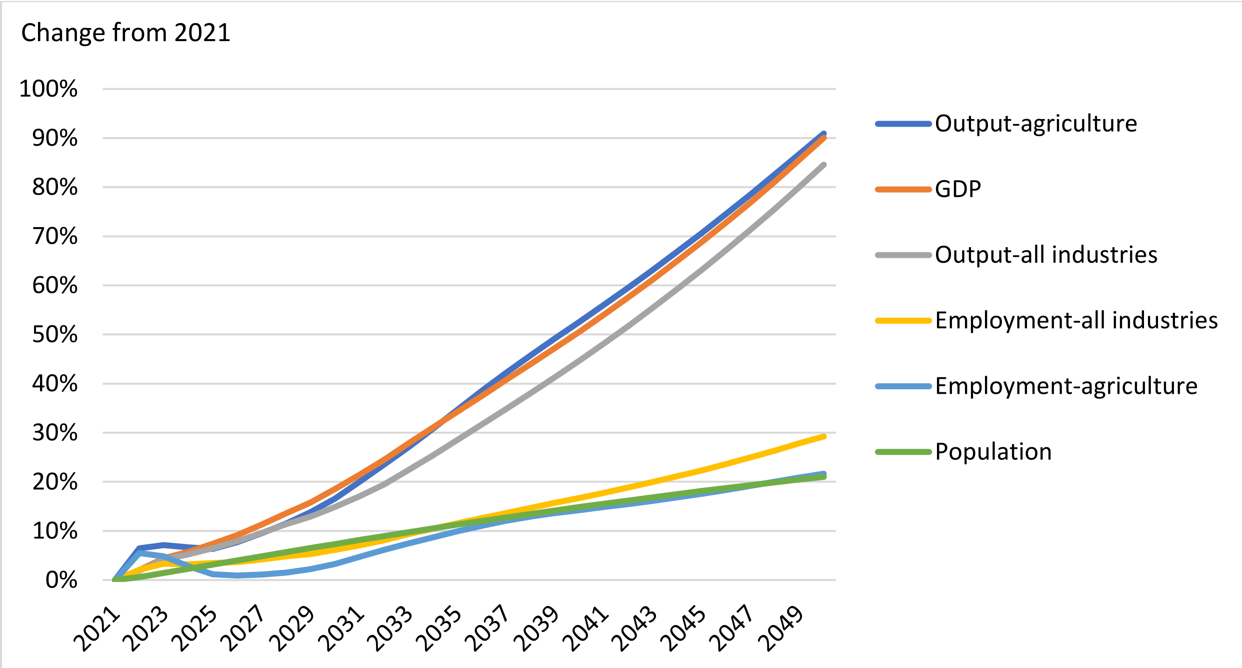
Industry Sector (NAICS)
Farms (111/112)
Animal production, except cattle and poultry and eggs (1129)
Beef cattle ranching and farming, including feedlots (11211)
Dairy cattle and milk production (11212)
Fruit and tree nut farming (1113)
Grain farming (11114/11115/11116/11119)
Greenhouse, nursery, and floriculture production (1114)
Oilseed farming (11112)
Other crop farming (1119)
Poultry and egg production (1123)
Vegetable/melon farming (1112)
Forestry, logging, fishing, hunting and trapping (113/114)
Support activities for agriculture and forestry (115)

Source: Regional Economic Models, Inc. and U.S. Census Bureau, NAICS definitions.

Baseline Population Forecasts

The baseline medium population growth economic forecast estimates from the REMI model for Miami-Dade County for the years 2021 to 2050 are presented in Table 19.2 and Figures 19.3-19.10. In round number terms, between 2021 and 2050 overall population in the County was forecast to increase 21 percent, and economic activity was forecast to increase 29 percent for employment, 83 percent for industry output, 88 percent for Gross Domestic Product (GDP), 84 percent for personal income, and 48 percent for real disposable personal income per capita (Table 19.2, Figure 19.3). Note that all monetary results are inflation adjusted, stated in fixed local 2023 dollar terms. The GDP and employment increases represented an annual average change of 3.02 percent and 1.01 percent, respectively. GDP increased more than employment, which implies that labor productivity (output per worker hour) is expected to increase. The farm sector was projected to grow more than the overall economy in terms of output (91%), and value added or GDP (97%), but to grow less for employment (10%) over the forecast period. Farm wages and salaries were projected to increase 132 percent, indicating significantly higher earnings per worker. The related sectors of forestry/logging/fishing and agricultural/forestry support services were projected to grow at lower rates for output (84%), value added (83%), and employment (55%). The forecast growth in Miami-Dade County during 2021-2050 is significantly higher than the REMI model forecast for U.S. population (12%), employment (13%), and GDP (65%), and also for farm output (81%) and employment (4%).

Figure 19.3. Chart of REMI model baseline economic forecast for Miami-Dade County, percent change 2021-2050



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Table 19.2. Summary of REMI model baseline economic forecast for Miami-Dade County, and for agricultural and related industry sectors, 2021, 2030, 2040, 2050.

	2021	2030	2040	2050	Change 2021-2050	Avg. annual change
County economy						
Disposable Personal Income	159,591	181,539	230,704	285,269	78.8%	2.72%
Gross Domestic Product	184,501	217,706	275,340	345,892	87.5%	3.02%
Labor Force (1,000 people)	1,297	1,398	1,532	1,676	29.2%	1.01%
Output	311,893	357,231	448,247	569,568	82.6%	2.85%
PCE-Price Index	109	135	166	204	88.0%	3.03%
Personal Income	178,558	208,291	264,810	328,082	83.7%	2.89%
Population (1,000 people)	2,716	2,915	3,119	3,286	21.0%	0.72%
Private Non-Farm Employment (1,000 jobs)	1,651	1,755	1,934	2,147	30.0%	1.04%
Real Disposable Personal Income	136,480	155,250	197,295	243,958	78.8%	2.72%
Real Disposable Personal Income per Capita (1,000$)	50	53	63	74	47.7%	1.65%
Residence Adjusted Employment	1,676	1,777	1,951	2,159	28.9%	1.00%
Total Employment (1,000 jobs)	1,808	1,919	2,110	2,336	29.2%	1.01%
Value-Added	184,501	217,706	275,340	345,892	87.5%	3.02%
Farms						
Demand	2,232	2,668	3,673	4,809	115.5%	3.98%
Intermediate Demand	977	1,175	1,635	2,091	114.0%	3.93%
Investment Activity Demand	-19	7	7	7	-134.6%	-4.64%
Output	1,500	1,751	2,292	2,868	91.1%	3.14%

	2021	2030	2040	2050	Change 2021-2050	Avg. annual change
Proprietors' Income	169	216	298	384	127.5%	4.40%
Total Employment (1,000 jobs)	9	9	9	10	9.9%	0.34%
Total Exports	1,500	1,751	2,292	2,868	91.1%	3.14%
Total Imports	2,232	2,668	3,673	4,809	115.5%	3.98%
Value-Added	520	631	829	1,024	96.9%	3.34%
Wages and Salaries	239	307	426	554	132.1%	4.56%
Forestry-logging-fishing, agricultural support services						
Demand	179	190	248	319	78.4%	2.70%
Intermediate Demand	138	148	194	252	82.6%	2.85%
Investment Activity Demand	2	3	4	5	137.9%	4.76%
Output	48	54	70	89	84.2%	2.90%
Proprietors' Income	5	4	5	6	34.2%	1.18%
Total Employment (1,000 jobs)	3	3	4	5	55.2%	1.90%
Total Exports	7	7	9	11	55.4%	1.91%
Total Imports	136	141	187	243	78.5%	2.71%
Value-Added	39	44	57	72	82.5%	2.85%
Wages and Salaries	73	83	101	120	65.4%	2.26%

Units in millions of fixed local 2023 dollars, thousand jobs or thousand people. The average annual changes represent simple arithmetic averages rather than compounded rates of change. Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

The high and low population growth forecasts for Miami-Dade County, farms and related agriculture industry sectors during 2021-2050 are summarized in Tables 19.3-19.4 and Figures 19.4-19.10.

Under the high population growth forecast, population in 2050 was projected to increase 45 percent, and economic activity was projected to increase 77 percent for employment, 147 percent for industry output, 154 percent for GDP, 127 percent for personal income, and 51 percent for real disposable personal income per capita, in constant dollar terms (Table 19.3, Figures 19.4-19.6). The GDP and employment increases represented annual average changes of +5.32 and +2.67 percent, respectively. The farm sector was projected to increase less rapidly in terms of output (129%), value added/GDP (136%), and employment (32%) (Figures 19.7-19.9). The forestry/logging/fishing and agricultural/forestry support services sectors were projected to grow in terms of output (150%), value added (147%), and employment (109%) (Figure 19.10). Note that the projected decreases in activity for farms and agriculture-related industries during 2023-2026 may reflect a delayed normalization in response to significant changes in the economy due to COVID-19 in 2020, which was the base year for the REMI model.

Under the low population growth forecast, population in 2050 was projected to decrease 3.2 percent, while employment was projected to decline 17.3 percent (Table 19.4). Economic activity would still increase for output (21%), GDP (23%), personal income 42%), and real disposable personal income per capita (44%) (Figures 19.4-19.6). The GDP growth represented an annual average change of +0.81 percent and the employment decline was -0.60 percent annually. The farm sector was projected to increase more slowly in terms of output (53%), and value added/GDP (58%), and to decrease for employment (-12%) (Figures 19.7-19.9). The forestry/logging/fishing and agricultural/forestry support services sectors were projected to change for output (18%), value added (17%), and employment (1%) (Figure 19.10).

Table 19.3. Summary of REMI model high population growth economic forecast for Miami-Dade County, and agriculture and related industries, 2021, 2030, 2040, 2050.

	2021	2030	2040	2050	Change 2021-2050	Avg. annual change
County economy						
Disposable Personal Income	160,805	201,834	272,139	353,497	119.8%	4.13%
Gross Domestic Product	186,262	257,329	353,578	473,614	154.3%	5.32%
Labor Force (1,000 people)	1,297	1,548	1,803	2,053	58.3%	2.01%
Output	314,773	421,606	574,370	777,865	147.1%	5.07%
PCE-Price Index	109	139	174	217	99.9%	3.45%
Personal Income	179,929	232,078	313,371	408,236	126.9%	4.38%
Population (1,000 people)	2,716	3,163	3,579	3,943	45.2%	1.56%
Private Non-Farm Employment	1,655	2,082	2,505	2,974	79.7%	2.75%
Real Disposable Personal Income	136,691	171,568	231,330	300,488	119.8%	4.13%
Real Disposable Personal Income per Capita ($1,000)	50	54	65	76	51.4%	1.77%
Residence Adjusted Employment (1,000 jobs)	1,679	2,093	2,506	2,965	76.5%	2.64%
Total Employment (1,000 jobs)	1,812	2,266	2,717	3,214	77.4%	2.67%
Value-Added	186,262	257,329	353,578	473,614	154.3%	5.32%
Farms						
Demand	2,234	2,997	4,408	6,076	172.0%	5.93%
Intermediate Demand	978	1,346	2,012	2,716	177.7%	6.13%
Investment Activity Demand	-19	8	8	8	-141.5%	-4.88%
Output	1,500	1,900	2,630	3,441	129.3%	4.46%
Proprietors' Income	170	235	340	456	168.7%	5.82%
Total Employment (1,000 jobs)	9	10	11	12	31.9%	1.10%
Total Exports	1,500	1,900	2,630	3,441	129.3%	4.46%
Total Imports	2,234	2,997	4,408	6,076	172.0%	5.93%
Value-Added	520	685	951	1,229	136.2%	4.70%
Wages and Salaries	240	335	493	673	180.4%	6.22%
Forestry-logging, fishing, agricultural support services						
Demand	180	219	306	416	131.6%	4.54%
Intermediate Demand	139	170	241	333	139.0%	4.79%
Investment Activity Demand	2	5	6	7	233.9%	8.07%
Output	49	64	90	121	149.6%	5.16%
Proprietors' Income	5	4	5	6	20.5%	0.71%
Total Employment (1,000 jobs)	3	4	5	6	108.9%	3.76%
Total Exports	7	7	9	10	46.5%	1.60%
Total Imports	137	165	235	325	137.2%	4.73%
Value-Added	39	52	73	98	147.4%	5.08%
Wages and Salaries	73	98	130	165	124.9%	4.31%

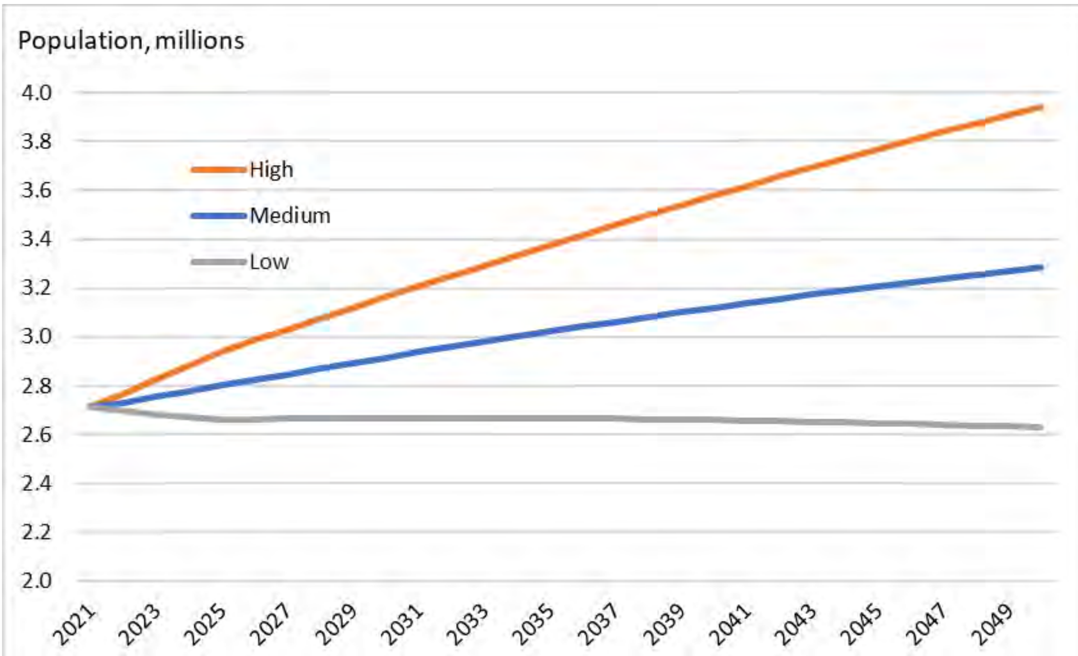
Units in millions of fixed local 2023 dollars, thousand people or jobs.
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Table 19.4. Summary of REMI model low population growth economic forecast for Miami-Dade County, and agriculture and related industries, 2021, 2030, 2040, 2050.

	2021	2030	2040	2050	Change 2021-2050	Avg annual change
County economy						
Disposable Personal Income	158,958	161,870	191,217	221,674	39.5%	1.36%
Gross Domestic Product	183,624	179,286	200,925	226,591	23.4%	0.81%
Labor Force (1,000 people)	1,297	1,246	1,250	1,264	-2.6%	-0.09%
Output	310,506	294,757	328,185	374,805	20.7%	0.71%
PCE-Price Index	109	130	156	187	72.7%	2.51%
Personal Income	177,862	185,221	218,484	253,213	42.4%	1.46%
Population (1,000 people)	2,716	2,667	2,659	2,629	-3.2%	-0.11%
Private Non-Farm Employment	1,655	1,433	1,382	1,359	-17.9%	-0.62%
Real Disposable Personal Income	136,691	139,196	164,431	190,622	39.5%	1.36%
Real Disposable Personal Income per Capita ($1,000)	50	52	62	73	44.1%	1.52%
Residence Adjusted Employment (1,000 jobs)	1,679	1,464	1,413	1,391	-17.2%	-0.59%
Total Employment (1,000 people)	1,812	1,576	1,522	1,498	-17.3%	-0.60%
Value-Added	183,624	179,286	200,925	226,591	23.4%	0.81%
Farm sector						
Demand	2,234	2,342	2,951	3,579	60.2%	2.08%
Intermediate Demand	978	1,004	1,261	1,474	50.7%	1.75%
Investment Activity Demand	-19	7	6	5	-127.6%	-4.40%
Output	1,500	1,603	1,954	2,294	52.9%	1.82%
Proprietors' Income	168	198	255	310	84.5%	2.91%
Total Employment (1,000 people)	9	8	8	8	-12.1%	-0.42%
Total Exports	1,500	1,603	1,954	2,294	52.9%	1.82%
Total Imports	2,234	2,342	2,951	3,579	60.2%	2.08%
Value-Added	520	577	707	819	57.5%	1.98%
Wages and Salaries	237	279	360	437	84.1%	2.90%
Forestry/logging/fishing/agricultural support services sectors						
Demand	178	162	191	224	26.0%	0.90%
Intermediate Demand	138	125	147	174	26.5%	0.91%
Investment Activity Demand	2	2	3	3	44.1%	1.52%
Output	48	44	50	57	18.2%	0.63%
Proprietors' Income	5	3	4	6	19.5%	0.67%
Total Employment (1,000 people)	3	3	3	3	0.7%	0.02%
Total Exports	7	8	9	11	67.8%	2.34%
Total Imports	136	118	140	165	21.3%	0.73%
Value-Added	39	36	41	46	17.3%	0.59%
Wages and Salaries	72	68	73	77	6.0%	0.21%

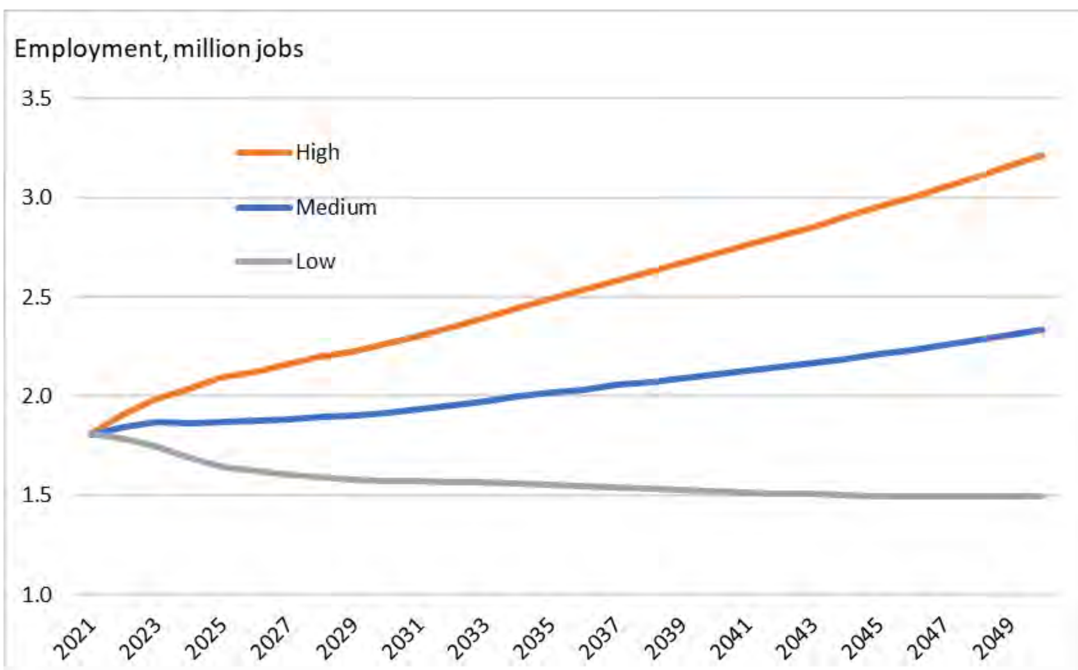
Units in millions of fixed local 2023 dollars, thousand people or jobs.
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.4. Population forecast for Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



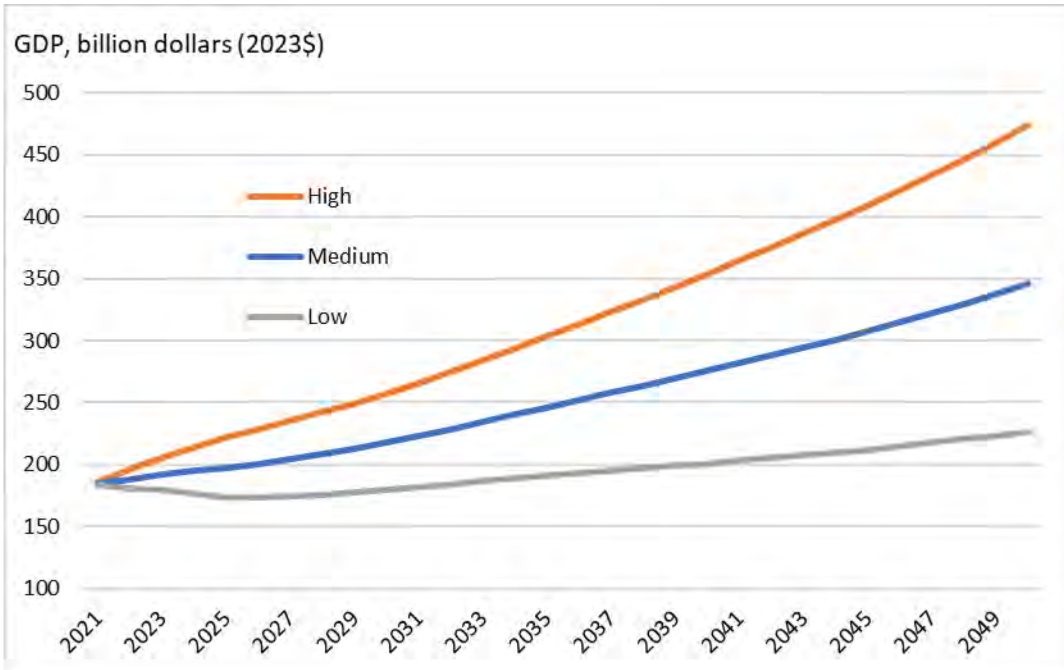
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.5. Employment forecast for Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



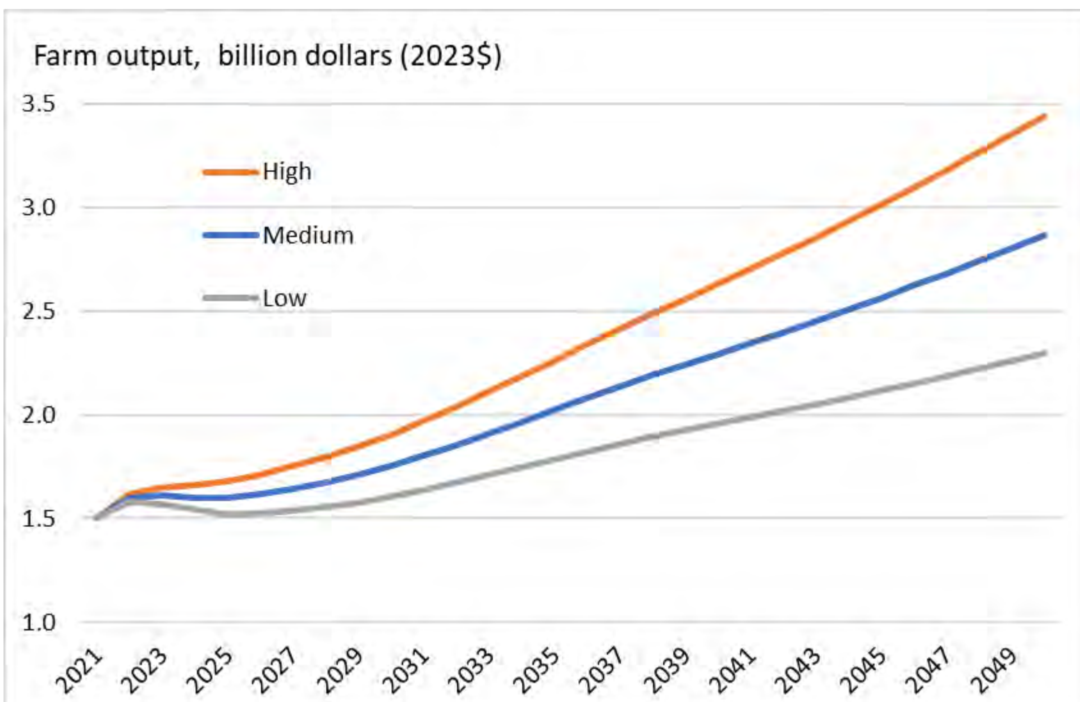
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.6. GDP forecast for Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



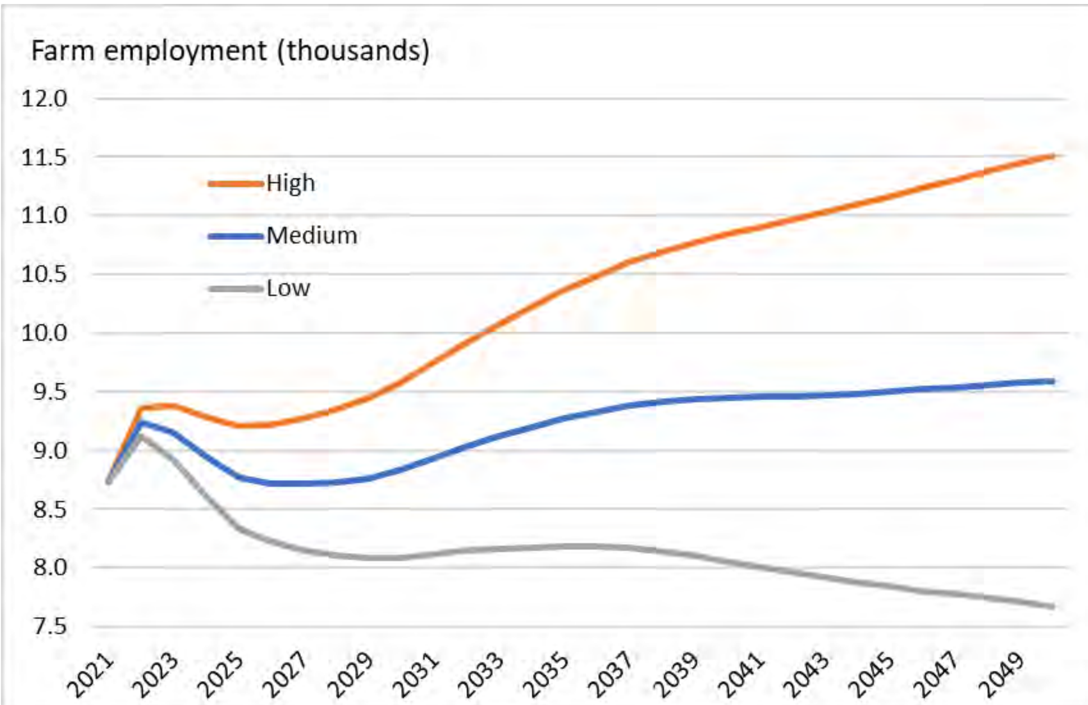
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.7. Farm output forecast for Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



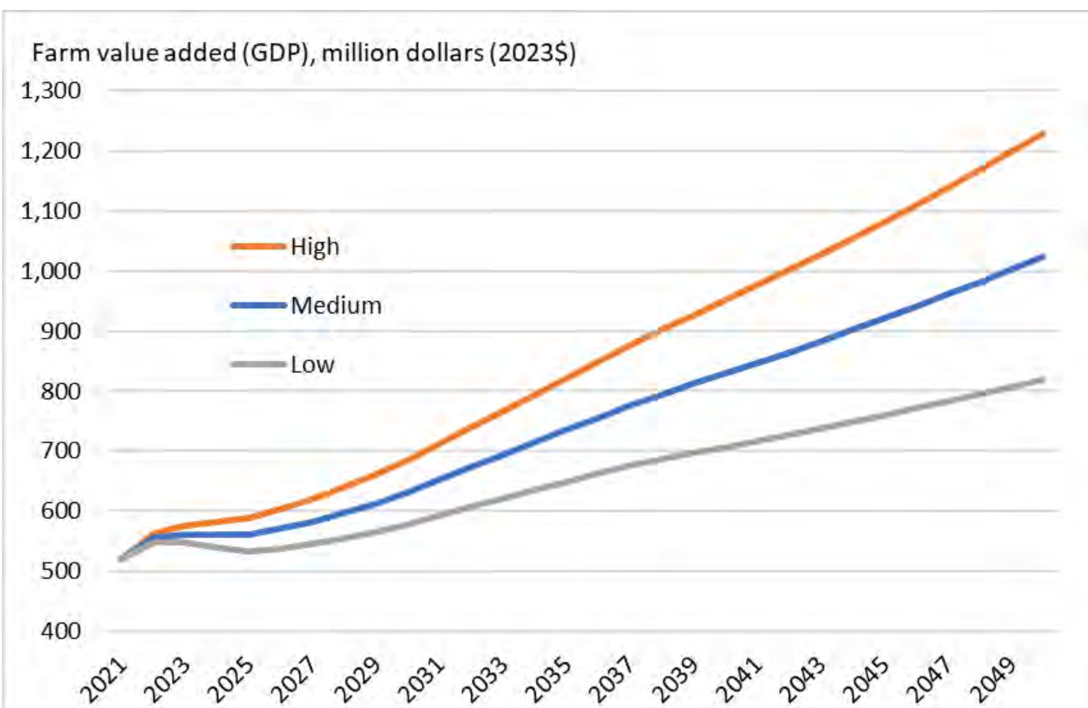
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.8. Farm employment forecast for Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



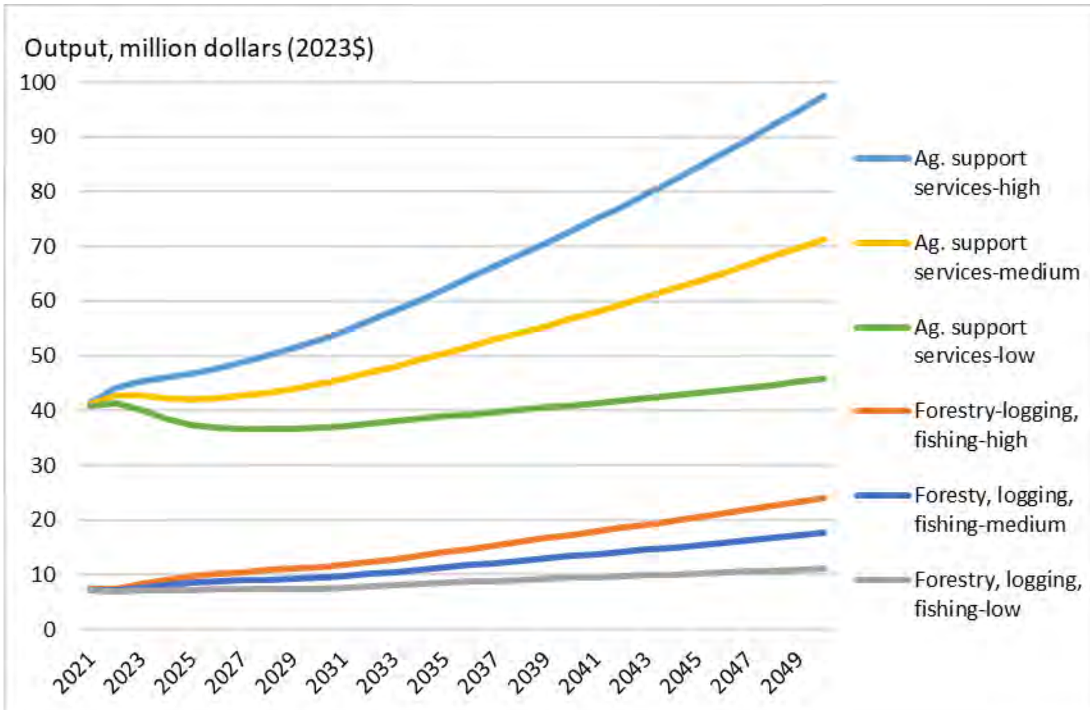
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.9. Farm value added forecast for Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.10. Output forecast for agricultural support services and forestry/logging/fishing industries in Miami-Dade County under medium, high, and low population growth forecasts, 2021-2050.



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

County Agricultural Scenarios

Future scenarios for agriculture in Miami-Dade County were developed for this study as described below and summarized in Table 19.5. The scenarios are intended to represent various opportunities and threats to the agricultural sector in the County, based on information developed throughout the project.

Baseline forecast. The baseline forecast uses population projections by Miami-Dade County Department of Regulatory and Economic Resources. Population was forecast to grow from 2.716 million in 2021 to 3.286 million in 2050. The results of all other scenarios are measured as changes from the baseline scenario.

High and low population growth forecasts. These forecasts represent alternative projections of population in the County above or below the baseline, based on the high/low population forecasts for Florida counties by the University of Florida-Bureau of Economic and Business Research (UF-BEBR). All economic sectors in the County are affected by these population projections. For the high growth case, population increases to 3.943 million people in 2050 (20% above baseline), and in the low growth case population decreases to 2.629 million (-20% below baseline). The high and low population growth forecasts can be considered in combination with the agriculture scenarios to represent the combined effect of scenarios and population growth assumptions.

Increased farm output growth scenario. This scenario modeled a +6 percent annual increase in farm output above the baseline forecast of +3.1 percent annually, or a total increase of +9.1 percent per year. For reference, growth in Miami-Dade County farm sales reported by the Census of Agriculture during 2012-2017 was about +6 percent annually, and the long-term increase in County farm sales from 1969 to 2017 was +5 percent annually (USDA-NASS). Therefore, this scenario represents a near doubling of the historic growth rate. This scenario, combined with the agritourism/local food development scenario (see below), can be considered a “best case” scenario for agriculture in the County.

<u>Agritourism, local food development scenario</u>. This scenario modeled a $25 million annual output change in each of three industries: farms, food and drinking establishments, and amusement and recreation industries. This split of activities is intended to represent a typical agritourism venue offering locally sourced food, food service, and entertainment. As context, visitor spending in southern Miami-Dade County in 2021 was estimated at $474 million, based on data from the Miami Convention and Visitors Bureau, so the $75 million change would represent an approximate 16 percent increase. Other consumer spending in the County was adjusted down to offset the increase in local food purchases, such that overall consumer spending per capita was held constant.

<u>Agricultural technology adoption scenario</u>. This scenario modeled new investment of $50 million annually in agricultural machinery, with a 5 percent net increase in farm output due to higher productivity, and a 5 percent decrease in farm employment due to labor-saving technology. The 5 percent net farm output change was specified in REMI as a 10 percent increase in farm output together with an automatically imputed 5 percent decrease associated with the decreased farm employment. The costs and benefits for adoption of improved agricultural technology could not be determined precisely in this research, so these changes should be regarded as placeholder estimates of possible changes. For further information on new technologies anticipated for specialty crop production see Appendix B: Emerging Agricultural Technologies.

<u>Increased foreign import competition scenario</u>. This scenario modeled a 5 percent loss of farm output to reflect low commodity prices coupled with a 10 percent loss of farm proprietor income to represent reduced farm operating margins. Import competition applies mainly to vegetables (row crops) and fruits, while the nursery/greenhouse sector is largely protected from import competition because of U.S. regulations prohibiting imports of live plants in soil media to prevent introduction of pests and diseases. The vegetable and fruit production sectors represent about 16 percent of County agricultural output that is exposed to import competition. The U.S. import value of specialty crops during 2008-2021 increased at an average annual rate of +6.2 percent, resulting in lower prices received by U.S. producers (Hodges et al., 2019). See the Current Situation section of the report for further information on trends in imported specialty crops and farm operating margins in the County.

<u>Agriculture land loss in Urban Expansion Area scenario</u>. This scenario modeled a -6 percent annual loss in farm output starting in 2030 and continuing to 2050. Miami-Dade County placed an option in its Comprehensive Development Master Plan that may allow for the expansion of the Urban Development

Boundary in the northwest and southeast parts of the County to possibly accommodate continued population growth and residential housing development (Miami-Dade County, 2021), although the County is also making great efforts to continue to accommodate growth within the existing boundary. The Urban Expansion Area currently has about 3,605 acres in agricultural use, with farm commodity production value estimated at $49.61 million, representing 5.9 percent of County farm sales in 2017 (USDA-NASS Census of Agriculture). The Urban Expansion Area would be considered available starting after 2030 to accommodate growth if necessary up to 2040.

Moderate climate change and sea level rise scenario. This scenario modeled an annual loss in farm output of -1 percent in 2023, increasing to -13.1 percent in 2050, reflecting agricultural lands with elevated water table under the Intermediate-High climate change projection by NOAA (Sweet et al., 2017), modeled in Appendix A: Climate and Hydrology Modeling for Miami-Dade County for this project. The increasing level of impacts over time reflects the progressively worsening conditions under climate change. The impacts of climate change/sea level rise on agricultural production could not be precisely determined in this research, so these estimates represent potential changes in the agricultural sector. A recent report that compiled published information from crop modeling studies and interviews with academic experts estimated a decrease of 17 percent for early yields and 11 percent for overall seasonal yields of Florida strawberries in 2050 in the Tampa Bay area of the state (Environmental Defense Fund, 2023). For further information, see Appendix A: Climate and Hydrology Modeling for Miami-Dade County.

Extreme climate change and sea level rise scenario. This scenario modeled a two-times higher level of annual loss in farm output, starting at -2 percent in 2023 and increasing to -26.2 percent in 2050. These greater impacts correspond to the High climate change projection by NOAA (Sweet et al., 2017). It is assumed that there would be significant losses in production due to a rise in groundwater elevation and salinity, heat stress on crops and animals, and mandatory work stoppages.

Major hurricane scenario. This scenario modeled two separate major hurricane events in 2023 and 2043, representing a 20-year return period. For historical reference, the average interval between major hurricanes in Miami-Dade County was 17 years (NOAA-NHC). The scenario reflects simulated damages by a Category 5 hurricane (e.g., Hurricane Andrew, 1992), as detailed in the project section on Weather Hazards. Losses in farm output for each hurricane were expected to occur over three years, including a 30 percent loss in the first year, 20 percent loss in the following year, and 10 percent loss in third year, because many fruit tree or perennial nursery crops in the County require several years to recover to a productive or saleable condition. In addition, a 5 percent loss of nonresidential capital stock was assumed in the first year of each hurricane to represent structural damages. Losses of capital stock triggers an investment response in the REMI model to rebuild it to previous levels. The capital stock variable affects all sectors in the County, so the results of this scenario represent not only impacts to farms.

Land price increase scenario. This scenario modeled a 5 percent increase in price of nonresidential (land) real estate to represent increasing scarcity of land in the County. This policy variable affects all sectors in the County, so the results of this scenario are not only for farms. For further background information, see the report sections on Urban Development and Agricultural Land Use in the County.

Worst case scenario. This scenario modeled a 75 percent reduction in farm output in the County due to any cause or the compound effects of multiple stressors or adverse events, representing a significant loss of the agricultural sector in the County. It is deemed to be unlikely that agriculture would completely disappear from Miami-Dade County under any circumstances, given the experience of other large urban metro areas (see report section on Assessment of the Current Situation and Outlook for Agriculture). It is expected that losses in the agricultural sector would be partly offset by increased urban development activity replacing agricultural land use, although that is not captured in this scenario because REMI is not a land use model, and additional assumptions would need to be made outside of the model to account for changes in land use.

Best case scenario. This scenario represents a combination of two scenarios described above: "increased farm output growth" and "agritourism/local food development."

Most likely case scenario. This scenario represents a combination of three scenarios described above: "increased foreign import competition," "agriculture land loss to Urban Expansion Area," and "moderate climate change and sea level rise." These three scenarios are all considered very likely to occur in the forecast timeframe.

Inputs to the REMI model for the scenarios were specified using selected policy variables for farm output (sales revenue), output for nonfarm sectors, farm employment (jobs), capital investment, capital stock, consumer demand, and real estate price, as described in Table 19.6. Inputs were entered for each year during the 2023-2050 modeling period as constant changes for all years, as changes for specific years, or as progressive changes over time, as described above.

Table 19.5. Summary of REMI model inputs for scenario analysis of Miami-Dade County agriculture.

Scenario	Variable(s)	Input value
Baseline (local control forecast)	Population	Forecast population
High population growth	Population	Forecast population 20% higher in 2050
Low population growth	Population	Forecast population 20% lower in 2050
Increased farm output growth	Farm output	+6% all years
Increased agricultural technology adoption	Detailed investment-agricultural machinery Farm output Farm employment	+$50,000,000 all years +5% all years -5% all years
Agritourism/local food promotion	Farm output Output-Food and drinking places Output-Amusement and recreation industries	+$25,000,000 all years +$25,000,000 all years +$25,000,000 all years
Agricultural land loss to Urban Expansion Area	Farm output	-6%, 2030 to 2050
Category 5 hurricane, 20-year return period (2 events)	Farm output Capital stock-nonresidential	-30% in 2023 and 2043 -20% in 2024 and 2044 -10% in 2025 and 2045 -5% in 2023 -5% in 2043
Increased foreign import competition	Farm output Proprietor income-farm	-5% all years -10% all years
Mid-range climate change/sea level rise, flood risk	Farm output	-1.0% in 2023, increasing to -13.1% in 2050
Extreme climate change/sea level rise, flood risk	Farm output	-2.0% in 2023, increasing to -26.2% in 2050
Increased land prices	Real estate price-nonresidential	+5% all years
Worst case	Farm output	-75% all years (2023-2050)
Best case: combination of scenarios for Increased farm output growth, and Agritourism/local food development	Farm output Farm output Output-Food and drinking places Output-Amusement and recreation industries	+10% all years +$25,000,000 all years +$25,000,000 all years +$25,000,000 all years
Most likely case: combination of scenarios for Increased import competition, Land loss to Urban Expansion Area, and Mid-range climate change/sea level rise	Farm output Proprietor income-farm Farm output Farm output	-5% all years -10% all years -6%, 2030 to 2050 -1.0% in 2023, increasing to -13.1% in 2050

Table 19.6. Description of REMI model policy (input) variables used for agricultural scenario analysis in Miami-Dade County.

Variable	Description
Farm output	The amount of production, including all intermediate goods purchased as well as value added (compensation and profit). Can also be thought of as sales or supply. The Farm industry is assumed to be exogenous in the REMI model. Therefore, all farm demand is imported, and all farm production is exported. Intermediate purchases from the Farm sector to itself are not included in the model's inter-industry transactions.
Farm employment	Employment comprises estimates of the number of jobs, full-time plus part-time, by place of work. Full-time and part-time jobs are counted at equal weight. Employees, sole proprietors, and active partners are included, but unpaid family workers and volunteers are not included.
Output (for nonfarm sectors)	The amount of production, including all intermediate goods purchased as well as value added (compensation and profit). Available for 66 Private Non-Farm Industries. Can also be thought of as sales or supply. The Output policy variables change the Output in the model. There are several options to choose from depending on what type of demand is being met with the new output. The Industry Sales (Exogenous Production) without Employment, Investment, and Compensation option should be used to override the model's default responses to production changes. For Retail and Wholesale sectors, be sure to enter the mark-up portion of sales only (receipts less cost of goods sold). For Transportation sectors, be sure to enter the transportation cost portion only (receipts). Do not include the total value of the goods being transported. For the Food services and drinking places sector, be sure to enter the total sales (receipts). Also, do not simultaneously use both sales and employment policy variables, as this will be double counting. If you are also entering construction and/or equipment associated with these sales, be sure to include the Nullify Investment Induced by Industry Sales policy variable and add the prior investment to nonresidential capital stock (if for a structure).
Proprietor income	Current-production income of sole proprietorships, partnerships, and tax-exempt cooperatives. Excludes dividends, monetary interest received by nonfinancial business, and rental income received by people not primarily engaged in the real estate business. The Proprietors' Income policy variable changes the level of Proprietors' Income in the specified industry. Available for 66 Private Non-Farm Industries or Farms.
Detailed investment	Consists of purchases of equipment and intellectual property products by private businesses and by nonprofit institutions. The Detailed Investment policy variables convert the amount entered into changes in Industry Demand using the technical coefficients from the Input/Output Matrix. This detailed variable uses the USDOC-BEA Benchmark Input-Output Accounts to capture the difference in technical coefficients between the specific equipment or intellectual property product category and the aggregate category in PI+. The investment category Agricultural machinery was used.
Capital stock	The amount of residential capital (housing structures) or nonresidential capital (non-housing structures) in the region accumulated over time net of depreciation. Decreases in capital stock stimulate expansion of output by businesses, leading to growth in employment, wages, and other economic indicators. The amount of residential or nonresidential investment spending entered will automatically be added to Actual Capital Stock. Actual Capital Stock should only be entered for one year to avoid changing the stock cumulatively year after year.
Real estate price	The Real Estate Prices policy variable can be used to change housing and land prices within a region by the proportion or percentage entered. The Residential (Housing) housing price changes Relative Housing Price which affects migration. The Nonresidential (Land) price changes the Relative Nonresidential Land Price which affects Capital Costs. Available for Residential (Housing) and Nonresidential (Land).

Source: Regional Economic Models, Inc.

Agricultural Scenario Forecasts for Miami-Dade County

The results of agricultural scenario forecasts for the entire Miami-Dade County economy are summarized in this section. The model provided forecasts for 2021-2050, but only results for 2023-2050 are presented here. Note that the results represent changes from the REMI model baseline forecast values, rather than absolute values, and are stated in constant dollar terms. Changes in County population, employment and GDP are summarized in Table 19.7 and charted graphically for population, employment, GDP, and personal income in Figures 19.11-19.14. The changes are reported for the forecast years 2030, 2040, and 2050 and cumulatively for the 2023-2050 period for monetary variables of output, personal income, and value added or GDP.

The scenarios for continued growth of farm output, agritourism/local food development, and agricultural technology adoption had positive effects on the County economy, while all other scenarios had negative effects. The scenario for continued growth of farm output increased population by 1,650 people, increased employment by 1,440 jobs in 2050, and increased GDP by $170 million in 2050 or $3.44 billion cumulatively during 2023-2050.

The scenario for agritourism/local food development increased population by 1,660 people in 2040, increased employment by 1,100 jobs in 2050, and increased GDP by $116 million in 2050 or $3.02 billion cumulatively during 2023-2050.

The scenario for agricultural technology adoption increased employment by 1,250 jobs in 2050, and increased GDP by $150 million in 2050 or $3.09 billion cumulatively during 2023-2050.

The “best case” scenario, combining both growth of farm output and agritourism/local food development, increased population by 3,130 people, increased employment by 2,540 jobs in 2050, and increased GDP by $286 million in 2050 or $6.45 billion cumulatively during 2023-2050.

The “worst case” scenario, representing a 75 percent reduction in farm output, decreased population by 20,610 people, decreased employment by 17,900 jobs in 2050, and decreased GDP by $2.10 billion in 2050 or $42.66 billion cumulatively during 2023-2050.

The scenario for a 5 percent increase in the price of land also had very severe negative consequences for the County due to its effect on all economic sectors, with population reduced by over 13,000 people, loss of over 8,000 jobs, and GDP decreased by $2.05 billion in 2050 or $46.11 billion cumulatively during 2023-2050.

The scenario for extreme climate change and sea level rise had significant negative consequences, including population losses of over 5,000, nearly 6,000 jobs lost by 2050, and $707 million in GDP lost in 2050 or $6.12 billion cumulatively during the forecast period.

The scenario for increased foreign import competition resulted in population loss of 1,600, loss of 1,410 jobs, and loss of $170 million in GDP in 2050 or $3.46 billion cumulatively during 2023-2050.

The scenarios for agricultural land loss to the Urban Expansion Area, Category 5 hurricanes (2 events), and mid-range climate change/sea level rise, had moderate negative impacts during the forecast period, including decreased cumulative GDP of $2.75 to $3.22 billion cumulatively.

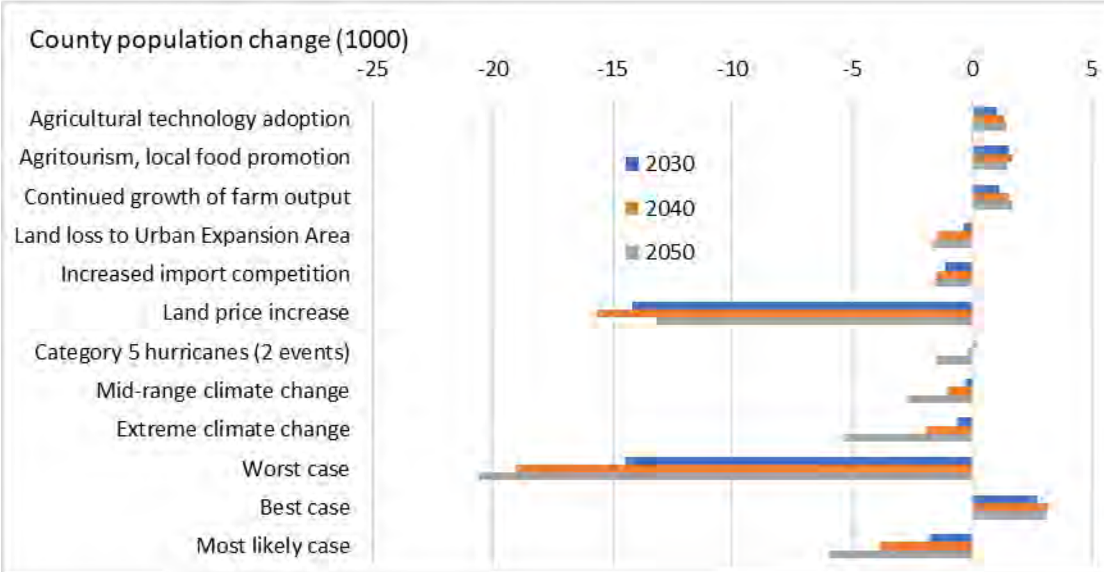
The "most likely" scenario, representing a combination of three negative scenarios described above, resulted in a population loss of 5,930 in 2050, employment loss of 5,790 jobs in 2050, and GDP loss of $690 million in 2050 or $9.27 billion cumulatively.

Table 19.7. Summary of changes in County population, employment and GDP under agricultural scenarios in Miami-Dade County, 2050

Scenario	Population (1,000)	Employment (1,000 jobs)	Gross Domestic Product (Million $)	
	2050	2050	2050	Cum. 2023-2050
Agricultural technology adoption	1.44	1.25	149.84	3,087.91
Agritourism, local food promotion	1.47	1.10	115.57	3,016.08
Increased growth of farm output	1.65	1.44	170.03	3,438.15
Agricultural land loss to Urban Expansion Area	-1.65	-1.41	-166.66	-2,747.80
Increased foreign import competition	-1.60	-1.41	-170.18	-3,456.25
Increased land price	-13.17	-8.37	-2,049.78	-46,106.42
Category 5 hurricane, 2 events	-1.47	0.02	-64.30	-3,224.77
Mid-range climate change/sea level rise	-2.68	-2.97	-353.50	-3,063.05
Extreme climate change/sea level rise	-5.35	-5.94	-706.56	-6,123.45
Worst case, 75% reduction in farm output	-20.61	-17.90	-2,104.62	-42,658.09
Best case: increased farm growth, and agritourism/local food development	3.13	2.54	285.59	6,454.24
Most likely case: Increased import competition, Land loss to Urban Expansion Area, and Mid-range climate change	-5.93	-5.79	-690.34	-9,267.10

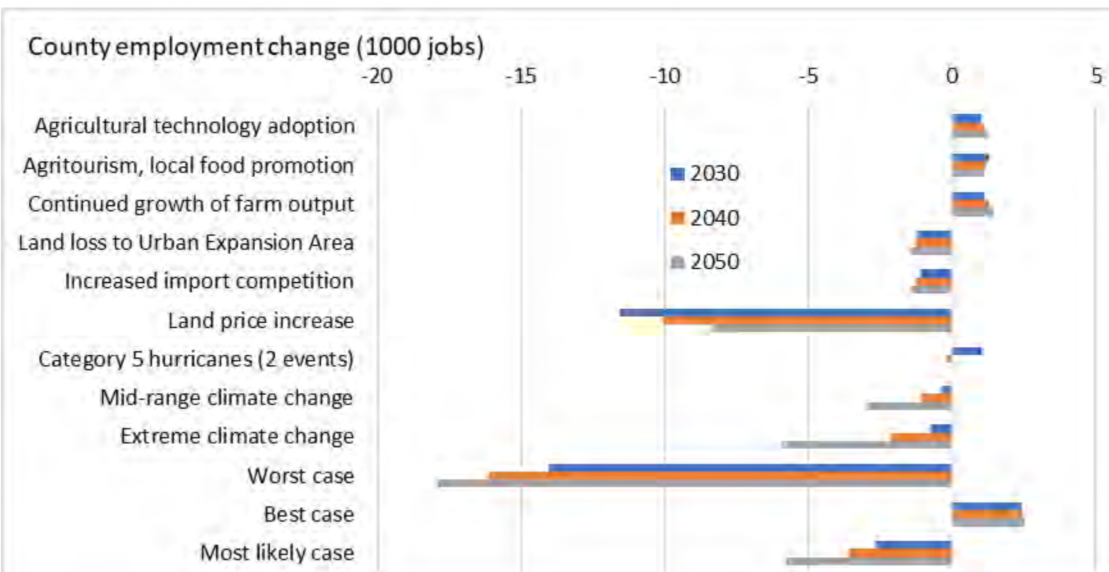
Units in millions of fixed local 2023 dollars, and thousands people, jobs or cumulative job-years.
Source: Regional Economic Models, Inc. and Miami-Dade County Dept. Regulatory and Economic Resources.

Figure 19.11. Forecast population change for Miami-Dade County under agricultural scenarios by decade.



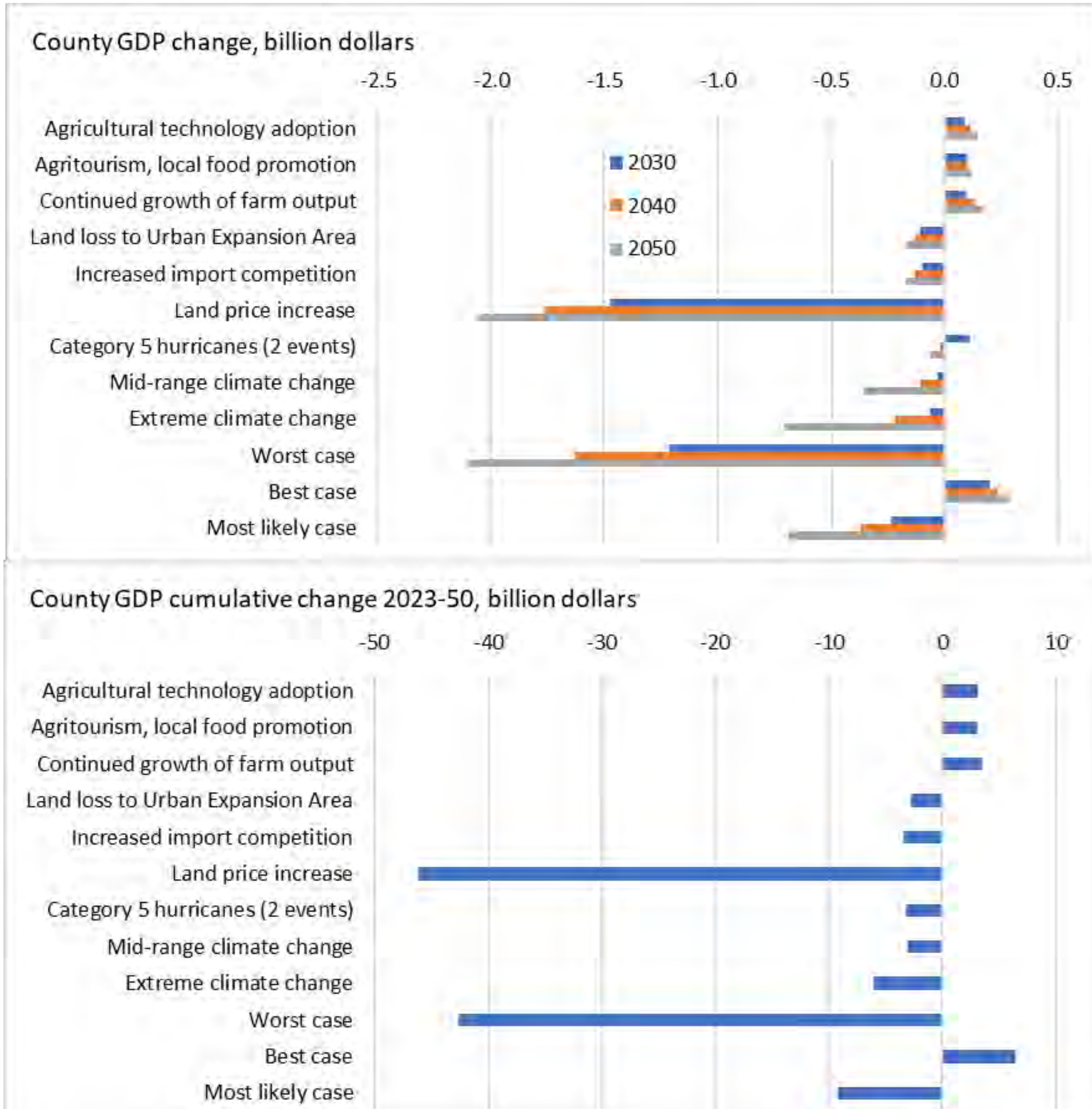
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.12. Forecast employment change for Miami-Dade County under agricultural scenarios by decade.



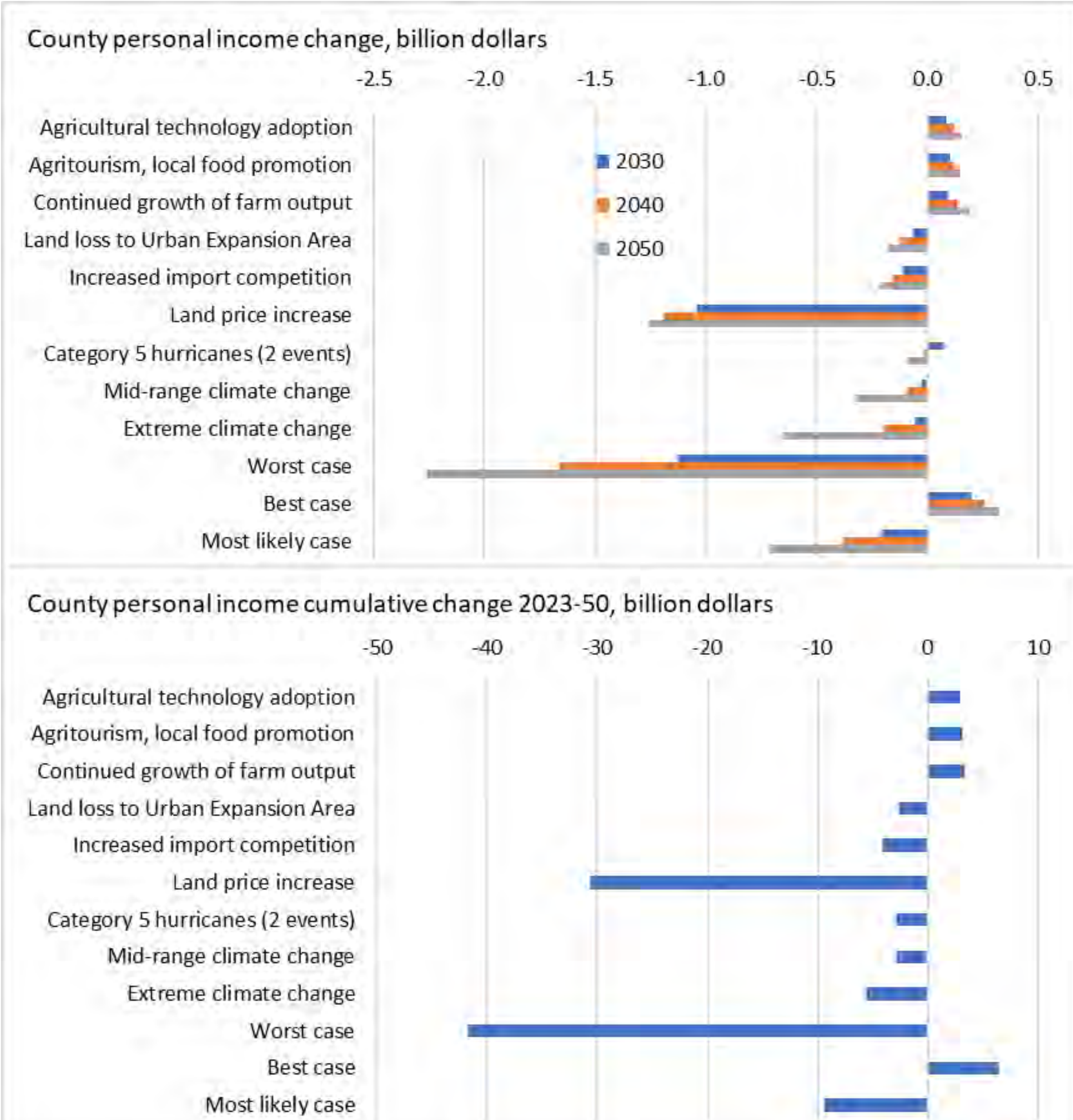
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.13. Forecast GDP change for Miami-Dade County under agricultural scenarios, by decade and cumulative, 2023-2050.



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.14. Forecast personal income change for Miami-Dade County under agricultural scenarios, by decade and cumulative, 2023-2050.



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

<u>Changes in activity for the agricultural sectors</u> (farms, forestry, logging, fisheries, agricultural support services) under the agricultural scenarios are summarized in Table 19.8 and charted in Figures 19.15-19.18. In general, the impacts on the agricultural sectors were less than for the County economy as a whole, reflecting only the direct effects and excluding the indirect multiplier effects in the REMI model.

Under the best-case scenario representing continued growth of farm output and agritourism/local food development, agricultural employment in the agricultural sectors increased 830 jobs in 2050 or 22,970 job-years cumulatively during 2023-2050, agricultural output increased $200 million in 2050 or $4.35 billion cumulatively, and agricultural value added (GDP) increased $73 million in 2050 or $1.60 billion cumulatively.

Under the worst case scenario, agricultural employment decreased 9,110 jobs in 2050 or 239,100 job-years cumulatively during 2023-2050, output decreased $2.18 billion in 2050 or $45.45 billion during 2023-2050, and value added (GDP) decreased $794 million in 2050 or $16.67 billion during cumulatively.

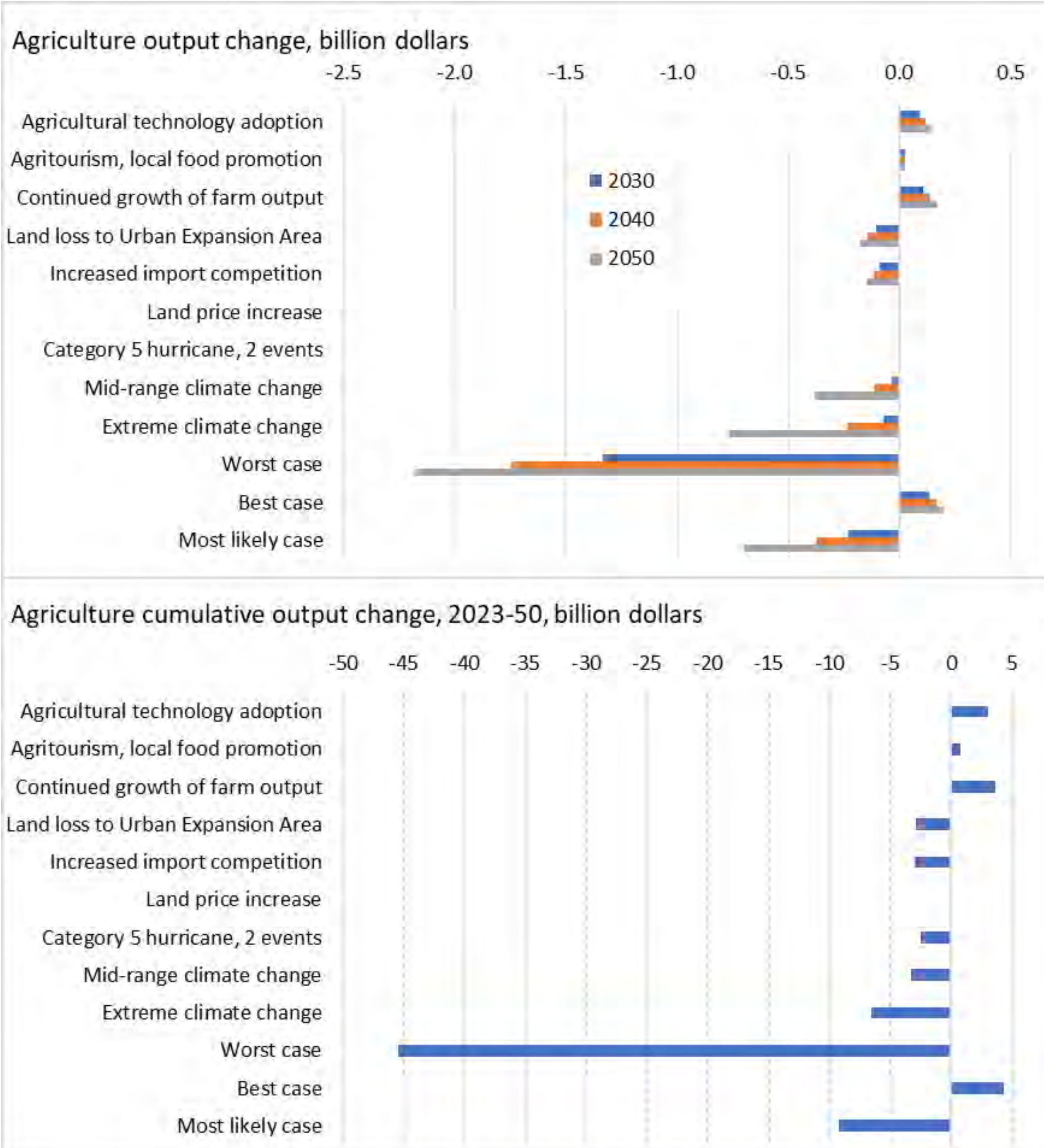
The most likely scenario estimated agricultural employment loss of 2,930 jobs in 2050 or 46,290 job-years cumulatively, and value added/GDP loss of $255 million in 2050 or $3.40 billion cumulatively. The value added change for agricultural industries in Table 8 is comparable to the GDP change in the County economy (Table 19.7). Agricultural sector output under the most likely scenario combined with the medium, high, and low population growth forecasts would increase during 2021-2050 by 45, 83, and 7 percent, respectively, as shown in Figure 19.18.

Table 19.8. Summary of changes in agricultural industries under agricultural scenarios in Miami-Dade County, 2050 and cumulatively 2023-2050.

Scenario	Employment (1,000 jobs)	Output (M$)		Value-Added (M$)	
	2050	2050	Cum. 2023-2050	2050	Cum. 2023-2050
Agricultural technology adoption	0.61	145.47	3,030.10	52.96	1,111.00
Agritourism, local food promotion	0.11	25.53	715.52	9.30	262.32
Increased growth of farm output	0.73	174.56	3,636.10	63.55	1,333.19
Agricultural land loss to Urban Expansion Area	-0.73	-174.56	-2,937.68	-63.55	-1,080.89
Increased foreign import competition	-0.61	-145.47	-3,030.17	-52.96	-1,111.06
Increased land price	-0.01	-0.30	-6.29	-0.22	-4.70
Category 5 hurricane, 2 events	0.01	0.09	-2,493.60	0.07	-906.14
Mid-range climate change/sea level rise	-1.60	-381.49	-3,296.34	-138.91	-1,208.41
Extreme climate change/sea level rise	-3.19	-762.98	-6,592.71	-277.83	-2,416.85
Worst case: 75% reduction in farm output	-9.11	-2,182.08	-45,453.40	-794.42	-16,666.79
Best case: increased farm growth and agritourism/local food development	0.83	200.09	4,351.62	72.84	1,595.51
Most likely case: Increased import competition, Land loss to Urban Expansion Area, Mid-range climate change	-2.93	-701.52	-9,264.18	-255.42	-3,400.36

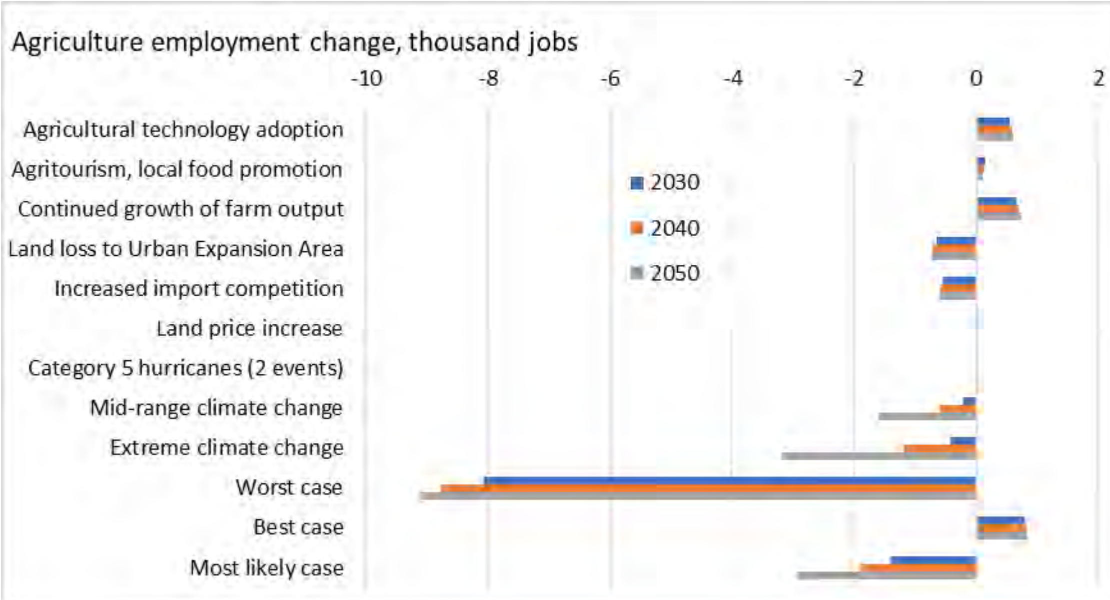
Units in millions of fixed local 2023 dollars, thousands jobs or cumulative job-years.
Results for all agriculture related industries (NAICS 111, 112, 113, 114, 115).
Source: Regional Economic Models, Inc. and Miami-Dade County Dept. Regulatory and Economic Resources.

Figure 19.15. Forecast farm output change for agricultural scenarios in Miami-Dade County, by decade and cumulatively 2023-2050.



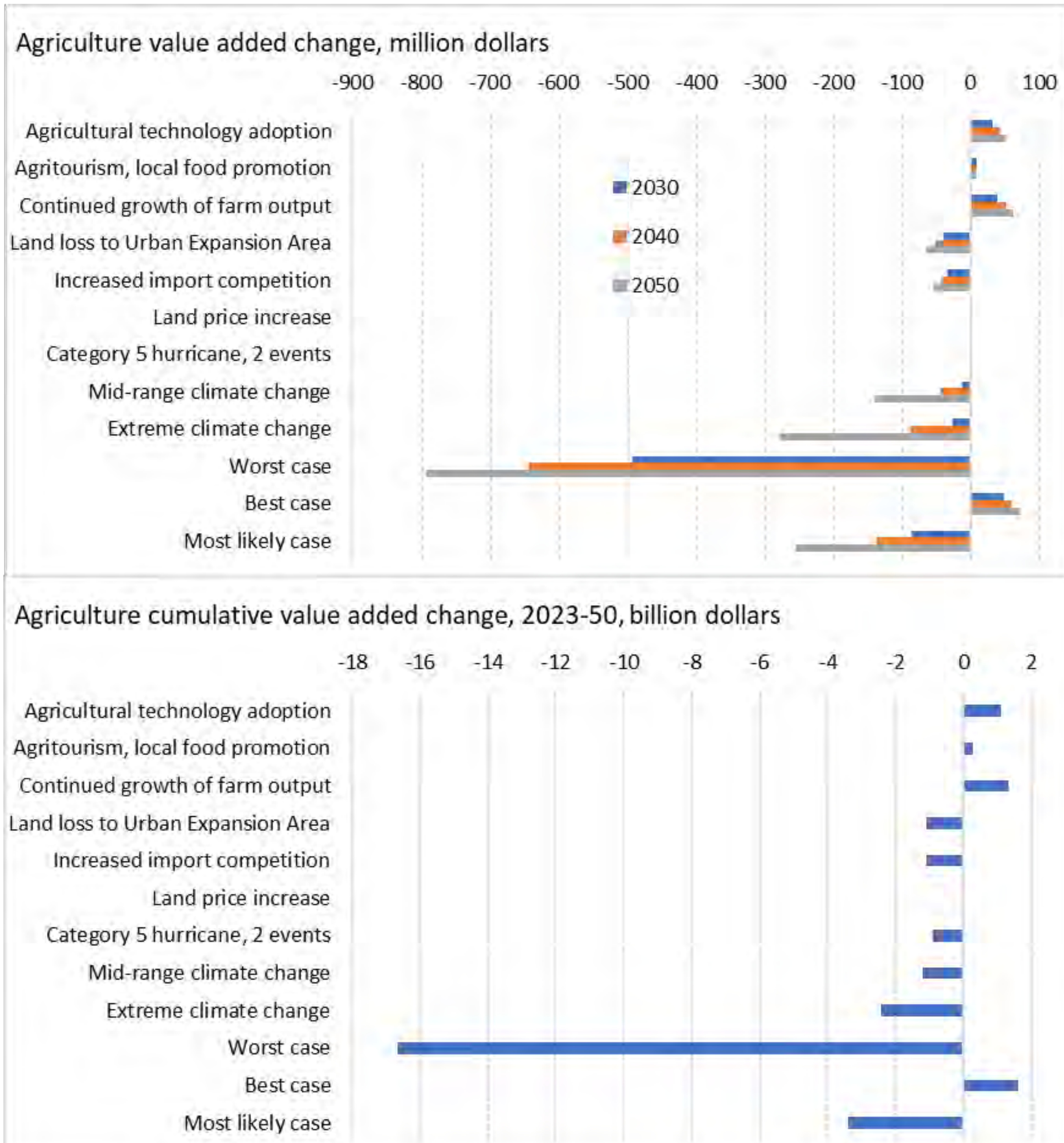
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.16. Forecast agricultural employment change for agricultural scenarios in Miami-Dade County, by decade.



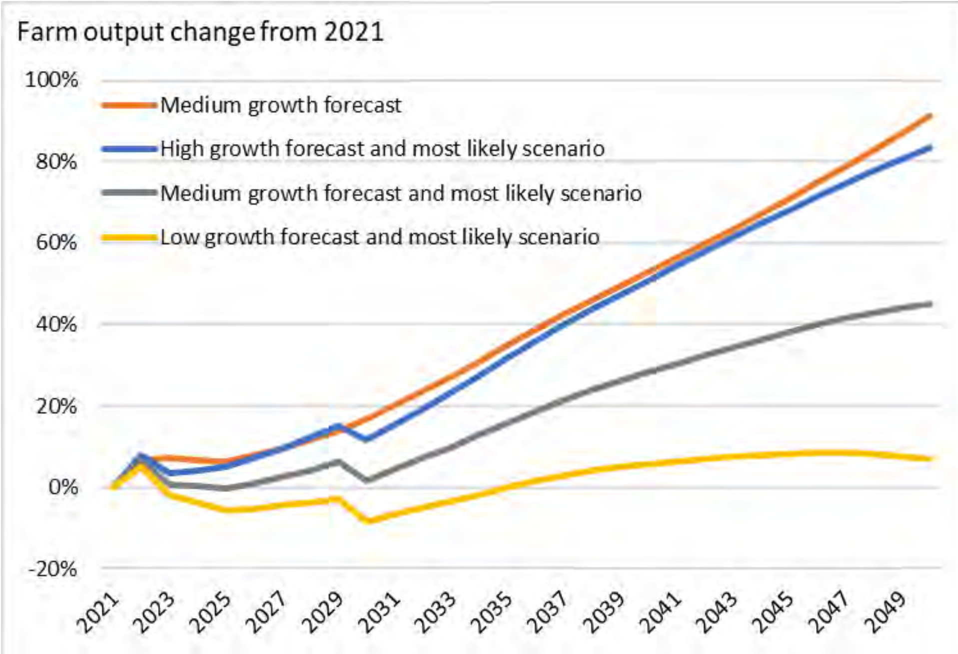
Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.17. Forecast agricultural value added (GDP) change for agricultural scenarios in Miami-Dade County, by decade and cumulatively 2023-2050.



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Figure 19.18. Farm output change for most likely agricultural scenario with medium, high, and low population growth forecasts for Miami-Dade County, 2021-2050 (medium growth forecast for comparison)



Source: Regional Economic Models, Inc. and Miami-Dade County Department of Regulatory and Economic Resources.

Conclusions

This assessment considered various agricultural scenarios for Miami-Dade County, analyzed in a dynamic regional economic model (REMI) that provided forecasts from present (2023) to the year 2050, based on historic economic data. The baseline model forecast, based on projected population growth of 570,000 people or 21.0 percent increase from 2021, indicates continued very strong economic growth in the County, with GDP forecast to increase 88 percent or 3.0 percent per year, and employment forecast to grow 29 percent or +1.0 percent annually over the 28-year forecast period. The baseline forecast for the farm sector indicates slightly higher growth than the overall County economy for output (91%) and value added/GDP (97%), but lower growth for employment (10%).

Agricultural scenarios were developed for the analysis to simulate various factors representing key opportunities and threats/risks facing the industry, to indicate potential outcomes for land use planning. Three of the scenarios are considered positive for the agricultural industry and seven scenarios are negative. Considered together, these scenarios indicate a very wide range of possible future trajectories for the agriculture industry in Miami-Dade County in the next 28 years. It was not possible to implement some agricultural scenarios contemplated because of limitations of the REMI model for the farm sector, as noted previously.

The best-case scenario assumed continued growth of the production agriculture industry together with development of agritourism and local food services. The upside potential of this case includes significant growth in population, over 2,500 new jobs, and $286 million in GDP added in 2050. The scenario for investment in agricultural technology also showed major benefits for the industry and the County economy.

Among negative scenarios, the worst-case scenario for a 75 percent reduction in agricultural output due to a combination of stressors could have dire consequences for the County, including population loss of nearly a half-million people, annual employment loss of nearly 18,000 jobs, and annual GDP loss of $2.10 billion in 2050. The worst-case scenario is considered extremely unlikely, although it reflects the level of decline seen over the last 20 years for agriculture in other major metropolitan counties in the U.S. such as Cook County (Chicago), and Los Angeles County. The scenario for increased land prices would also severely impact the County economy, resulting in over 8,000 jobs lost in 2050, although this scenario is not confined to the agricultural sector. The scenario for extreme climate change would result in loss of nearly 6,000 agricultural jobs in 2050, while the more likely scenario of mid-range climate change would result in about half that number of agricultural jobs lost. Of course, climate change could also cause large negative impacts in other parts of the County economy. Major hurricanes in the County would have intense negative impacts due to loss of production for several years, but lead to new investment and rebuilding that partly offsets the agricultural production loss (West and Lenze, 1994).

Increased foreign import competition is considered highly likely, and would lead to significant losses, particularly in the fruit and vegetable industries, although these losses could be offset by increased farmland area available for high value nursery/greenhouse crops. Loss of agricultural land for the Urban Expansion Area is expected to reduce agricultural production starting in 2030 and would result in the loss of over 1,300 jobs that year; however, this would be partly offset by new urban development in those areas, and this caveat applies to the other negative scenarios as well. Although the climate change/sea level rise scenario projections are very uncertain, it is reasonable to assume that there will be impacts in Miami-Dade County. These three latter scenarios combined together represent a “most likely” scenario, with an estimated loss of 2,930 jobs in the County in 2050 and loss of $9.27 billion in GDP cumulatively during 2023-2050.

Agricultural Land Projections to 2030, 2040, and 2050

Defining Viability of Agriculture

The interlocal agreement between the University of Florida-IFAS and Miami-Dade County Board of County Commissioners (Resolution R6907) requires the contractor to identify the amount of agricultural land needed for a viable agricultural industry in Miami-Dade County in the future years of 2030, 2040, and 2050. The agreement emphasizes that the County's Comprehensive Development Master Plan (CDMP) "…has long supported agriculture as a viable economic use of suitable lands." CDMP Policy LU-1R states that the County "…shall take steps to reserve the amount of land necessary to maintain an economically viable agricultural industry…and…determine the amount of land necessary to maintain an economically viable agricultural industry to inform implementation of the aforementioned CDMP policies…"

Defining the term "viable" is necessary to understand the practical meaning of this policy, and this section of the project report attempts to do so. The task requires more than just a dictionary definition, because it is complex, with considerations including the structure of the County economy, the make-up of the agricultural sector, linkages between agriculture and other sectors in the local economy, industry trends, and local, state, and federal government policies affecting the industry. Therefore, the definition of viability may differ across states, counties and communities. According to one source, "measuring agriculture viability is further complicated by yearly variations and external forces, including environmental and biological ones (e.g., droughts, floods, pest pressures, etc.). . . many factors that contribute to agricultural viability are beyond local control, particularly climate and global events" (Christensen and Limbach, 2019).

There are at least three primary characteristics of a viable and sustainable industry: profitability, resiliency, and capacity, which are discussed as follows.

<u>Profitability</u>. Profitability is essential to the long-term sustainability of any industry. Seeking profits is the underlying motivation for private business. Without profitability firms and industries will eventually decline or disappear. Viable firms (farms) must operate efficiently, market their products and services effectively, cover operating expenses and debt payments, maintain facilities and equipment, and earn a positive return on investment over the long-term. Different businesses may have dramatically different levels of profitability, depending upon the level of domestic or international competition, region, capital risk, entrepreneurship, and level of development and maturity. Increasing production costs and costs for assets such as land may adversely affect profitability.

According to U.S. Department of Commerce, Bureau of Economic Analysis (USDOC-BEA) statistics on farm income and expenses, net farm income in Miami-Dade County averaged $217.88 million during the historic 52-year period of record for 1969-2021 (in constant dollar terms) and net operating margin (net income/total income) averaged 30.4 percent. Net farm income and net margin were highly variable year-to-year; however, analysis indicated no discernable trend over time. According to USDA-NASS Census of Agriculture information on value of farm assets in land, buildings, and equipment, together with net farm income, the calculated rate of return on assets for farms in Miami-Dade County declined from over 21 percent in 1997 to under 8 percent in 2017, although there was quite high variability across census periods. We conclude that agriculture in the County is still profitable, but may be becoming less so due to increasing production costs.

Resiliency. The concept of resiliency acknowledges that not every year is profitable in business, but to exist long-term requires profit in most years. Resiliency takes many forms. Farms must be adaptable to many events such as adverse weather or natural disasters, pests and diseases, and market disruptions. According to the Organization of Economic Cooperation and Development (OECD), "there is a need for the agricultural sector to become more resilient to production and market risks, as risk and uncertainties in agriculture are increasing…governments should provide an enabling environment for investments that strengthen resilience to risk by building farmers' capacities to absorb, adapt, and transform in response to weather, market, or other shocks." A public report noted "the best strategy for economic viability is flexibility to respond to future food and fiber abundance or shortfall because of the inability to predict accurately the future" (CAST, 1988). The report further stated that it is preferable to have more land available for production to cope with risk and uncertainty and to support viable farms and farming industry. In a show of resilience during the past 40 years, Miami-Dade County agricultural production has shifted from major crops toward specialty crops, due to changes in consumer demand, climate change, adverse weather events, pests, diseases, government policies, and trade agreements. All these stressors facing the industry will continue into the future, leading to adoption of new products and practices in the industry.

An important aspect of resiliency is economic diversity. A diversified economy is generally considered to be more resilient than an economy that is heavily dependent on few industries. One source noted "…a diversified economy provides a more stable environment for small businesses, which tend to be the most vulnerable in turbulent times, to grow and thrive…a healthy mix of businesses of different types, sizes, and industry sectors generates a sustainable dynamic…diversification is one of the most effective ways to increase long-term economic resilience" (Smart Growth America). Miami-Dade County has a diversified economy and a highly diversified agricultural sector, producing at least 80 different specific agricultural commodities, whereas many other regions may have only a few commodities.

A feature of economic resiliency is the existence of a large number of firms, ensuring that failure of any dominant individual firm does not jeopardize the entire industry. Agriculture is comprised of many individual firms or farms that collectively form the industry. Miami-Dade County had 2,752 farms in 2017, with about 43,000 acres (55%) owned and 35,600 acres rented (USDA-NASS Census of Agriculture). Farms greater than 100 acres in size accounted for about 56,000 acres, or 71 percent of the land used in agriculture; however, about 95 percent of farms were less than 100 acres. The County has many competitive firms in the agricultural industry, particularly in the nursery/floriculture sector, which has become the leading sector over the past 20 years.

Resiliency is also enhanced through diverse international and interregional trade, which lessens the dependence upon local economic conditions. In general, a high level of trade through imports and exports of goods and services is favorable to economic competitiveness, connectedness, and general welfare. The agricultural sector in Miami-Dade County exports a higher share of commodities produced (89%) than all other sectors of the economy (averaging 34%, IMPLAN). A high level of goods and services sold outside the County brings new dollars into the local area, which generates additional multiplier effects from re-spending. The large port and international airport in the County enable shipment of agricultural products throughout the nation and world. On the other hand, only about 11 percent of the output produced by the agricultural sector is purchased locally and available for additional value-added processing into consumer products or associated services. Investments in local food systems may have the potential to increase local sales, increase agricultural demand, and retain more consumer spending in the local economy.

A growing, stable, or non-declining share of local economic activity is an attribute of a resilient, sustainable and viable industry. During the period of 2001 to 2021, GDP in the Miami-Dade County economy grew by 55 percent, while the agriculture/forestry/fisheries sector in the County grew 9 percent, in constant dollar terms (IMPLAN). During this same period, the County economy had a 40 percent increase in number of full-time and part-time jobs; however, employment in the agricultural sector was steady or declined slightly.

Capacity. A third component of agricultural viability is capacity. This implies unfettered access to the basic factors of production: land, labor, and capital. The long-run availability of agricultural land in Miami Dade County has declined, as documented in the Assessment of the Current Situation chapter of this report. Farmland in the County decreased about 7.7 percent between 1997 and 2017, representing an annual -0.4 percent reduction. Agricultural land loss in Miami-Dade County was the smallest among the 10 largest populated counties in the U.S., probably due to the existence of the Urban Development Boundary to limit urban sprawl and maintain open space for agriculture. Land available for agriculture impacts viability because suitable space for agricultural production is generally finite, except for limited enclosed production systems such as vertical growing and rooftop farming. Once farmland is converted to other uses, it rarely returns to agricultural production. Different types of crops require different types of production space. For example, nursery production takes place on a smaller footprint than fruit orchards or vegetables/row crops.

Miami-Dade County has “unique” agricultural lands, defined as land other than prime farmland that is used for production of high-value crops such as fruits and vegetables (USDA-NRCS). Agricultural production in Miami-Dade County is certainly unique by virtue of its geographic location, climate, soils, and seasonal markets. These lands are important not only to the state, but to the U.S. and world. Nursery/floriculture sales in Miami-Dade County ranked first in the U.S., with total agricultural sales in the top 1.5 percent of all 3,000+ U.S. counties and second largest among Florida counties in 2017 (USDA-NASS Census of Agriculture).

One of the largest concerns for agriculture in Miami Dade County is increasing land prices. According to County Property Appraiser data for 2021-2022, the average sales price for agricultural land was over $80,000 per acre, and the average sales price for non-agricultural property was $3.97 million per acre (see the report section on *Urban Development*). High land prices are daunting to farmers wishing to expand their operations or to new farmers wishing to purchase land. For older farmers contemplating retirement and not having family interested in continuing the operation, high land prices are an incentive to sell out. High land values will continue in the future as a capacity issue in Miami Dade County.

Ready access to inputs for production is an important part of industry capacity for viability. All businesses must be able to procure needed materials and services, preferably from local sources, such that they can be obtained quickly without the risk of supply chain disruptions. When industries decline, there may be a loss of supplier industries that no longer have the economy of scale to sustain business. Farms purchase inputs such as fertilizers, chemicals, nursery containers, ground cloth, irrigation parts, etc., and most farm inputs are currently available from local sources in Miami-Dade County. Continued access to inputs in the County is dependent on the continuation of overall agricultural activity above a critical threshold.

Finally, access to new technology has the potential to increase agricultural production intensity and reduce the land required to maintain production levels. In Miami-Dade County, specialty crops such as nursery plants, fruits, and vegetables are heavily dependent on farm labor, with most tasks done by workers rather than machines. The cosmetic appearance of these products matters for consumer choice and price in the marketplace, requiring the type of careful product handling that is less likely to be available from machines. Labor costs are generally increasing for all industries, including wages, taxes, insurance, and healthcare. While technology can partly substitute for labor, it does not completely eliminate the need for workers, and may require more specialized skills and training for employees. Like many other industries, agriculture is capital intensive. Agricultural equipment is expensive and will continue to increase in cost in the future, and large amounts of financial capital will be needed to adopt increasingly sophisticated agricultural technology.

Information Sources for Economic and Land Use Projections

This report makes projections of future agricultural land use in Miami-Dade County in 2030, 2040, and 2050 as part of this study, in support of long-term land use planning in the County. Information on historic trends in economic data were compiled from various sources to forecast agricultural land use. A primary data source for this assessment is the Census of Agriculture by the U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). Data on farmland area, agricultural product sales, and value of assets in land, buildings and equipment were compiled for the historic period of record from 1959 to 2017. Data on farm income and expenses for 1969 to 2021 were compiled from the U.S. Department of Commerce, Bureau of

Economic Analysis, Regional Economic Information System (USDOC-BEA). In addition, a forecast of farm output for 2021 to 2050 by a general equilibrium economic model for the County by Regional Economic Models, Inc. (REMI) was also used, as described in the Scenario Analysis section of this project report.

The Census of Agriculture (USDA-NASS) is considered the most reliable information source available on the agricultural sector; however, all such survey-based data are subject to reporting, sampling, and estimation errors and statistical anomalies. A limitation of the USDA-NASS Census of Agriculture is that it is reported only every five years, with the latest data being for 2017, while more recent information for 2022 will not be available until 2024 or later. USDOC-BEA data on farm income and expenses is based on income tax returns and other administrative records and captures cash income from marketing and total income from all sources, providing a more comprehensive accounting of income, and is reported annually, providing more data points for analysis, so it is a preferred source for forecasting. The REMI model utilizes historic information from USDOC-BEA for forecasting local, state, and national economic activity.

Trends and relationships in these data were used to make projections of future land use. Projections using historic data are presumed to capture long-term trends in the mix of crops (nursery/floriculture, vegetables, fruits) and animal commodities, demand, market conditions, prevailing production practices, operating costs, profitability, labor, technology use, etc. Projected values for agricultural sales, income, employment, and assets were considered measures of the size of the agricultural industry, while projected per acre values for these variables were measures of land use intensity; taken together, these measures were used to calculate future agricultural land use. For example, farm sales divided by sales per acre equals acres of farmland.

Historic Trends in County Agriculture

Farmland in Miami-Dade County in 2017 totaled 78,543 acres, including 55,206 acres of cropland, 9,846 acres of pastureland, 2,141 acres of woodland, and 11,218 acres for other areas used for farm buildings, parking, and service areas (USDA-NASS, 2017). Note that the total area reported is net of multiple-uses, such as land that may be used seasonally for crops and pasture, to avoid double-counting. This acreage figure is considered the starting point for projections of future agricultural land use. This acreage is higher than the total agricultural land reported by the Miami-Dade County Property Appraiser in 2022 (62,088 acres) because some land that is actually being used for agricultural purposes may not have a County agricultural classification.

Among major crop groups in in the County in 2017, vegetables occupied 19,003 acres (38% of total cropland area), nursery/floriculture occupied 17,477 acres (35%), and fruit/orchards occupied 13,343 acres (27%). During the 21-year period of 1997-2017, nursery/floriculture land use increased dramatically (+128%), while vegetable production area decreased significantly (-45%), and fruit orchards decreased marginally (-2.2%). During this same period, overall agricultural land in the County decreased 7.7 percent, including decreased cropland (-19%) and woodland (-57%), but increased pastureland (+23%) and other non-specific land uses (+96%).

Historic information from the USDA-NASS Census of Agriculture for 1959 to 2017 is summarized in Table 20.1 for farmland area, cropland, agricultural product sales, crop sales, assets in land and buildings, machinery and equipment, average sales per acre, and assets per acre. Over this 59-year time span, farmland area in the County generally declined, except for a few periods, from over 128,000 acres in 1959 to 78,543 acres in 2017, representing a 39 percent decrease overall, or an annual average change of -0.67 percent (Figure 20.1). A very large decrease of nearly 38,000 acres of farmland occurred between 1964 and 1969, declining from 116,768 to 79,056 acres, but since 1969 farmland area remained more stable, fluctuating between 99,000 and 67,000 acres. Area used only for growing crops, excluding other agricultural land uses like pasture or forest, declined from over 80,000 acres in 1959 to around 55,000 acres in 2017, representing a change of -32.0 percent or -0.55 percent annually (Figure 20.1).

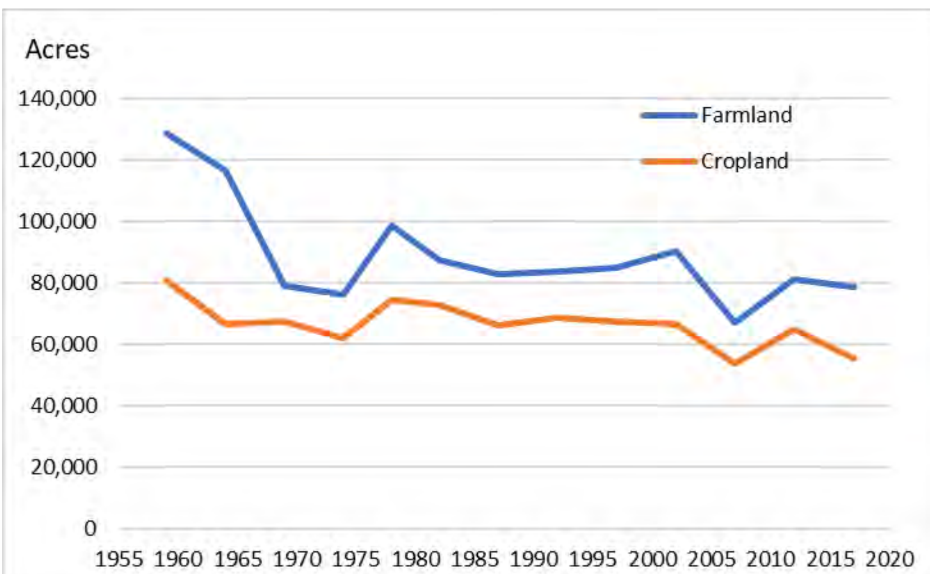
Monetary values for data from the USDA-NASS Census of Agriculture on sales and assets are expressed in constant 2017 dollars using the GDP Implicit Price Deflator (USDOC-BEA). Farm sales of agricultural products increased from around $269 million in 1969 to $828 million in 2017, or 4.4 percent annually, while crop sales increased 4.8 percent annually, in constant dollar terms (Table 20.1, Figure 20.2). Sales increased steadily during this period, except for a decline in 2012. The value of agricultural land and buildings increased from around $735 million in 1969 to over $2.941 billion in 2017, or an average annual rate of 6.3 percent (Table 20.1, Figure 20.3). Asset values declined from 1978 to 1997 but increased rapidly and continuously during 1997-2017. As an indication of trends in land use intensity, reflecting both declining land area and increasing sales, agricultural product sales per acre of farmland increased from $3,406 in 1969 to $10,666 in 2017, representing a 4.4 percent average annual change (Table 20.1, Figure 20.4). As further evidence of intensification of capital investment, the value of land and buildings per acre of farmland increased from $9,290 in 1969 to $37,450 in 2017, or 6.3 percent annually (Table 20.1, Figure 20.5).

Table 20.1. Historic farmland area, sales, and assets in Miami-Dade County, 1959-2017.

Year	Farm land (acres)	Crop land (acres)	Agric. sales ($1,000)	Crop sales ($1,000)	Value land & buildings ($1,000)	Value machinery, equipment ($1,000)	Sales per acre ($)	Crop sales per acre ($)	Value land and buildings per acre ($)
1959	128,550	80,736	NA	NA	NA	NA	NA	NA	NA
1964	116,768	66,808	NA	NA	NA	NA	NA	NA	NA
1969	79,056	67,507	269,279	252,178	734,399	NA	3,406	3,736	9,290
1974	76,318	62,096	348,880	251,752	1,111,489	NA	4,571	4,054	14,564
1978	98,574	74,506	366,958	341,313	1,611,032	NA	3,723	4,581	16,343
1982	87,420	72,784	394,193	379,631	1,502,014	NA	4,509	5,216	17,182
1987	83,061	66,313	473,501	460,416	1,051,614	122,977	5,701	6,943	12,661
1992	83,681	68,795	571,672	565,300	1,180,142	120,645	6,832	8,217	14,103
1997	85,093	67,550	603,197	592,120	999,456	122,497	7,089	8,766	11,745
2002	90,373	66,564	768,594	762,410	1,627,734	128,302	8,505	11,454	18,011
2007	67,050	53,816	768,886	786,878	2,156,061	131,675	11,467	14,622	32,156
2012	81,303	64,904	651,025	638,127	2,227,049	151,639	8,007	9,832	27,392
2017	78,543	55,206	837,734	827,873	2,941,409	142,108	10,666	14,996	37,450

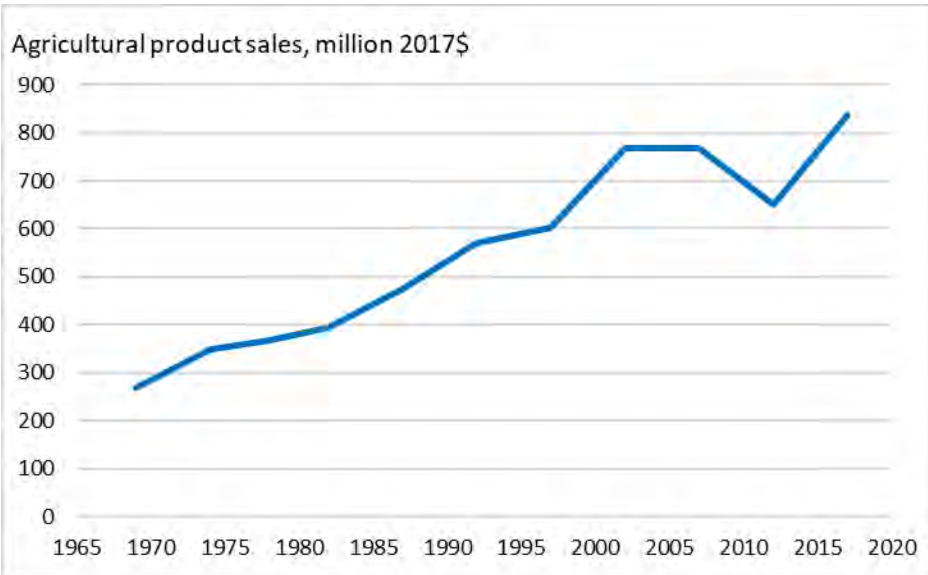
Values adjusted for inflation, expressed in constant 2017 dollars using U.S. GDP Implicit Price Deflator (USDOC-BEA). Some data for early years was not reported (NA). Source: USDA-NASS, Census of Agriculture.

Figure 20.1. Farmland and cropland area in Miami-Dade County, 1959-2017.



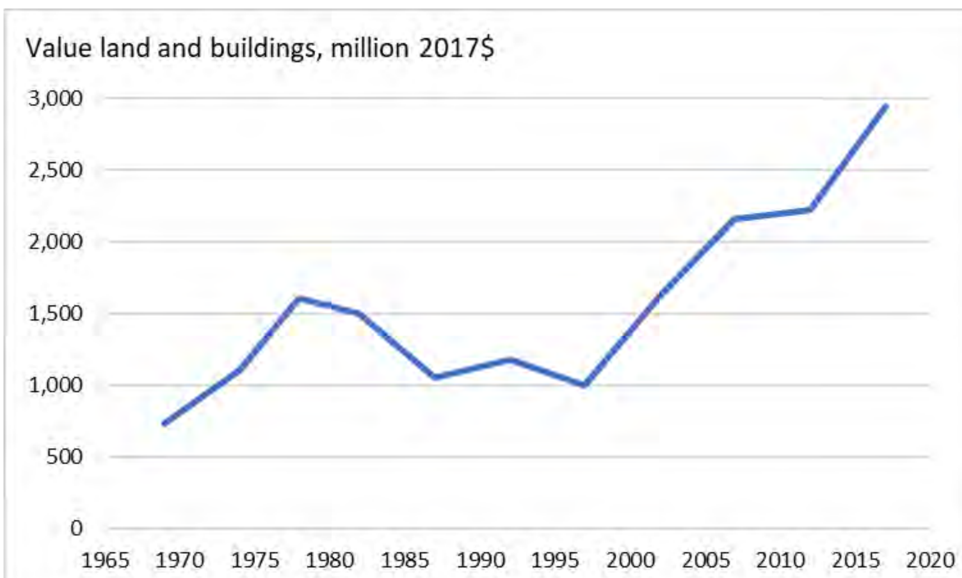
Source: USDA-NASS, Census of Agriculture.

Figure 20.2. Agricultural product sales in Miami-Dade County, 1969-2017.



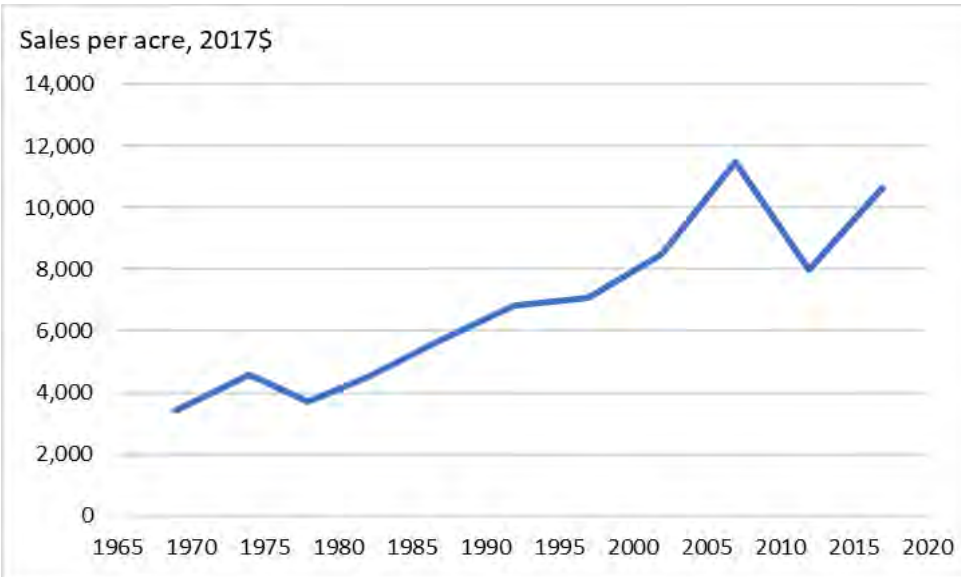
Source: USDA-NASS, Census of Agriculture, and author's calculations.
Values expressed in constant 2017 dollars using the U.S. GDP Implicit Price Deflator.

Figure 20.3. Value of agricultural land and buildings in Miami-Dade County, 1969-2017.



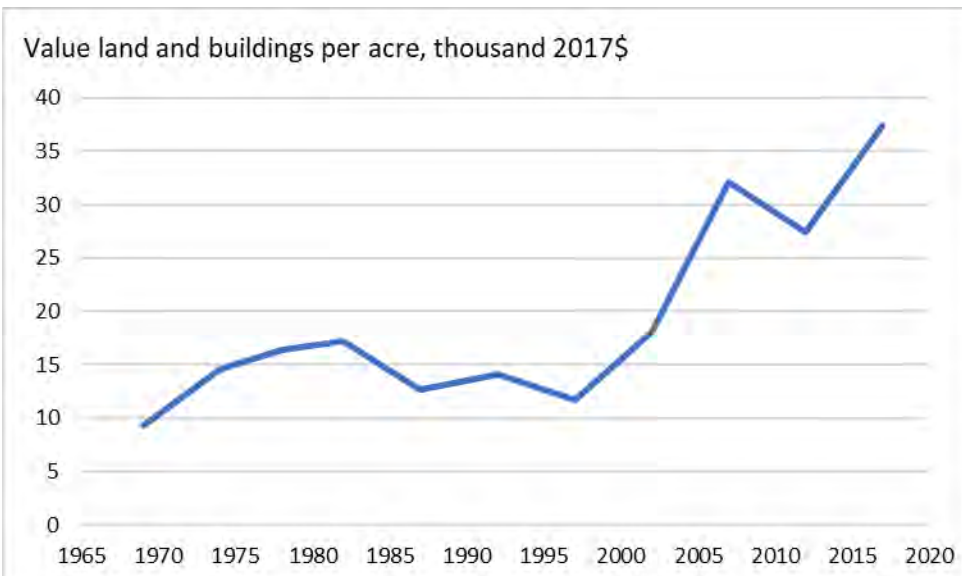
Source: USDA-NASS, Census of Agriculture and author's calculations.
Values expressed in constant 2017 dollars using the U.S. GDP Implicit Price Deflator.

Figure 20.4. Agricultural product sales per acre in Miami-Dade County, 1969-2017.



Source: USDA-NASS, Census of Agriculture data and author's calculations.
Values expressed in constant 2017 dollars using the U.S. GDP Implicit Price Deflator.

Figure 20.5. Value of agricultural land and buildings per acre in Miami-Dade County, 1969-2017.



Source: USDA-NASS Census of Agriculture data and author's calculations.
Values expressed in constant 2017 dollars using the GDP Implicit Price Deflator.

Another key information source for this study is data on farm income, expenses, and employment from the U.S. Department of Commerce, Bureau of Economic Analysis (USDOC-BEA). These annual data are available for the 52-year period from 1969 to 2021. The USDOC-BEA data for Miami-Dade County for years corresponding to the USDA-NASS Census of Agriculture are summarized in Table 20.2, where per acre values are calculated using USDA-NASS data on farmland acreage. USDOC-BEA annual income and employment data for 1969-2021 are charted in Figures 20.6 and 20.7. Cash receipts from marketing (USDOC-BEA) are equivalent to farm sales from USDA-NASS, while total income from all sources (USDOC-BEA) includes sales, plus inventory change, investments, and government payments. Production expenses (USDOC-BEA) include hired farm labor, seed, fertilizer/chemicals, petroleum products, feed, livestock, and all other expenses. Monetary values are adjusted for inflation to express in constant 2021 dollars using the GDP Implicit Price Deflator.

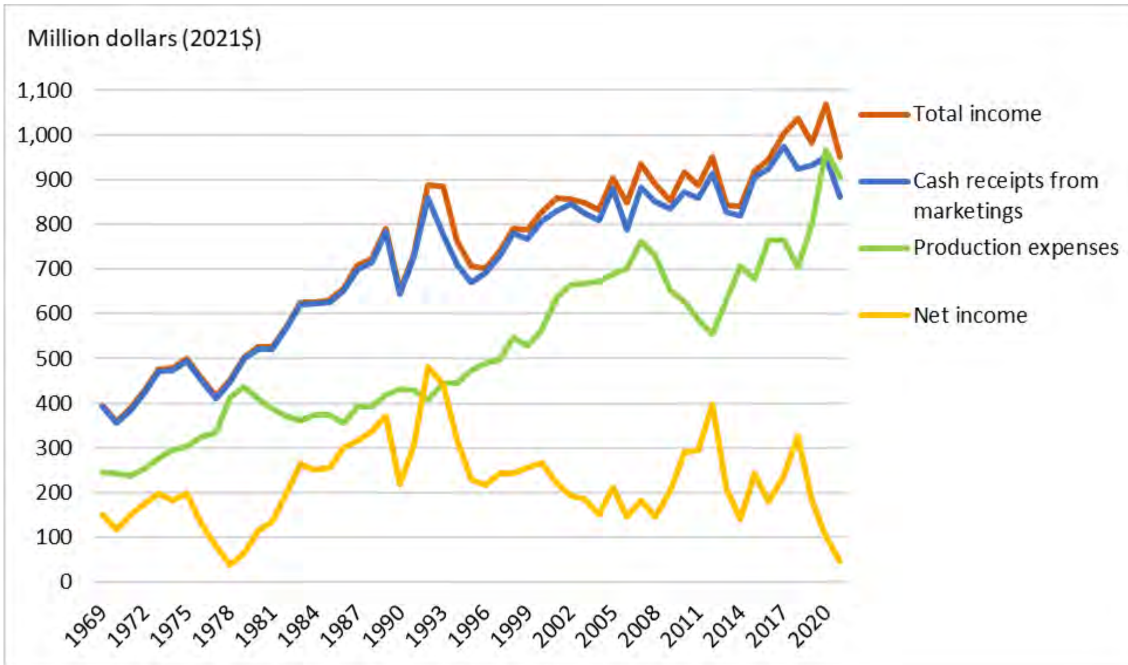
Total farm income in Miami-Dade County increased 2.4 times from $395 million in 1969 to $950 million in 2021, or an average of +2.7 percent annually (Figure 20.6). Production expenses increased dramatically in 2020-2021, possibly due to higher labor costs for increased use of H-2A visa workers to address domestic labor shortages, supply chain disruptions stemming from the COVID-19 pandemic, and additional costs associated with pandemic safety protocols. As a result of reduced revenues in 2021 and higher production costs in 2020-2021, net income was significantly reduced, reaching the lowest level since 1978. Net margin, a measure of profitability calculated as the ratio of net income to total income, historically averaged around 30 percent, but fell to 9.5 percent in 2020, and further dropped to 4.8 percent in 2021 (not shown in table or charts).

Table 20.2. Historic farm employment, cash receipts, total income, and production expense totals and values per acre, Miami-Dade County, 1969-2017.

Year	Employment (jobs)	Cash receipts (million$)	Total income (million$)	Production expense (million$)	Net income (million$)	Employment per acre (jobs)	Cash receipts per acre ($)	Total income per acre ($)	Net income per acre ($)	Production expense per acre ($)
1969	3,772	391.8	394.9	244.6	150.6	0.0477	4,956	4,995	1,904	3,094
1974	3,843	473.8	478.2	295.8	183.6	0.0504	6,208	6,266	2,406	3,876
1978	4,923	447.1	452.6	414.5	39.5	0.0499	4,536	4,591	401	4,205
1982	6,083	567.5	571.0	372.1	199.5	0.0696	6,492	6,532	2,283	4,256
1987	5,340	700.2	708.2	392.5	315.3	0.0643	8,430	8,527	3,796	4,726
1992	6,403	859.5	887.4	407.2	482.6	0.0765	10,271	10,605	5,767	4,866
1997	6,318	727.5	739.3	497.3	242.2	0.0742	8,549	8,688	2,847	5,844
2002	7,271	844.5	855.9	664.4	192.8	0.0805	9,345	9,470	2,134	7,352
2007	7,523	882.2	935.1	760.9	182.0	0.1122	13,157	13,947	2,715	11,348
2012	7,917	912.6	950.3	555.4	398.5	0.0974	11,225	11,688	4,901	6,831
2017	7,621	974.9	1,002.1	764.0	238.3	0.0970	12,412	12,758	3,034	9,727

Values adjusted for inflation, expressed in constant 2021 dollars using GDP Implicit Price Deflator (USDOC-BEA).
Data are only for USDA-NASS Census of Agriculture years to calculate per acre values.
Source: USDOC-BEA.

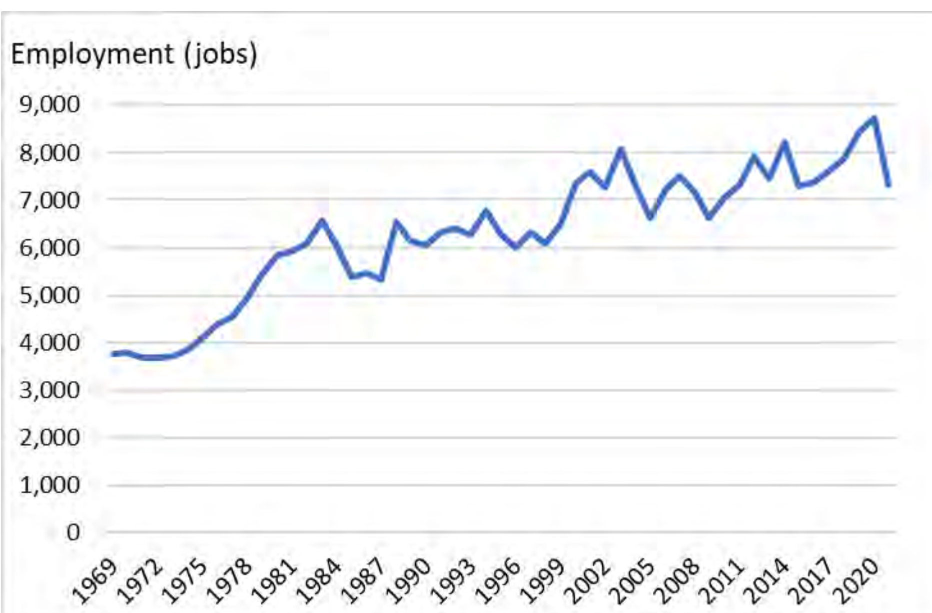
Figure 20.6. Farm income, production expenses, and net income in Miami-Dade County, 1969-2021.



Source: USDOC-BEA, Farm income and expenses (CAINC45 series), and author's calculations.
Values expressed in constant 2021 dollars using the GDP Implicit Price Deflator.

Farm employment in Miami-Dade County fluctuated considerably from year to year, but roughly doubled during the 1969-2021 period, from about 4,000 to 8,000 jobs, although it has grown more slowly since 2001, consistent with slowing job growth in many sectors of the U.S. economy due to increasing labor productivity (Figure 20. 7). Further discussion of trends in farm income, expenses, and employment is provided in the Assessment of the Current Situation section of this report.

Figure 20.7. Farm employment in Miami-Dade County, 1969-2021.



Source: USDOC-BEA, regional economic information system. Data for 1969-2000 were compiled under the Standard Industrial Classification System (SIC), while data for 2001-2021 were compiled under the North American Industry Classification System (NAICS).

Analysis of Historic Trends in County Agricultural Activity

The historic data on the farm sector in Miami-Dade County were statistically analyzed to make future projections of the size of the industry as a basis for estimating farmland demand.

The historic data were analyzed using the Excel chart trendline analysis tool to provide technical forecasts for the future out to year 2050. Regression models were fitted to the data with trendlines for linear, logarithmic, exponential, and power mathematical functions, which represent different assumptions about the underlying structure of the data. Linear models assume a constant rate of change over time, while logarithmic, exponential, and power functions assume an increasing or decreasing rate of change (i.e., an accelerating or decelerating trend). Regression models are represented by equations that describe the position of the curve and its slope or rate of change from one year to the next. For example, linear model equations take the form of $A + \beta X$, where A is a constant term representing the starting position in the first year, β indicates the slope of the line, and X represents the year in the time series.

Correlation coefficients (R^2 values) for the various regression models are an indication of the goodness-of-fit to the data, as summarized in Table 20.3. The models for farm sales and average sales per acre had very high correlations, ranging from 0.83 to 0.92. This means that 83 to 92 percent of variations from the forecast trend line were accounted for. Regression models for USDOC-BEA farm cash income data also had high correlations of 0.83 to 0.91. Models for value of land and buildings and value per acre had moderately high correlations of 0.64 to 0.73. In general, the correlations for the various regression models were comparable for each set of variables, and did not significantly differ; however, the exponential and power function models provided higher estimates of sales and asset values and values per acre than the linear and logarithmic regression models, due to the nature of the underlying mathematical functions.

Table 20.3. Summary of regression model correlation coefficients for agricultural data in Miami-Dade County.

Data (source)	Model correlation coefficients (R^2)			
	Linear	Logarithmic	Exponential	Power function
Farmland acres, 1959-2017 (NASS)	0.43	0.43	0.45	0.64
Farmland acres, 1969-2017 (NASS)	0.07	0.07	0.07	0.07
Farm sales (NASS)	0.91	0.91	0.87	0.87
Value land and buildings (NASS)	0.64	0.64	0.72	
Farm total income (BEA)	0.90	0.83		0.90
Farm sales (cash receipts) (BEA)	0.89	0.85		0.91
Farm net income (BEA)	0.02			
Farm employment (BEA)	0.83	0.83		0.87
Farm sales per acre (NASS)	0.85	0.85	0.83	0.83
Value land and buildings per acre (NASS)	0.65	0.65	0.73	
Farm sales per acre (BEA, NASS)	0.84			
Farm income per acre (BEA, NASS)	0.83			
Farm net income per acre (BEA, NASS)	0.19			
Farm employment per acre (BEA, NASS)	0.86			

Sources: USDOC-BEA farm cash receipts, farm income, net income, employment, reported annually, 1969-2021; USDA-NASS Census of Agriculture, farmland (acres), farm sales, value of land and buildings, reported every 5 years, 1969-2017; Excel software, chart trendline analysis feature.

Future Projections of County Agricultural Activity

Projections for farm sales, total income, net income, employment, and value of land and buildings in Miami-Dade County as measures of the size of the industry in future years 2030, 2040, and 2050 are summarized in Table 20.4. Projections were made using different models chosen based on inspection of fit of trend lines to historic data and investigator experience. Note that model selection is not based solely on the highest correlation coefficient.

Table 20.4. Summary of projected agricultural activity in Miami-Dade County, 2030, 2040, 2050.

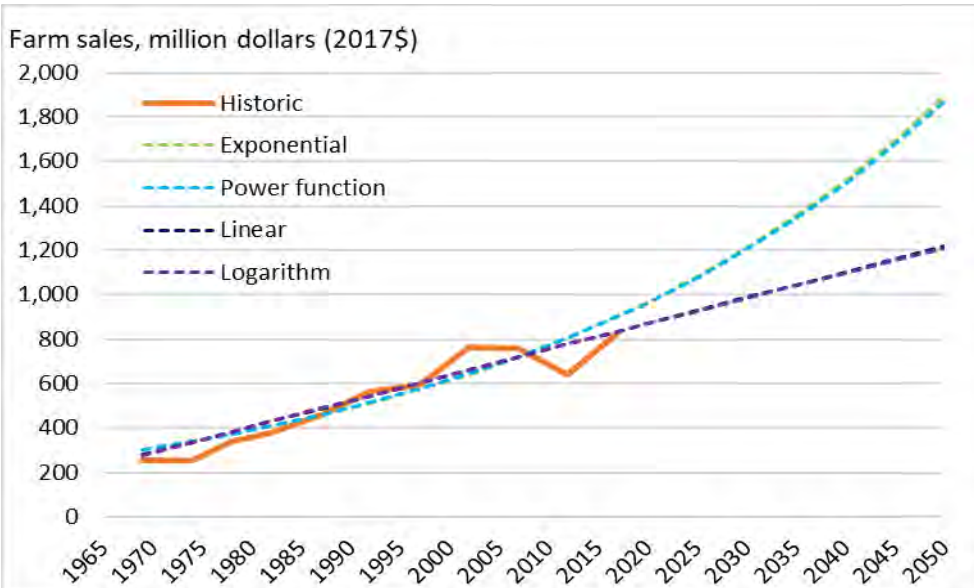
Projection, data source	Model form	2030	2040	2050
Farmland, acres, (NASS, 1959-2017)	Linear	63,937	58,029	52,122
	Logarithmic	64,067	58,282	52,525
	Exponential	67,809	63,828	60,080
	Power	67,960	64,051	60,384
Farmland, acres (NASS, 1969-2017)	Linear	77,608	76,230	74,853
	Logarithmic	77,658	76,315	74,978
	Exponential	76,940	75,655	74,391
	Power	77,425	76,166	74,933
Farm sales, million 2017$ (NASS)	Linear	986	1,102	1,218
	Logarithmic	983	1,096	1,209
	Exponential	1,206	1,511	1,893
	Power	1,202	1,499	1,868
Value farmland and buildings, million 2017$ (NASS)	Linear	2,799	3,130	3,460
	Logarithmic	2,788	3,111	3,433
	Exponential	3,094	3,791	4,645
Farm income, million 2021$ (BEA)	Linear	1,150	1,269	1,388
	Logarithmic	952	982	1,008
	Power	993	1,040	1,083
Farm sales (cash receipts), million 2021$ (BEA)	Linear	1,087	1,195	1,303
	Logarithmic	910	938	961
	Power	948	990	1,029
Farm employment, jobs (BEA)	Linear	9,097	9,898	10,699
	Power	8,069	8,375	8,651
Farm net income, million 2021$ (BEA)	Linear	246	254	262

BEA data are annually 1969-2021, USDA-NASS Census of Agriculture data are every 5 years 1969-2017.
Values in constant 2017 or 2021 dollars using the GDP Implicit Price Deflator.
Source: USDA-NASS Census of Agriculture data and author's calculations.

Projections for Miami-Dade County farm sales based on USDA-NASS Census of Agriculture for 1969-2017 are shown in Figure 20.8. The various models projected farm sales to rise from around $838 million in 2017 to about $1.21 billion in 2050 under the linear and logarithmic models, and as high as $1.89 billion under the exponential and power function models. As noted previously, all these models had quite good fit to the historic data, with correlations of 0.87 to 0.91; however, the linear and logarithmic model sales projections are considered more likely, assuming a continuation of historic growth rates in the industry, because the exponential and power function projections assume increasing growth rates over time.

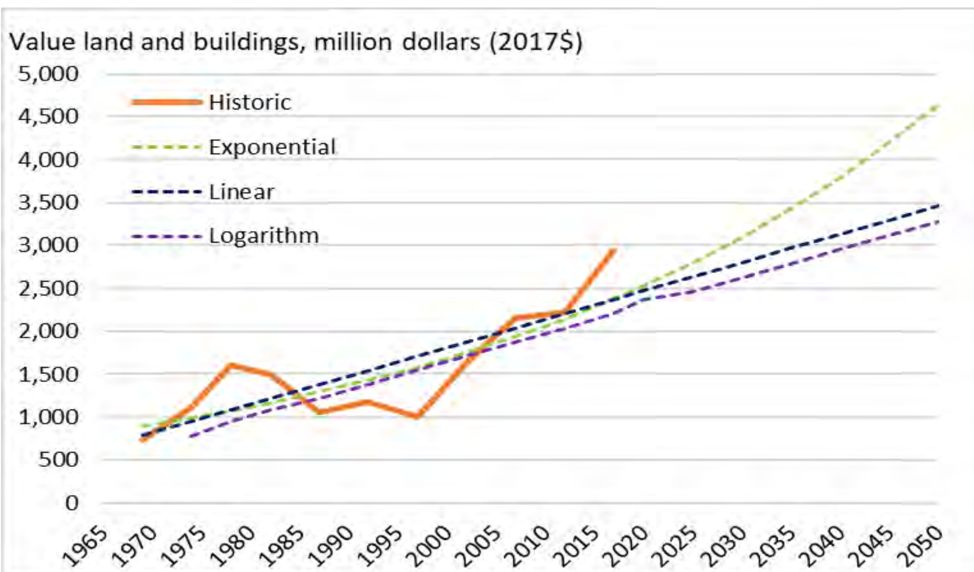
Projections of the asset value of farmland and buildings in the County are shown in Figure 20.9. The value was projected to increase from $2.94 billion in 2017 to between $3.43 and $4.65 billion in 2050 under the different models. Again, the linear and logarithmic models estimated lower values, based on continuation of historic growth rates, while the exponential model gave higher estimated values that reflect increasing growth rates.

Figure 20.8. Farm sales in Miami-Dade County projected to 2050.



Source: USDA-NASS Census of Agriculture and author's analysis.

Figure 20.9. Value of farmland and buildings in Miami-Dade County projected to 2050.

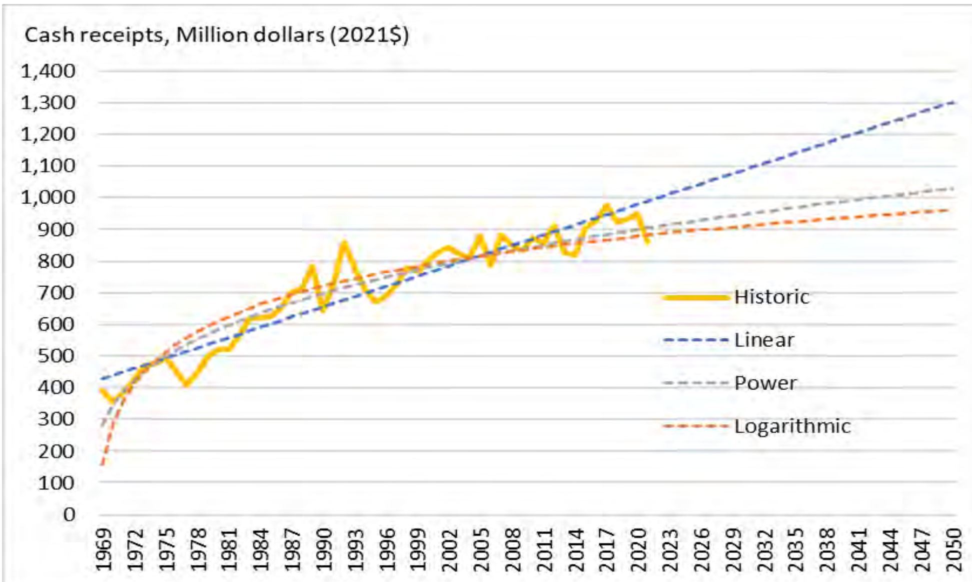


Source: USDA-NASS Census of Agriculture and author's analysis.

Projections of farm cash receipts from USDOC-BEA data are shown in Figure 20.10. This represents an alternative data source that is equivalent to the USDA-NASS information on farm sales, although this information is reported annually instead of every five years, and the most recent information is available through 2021 instead of 2017. Farm cash receipts were projected to increase from $860 million in 2021 to $961 million in 2050 under the logarithmic model, and as high as $1.30 billion under the linear model. The linear and logarithmic models assume a continued steady growth rate for industry sales, while the power model assumes a slowing of growth rate of sales that is probably more realistic because the specialty crop sectors are mature industries in Miami-Dade

Projections made using USDOC-BEA data on total farm income showed a pattern similar to cash receipts, although with slightly higher values, increasing from $950 million in 2021 to $1.01 to $1.39 billion in 2050. Projections on net farm income were not statistically reliable due to large historic yearly variations between $50 million and $500 million, as indicated by a very low correlation coefficient for the linear model (0.02).

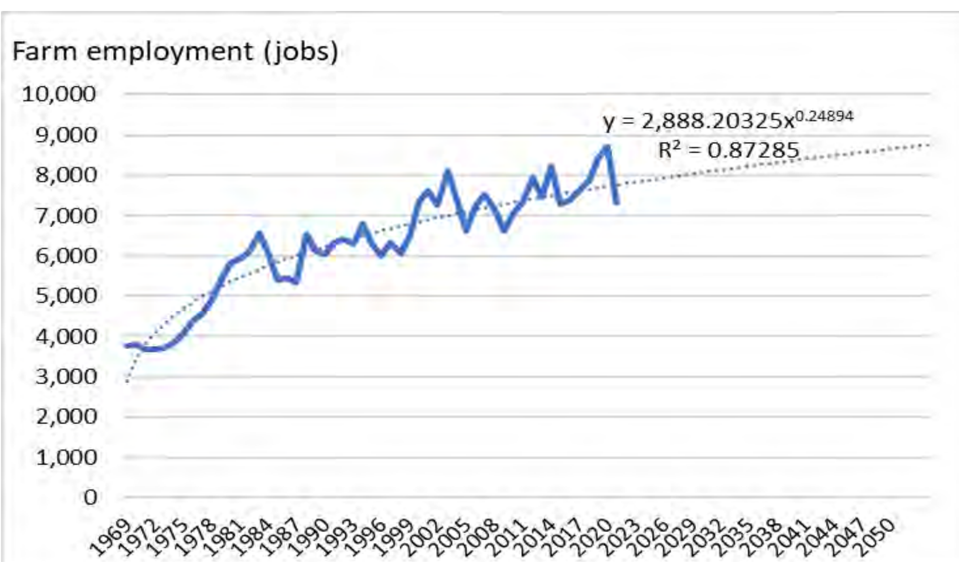
Figure 20.10. Farm cash receipts for Miami-Dade County projected to 2050.



Source: USDOC-BEA, Farm income and expenses, and author's analysis.

Projections on USDOC-BEA farm employment data for the County are shown in Figure 20.11. Employment was projected to increase from 7,314 jobs in 2021 to 10,699 jobs in 2050 using a linear model (not shown). Under a power model that reflects slowing growth rates, 8,651 jobs were projected in 2050, about the same as the peak level in 2020. This lower projection appears to be a better fit to the data and appears to be more realistic, given the very tight labor market and restrictions on immigrant labor.

Figure 20.11. Farm employment for Miami-Dade County projected to 2050 (power model).



Source: USDOC-BEA, regional economic information system, and author's analysis.

Projections of Agricultural Land Use Intensity

Because of the high cost of land in the County, it is expected that agricultural production will continue to intensify, resulting in higher value of production per acre. Values per acre of farm sector variables for sales, income, value of land and buildings, and employment were used to represent the land use intensity of agricultural activity. Values per acre were calculated for these variables using historic farmland area information for each period of the USDA-NASS Census of Agriculture. All monetary values were adjusted for inflation to express in constant dollar terms: 2017 dollars for USDA-NASS data, 2021 dollars for USDOC-BEA data. Projected per acre values of farm sector variables in Miami-Dade County in 2030, 2040, and 2050 under the various regression models are summarized in Table 20.5 and charted in Figures 20.12-20.15.

Projected farm sales per acre in 2050 from USDA-NASS data ranged from around $15,000 under linear and logarithmic models, which are more conservative, to a high of $25,000 under exponential and power models (Figure 20. 12). Alternatively, USDOC-BEA data on cash receipts (sales) per acre were projected to increase from around $12,400 per acre in 2017 to $18,400 in 2050 using a linear model (Figure 20. 13). USDOC-BEA data on total farm income per acre were projected to increase from around $12,800 in 2017 to $19,200 in 2050 with the best-fitting linear model. Net farm income per acre was projected to increase from about $3,000 in 2017 to $5,200 in 2050; however, these projections were considered not reliable due to high variability in the historic data (not shown). In general, the linear models were a reasonably good fit for projecting increasing intensity of production at a constant rate of growth. Increasing sales or income per acre reflects changes in production practices, technology, market prices, and the shift toward higher value nursery and floriculture products rather than vegetables/row crops.

The average value per acre of farmland and buildings was projected to increase from about $37,500 in 2017 to $45,000 in 2050 with the linear and logarithmic models, and a high of $62,000 under an exponential model (Figure 20.14). Again, the linear model was considered the best for this projection, as the exponential model indicates a rapid acceleration in growth.

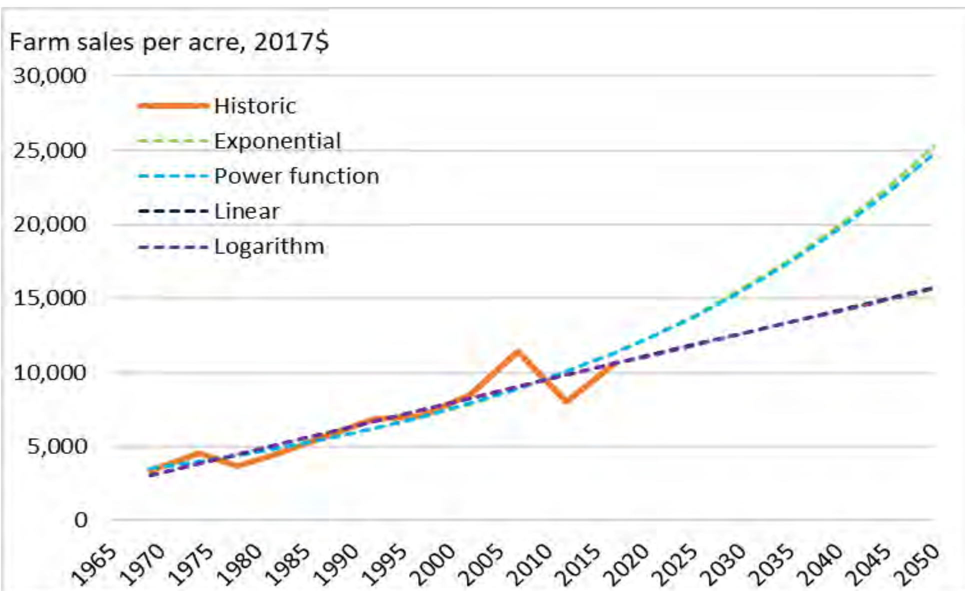
Farm employment intensity was projected to increase from 0.0970 jobs per acre in 2017 to 0.1462 jobs per acre in 2050 (Figure 20.15). Stated another way, these results are equivalent to 10.3 acres per job in 2017 and 6.8 acres per job in 2050, a decreasing number of acres per job due to increasing efficiencies. To be clear, these results indicate a change in employment intensity in relation to land use, <u>not</u> an increase in the overall number of jobs.

Table 20.5. Summary of farm sector land use intensity projections in Miami-Dade County, 2030, 2040, 2050.

Projection, data source	Model form	2030	2040	2050
Farm sales per acre, 2017$ (NASS)	Linear	12,649	14,216	15,783
	Logarithmic	12,610	14,145	15,672
	Exponential	15,582	19,851	25,291
	Power	15,491	19,639	24,869
Value farmland and buildings per acre, 2017$ (NASS)	Linear	36,416	41,009	45,602
	Logarithmic	36,259	40,750	45,219
	Exponential	39,990	49,831	62,094
Farm employment (jobs) per acre (BEA, NASS)	Linear	0.1215	0.1339	0.1462
Farm sales per acre, 2021$ (BEA, NASS)	Linear	15,008	16,691	18,374
Farm income per acre, 2021$ (BEA, NASS)	Linear	15,632	17,421	19,210
Farm net income per acre, 2021$ (BEA, NASS)	Linear	4,415	4,812	5,208

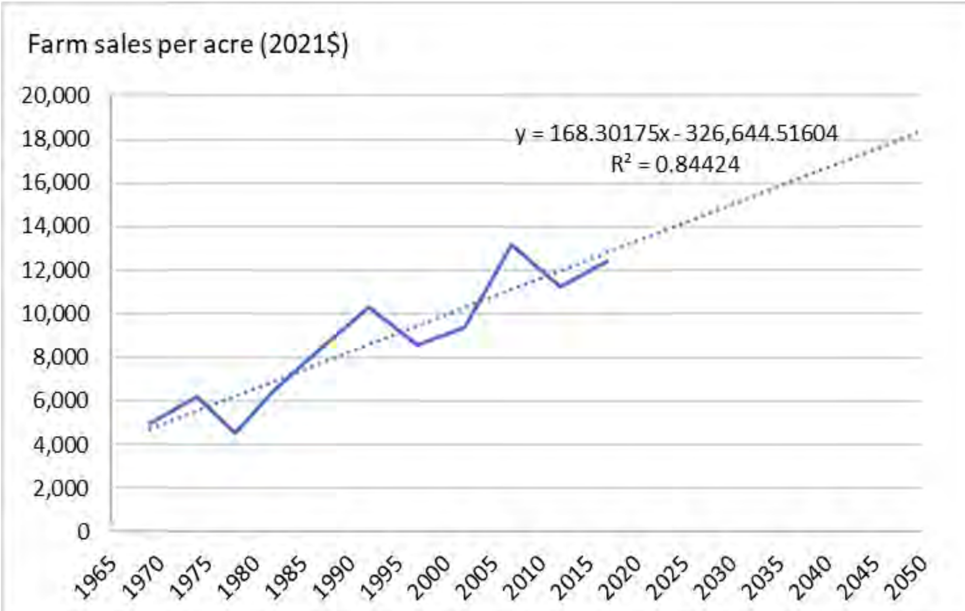
Values in constant 2017 or 2021 dollars using U.S. GDP Implicit Price Deflator.
USDOC-BEA data are annually 1969-2021, USDA-NASS Census of Agriculture data are every 5 years 1969-2017.
Source: USDA-NASS Census of Agriculture, USDOC-BEA Farm Income and employment, and author's analysis.

Figure 20.12. Farm sales per acre for Miami-Dade County projected to 2050.



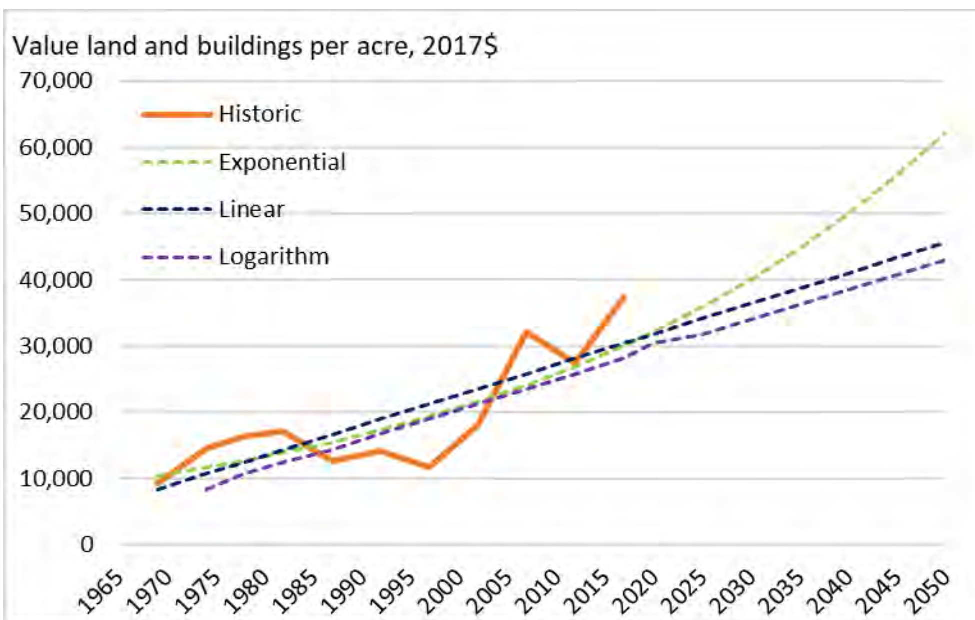
Source: USDA-NASS Census of Agriculture, and author's analysis.

Figure 20.13. Farm cash receipts (sales) per acre for Miami-Dade County projected to 2050 (linear model).



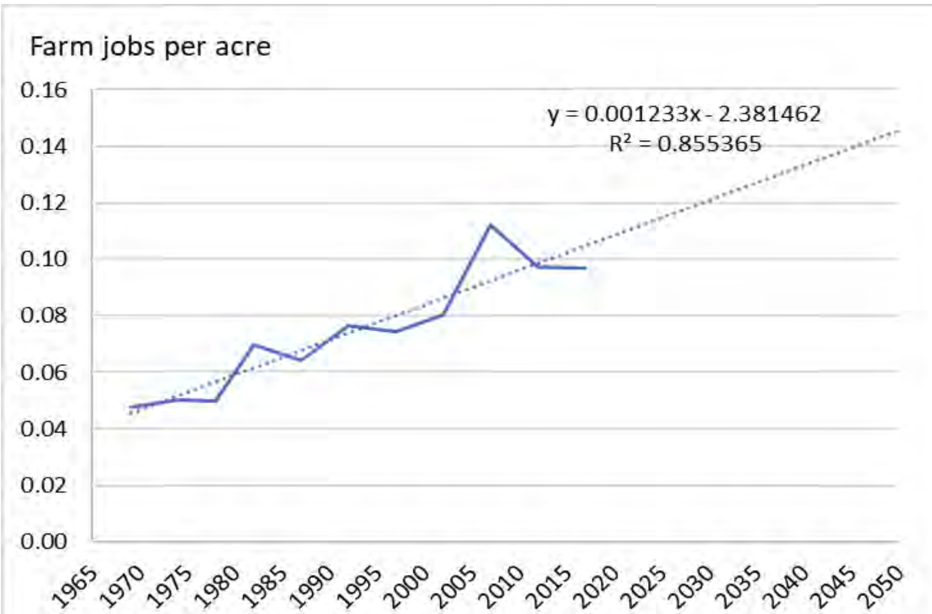
Source: USDOC-BEA Farm Income and Expenses, USDA-NASS Census of Agriculture, and author's analysis.

Figure 20.14. Value of farm land and buildings per acre for Miami-Dade County projected to 2050.



Source: USDA-NASS Census of Agriculture, and author's analysis.

Figure 20.15. Farm employment per acre for Miami-Dade County projected to 2050 (linear model).



Source: USDOC-BEA Regional Economic Information System, USDA-NASS Census of Agriculture, and author's analysis.

REMI Model Projections of Farm Output and Employment

Additional projections of farm sector activity in Miami-Dade County were done using REMI model forecasts for the local economy under alternative scenarios for the agricultural sector, as described in the report chapter on Agricultural Scenario Analysis. Forecasts were provided for high, medium, and low population growth baselines, and agricultural industry scenarios reflecting a range of positive and negative factors potentially affecting the industry, including: increased growth in output, technology adoption, development of agritourism and local food, land loss to the Urban Expansion Area, increased foreign competition, price of land, major hurricanes, and climate change/sea level rise. A "most likely" case scenario incorporates the combined effects of the Urban Expansion Area, foreign competition, and mid-range climate change/sea level rise, which resulted in a projection of reduced agricultural output and employment from the baseline population growth forecasts.

REMI model projections for farm output and employment for the three population growth baseline forecasts and the "most likely" agricultural scenario are summarized in Table 20.6 and charted in Figures 20.16-20.17. Farm output, indexed to the initial value of $860 million in 2021 (farm cash receipts, USDOC-BEA), was projected to grow to $1.64 billion in 2050 under the medium population growth forecast, and $1.25 billion with the addition of the most likely agricultural scenario. The high growth forecast of $1.97 billion in 2050 is considered unlikely, since it assumes higher population growth and doesn't include likely challenges due to adverse factors for agriculture. The low population growth forecast plus most likely agricultural scenario provides a low-end farm output projection of $919 million in 2050, which is close to the current level and considered unlikely since agriculture has shown consistent growth in the County (Figure 20.16). In relative terms, the REMI model farm output forecast in 2050 represents an increase of 91 percent under the medium growth baseline, and a 45 percent increase under the medium growth baseline combined with the most likely agricultural scenario.

Farm employment was projected by the REMI model to increase from 8,728 jobs in 2021 to nearly 9,600 jobs in 2050 under the medium growth baseline forecast, and to decrease to less than 7,300 jobs in 2050 under the medium growth forecast with most likely agricultural scenario (Figure 20.17). The high growth baseline forecast and most likely scenario showed only a minor increase in jobs from the current level. The low growth baseline forecast and medium growth baseline forecast with most likely scenario showed an overall decline in employment to under 8,000 jobs in 2050, while the low growth forecast and most likely scenario projected less than 5,400 total jobs.

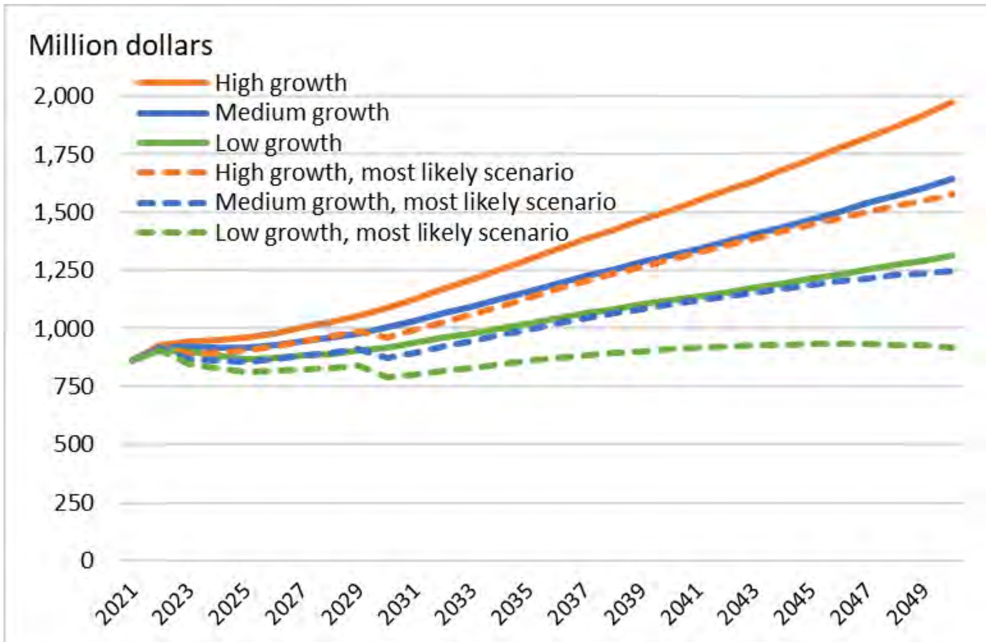
The output forecasts from the REMI model were considerably higher than projections from time series analysis of the historic USDA-NASS and USDOC-BEA farm sales or income data, and represent a more optimistic outlook for the industry, while the employment forecasts from REMI were in line with the statistical model projections of USDOC-BEA employment data.

Table 20.6. Summary of farm output and employment projections from REMI model baseline population forecasts and most likely agricultural scenario for Miami-Dade County, 2030, 2040, 2050.

Variable	Population Forecast, Scenario	2030	2040	2050	Change 2021 to 2050	Percent change
Farm output indexed to 2021 (million$)	Medium growth	1,004	1,314	1,644	784	91.1%
	High growth	1,090	1,508	1,973	1,113	129.3%
	Low growth	919	1,121	1,315	455	52.9%
	Medium growth, most likely scenario	874	1,103	1,248	387	45.0%
	High growth, most likely scenario	960	1,297	1,577	716	83.2%
	Low growth, most likely scenario	789	910	919	59	6.8%
Farm employment (jobs)	Medium growth	8,833	9,447	9,593	865	9.9%
	High growth	9,584	10,840	11,511	2,783	31.9%
	Low growth	8,082	8,053	7,674	-1,053	-12.1%
	Medium growth, most likely scenario	7,689	7,930	7,280	-1,448	-16.6%
	High growth, most likely scenario	8,440	9,324	9,198	471	5.4%
	Low growth, most likely scenario	6,939	6,537	5,361	-3,366	-38.6%

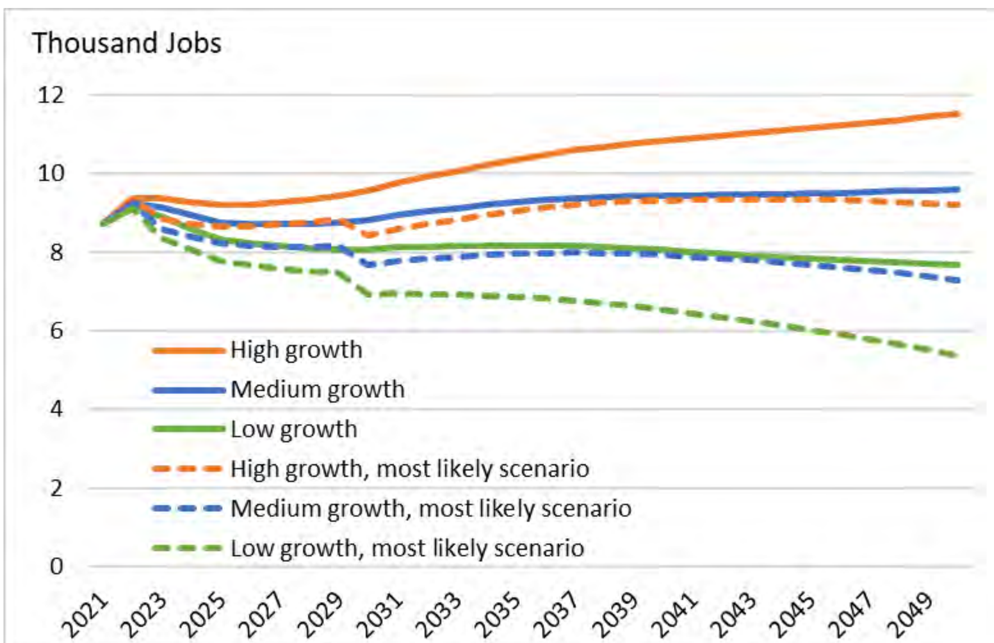
Source: REMI model for Miami-Dade County, and author’s calculations.

Figure 20.16. Farm output in Miami-Dade County for REMI model baseline population forecasts and most likely agricultural scenario, 2021-2050.



Source: REMI model for Miami-Dade County, and author's calculations.

Figure 20.17. Farm employment in Miami-Dade County for REMI model baseline population forecasts and most likely agricultural scenario, 2021-2050.



Source: REMI model for Miami-Dade County, and author's calculations.

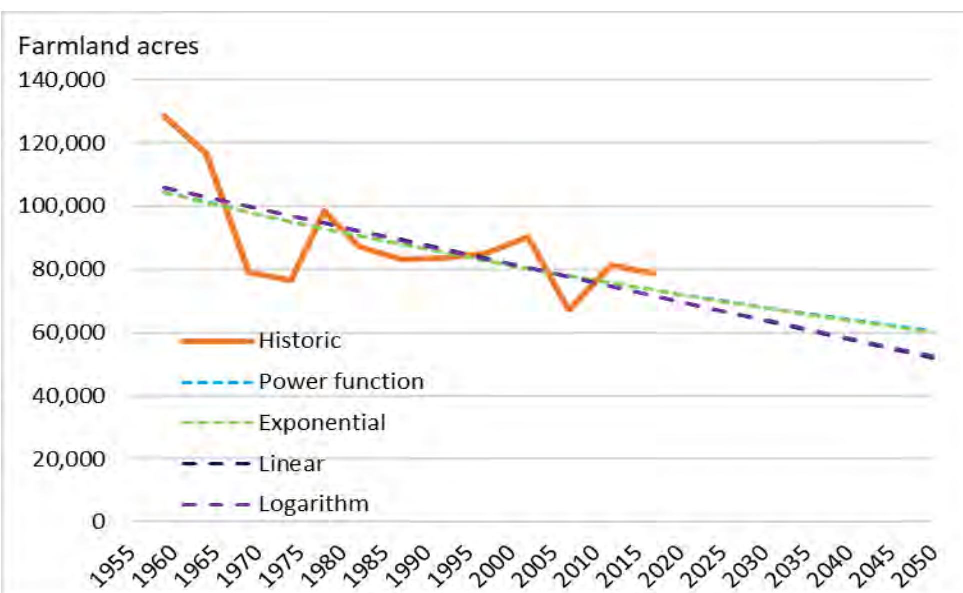
Projections of Farmland Area

Projections from Historic Farmland Area

Projections of future farmland area were first done using the historic data on farmland acreage for the entire period of record (1959-2017) and for a shorter period (1969-2017) that is consistent with the data used for all other projections in this report. Note that these farmland area projections assume a continuation of historic trends in markets, product mix, labor relations, production practices, and technology, but presumably do not capture the possible effects of favorable or unfavorable factors or events affecting farmland area in the future (e.g., changes to the Urban Development Boundary).

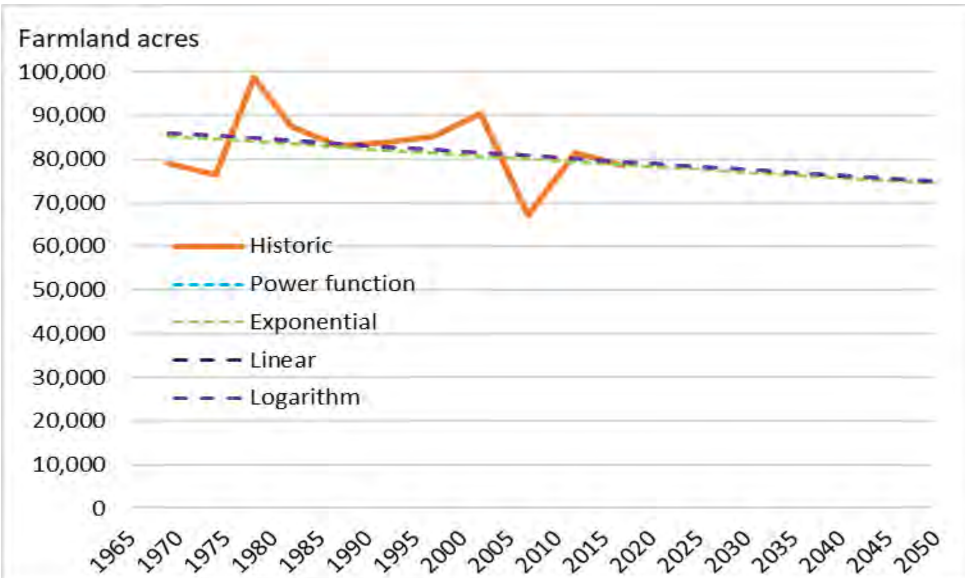
For data on farmland from the complete historic period of 1959-2017, the linear and logarithmic models were in close agreement, forecasting around 52,000 acres in 2050, while the exponential and power function models predicted around 60,000 acres in 2050 (Figure 20.18). For farmland data from the shorter period of 1969-2017, the models were in close agreement, forecasting around 75,000 acres in 2050 (Figure 20.19). The estimates in Figure 20.19 were higher because the significantly larger farmland area values for the early years were excluded, resulting in a projected less rapid decline in future years. It should be noted that Miami-Dade County experienced high in-migration and development in the period 1959-1969, associated with a large loss of farmland area. Nevertheless, the regression models for farmland area had less strong fit to the historic data, with correlation coefficients of 0.43 to 0.64 (Table 20.2), so these were considered less reliable than the alternative estimates using sales, income, assets, or employment, as described below.

Figure 20.18. Projected farmland area in Miami-Dade County to 2050 based on the complete historic record, 1959-2017.



Note that some model curves may not be visible because of coincident lines.
Source: USDA-NASS Census of Agriculture, and author's analysis.

Figure 20.19. Projected farmland area in Miami-Dade County to 2050 based on restricted historic period, 1969-2017.



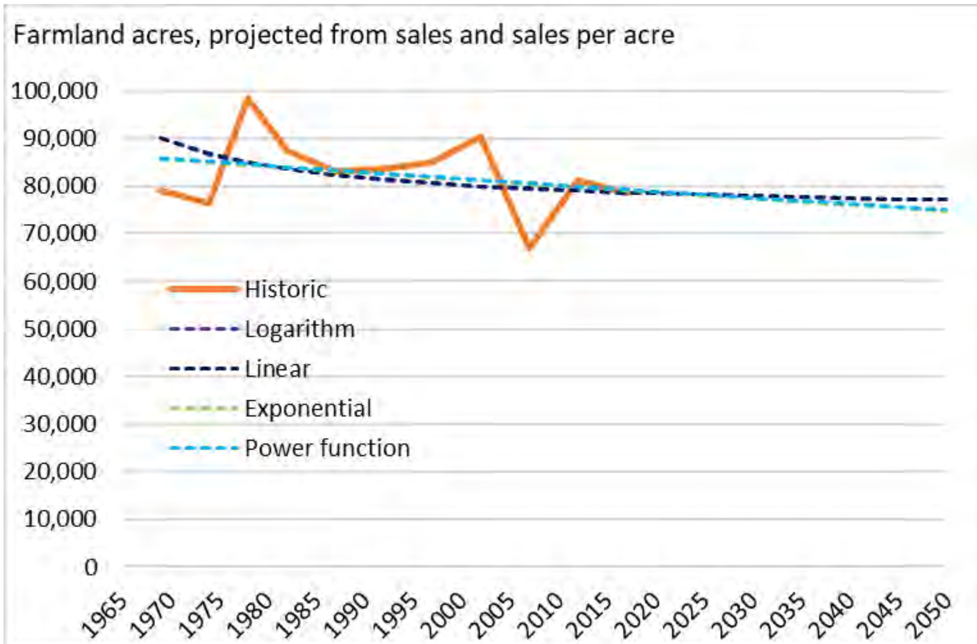
Note that some model curves may not be visible because of coincident lines.
Source: USDA-NASS Census of Agriculture, and author's analysis.

Projections from Agricultural Activity and Intensity

Additional projections of future farmland area in Miami-Dade County were made by combining the projections of sales, income, output, employment, and assets together with projected per-acre land use intensity variables.

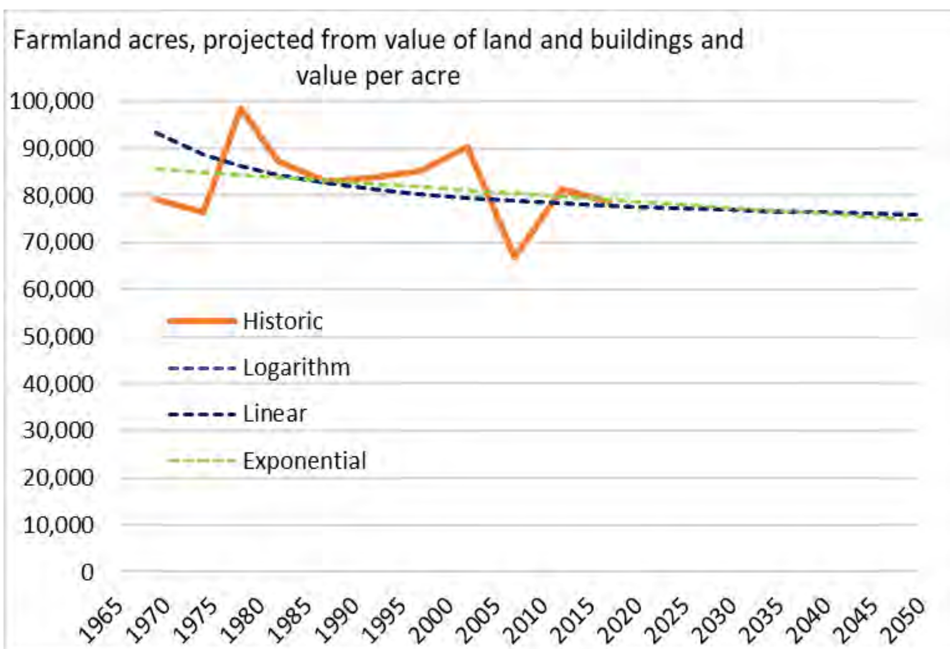
Projected County farmland area in 2050 based on USDA-NASS farm sales and sales per acre was estimated at about 77,100 acres using a combination of logarithmic and linear models, which represented the highest estimate of all models (Figure 20.20). The power function model for sales or income assumes a decreasing growth rate in the future (unlikely, so not shown), while the linear model for value per acre assumes that land use intensity will continue to increase similar to historic rates. Projected farmland in 2050 using a combination of models for value of land and buildings and value per acre was estimated at about 75,900 acres (Figure 20.21) by both linear and exponential models. This estimate was close to the projection of about 75,000 acres based on a linear model of trends in farmland area during 1969-2017, as described previously (Figure 20.19).

Figure 20.20. Farmland area in Miami-Dade County projected to 2050 based on USDA-NASS farm sales trends.



Note that some model curves may not be visible because of coincident lines.
Source: USDA-NASS Census of Agriculture and author's analysis.

Figure 20.21. Farmland area in Miami-Dade County projected to 2050 based on value of land and buildings trends.

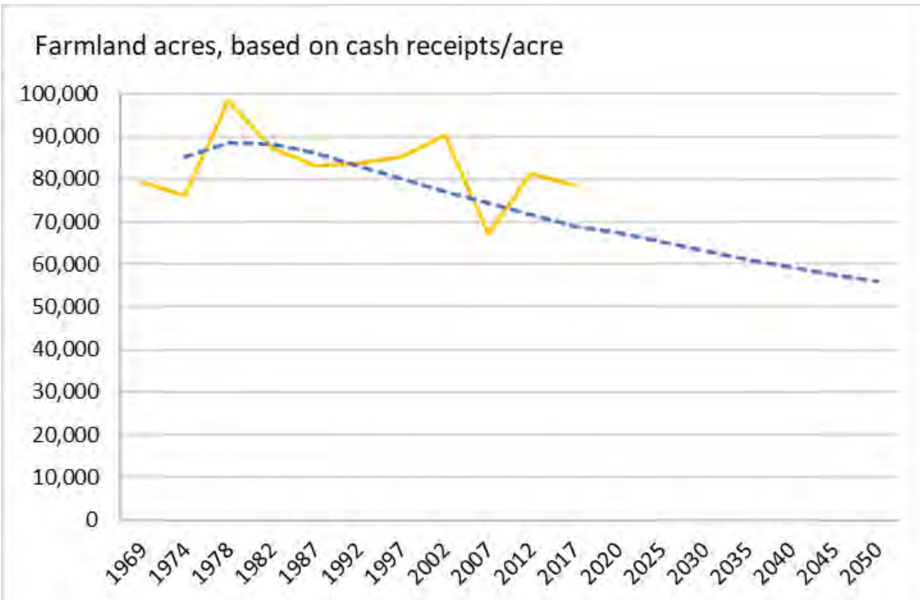


Source: USDA-NASS Census of Agriculture and author's analysis.

Alternatively, future farmland area was estimated using projected farm cash receipts (sales) and income data from USDOC-BEA together with per acre values. Because of the larger number of observations for these data, this source was considered to be much more robust for estimating future agricultural land use in the County.

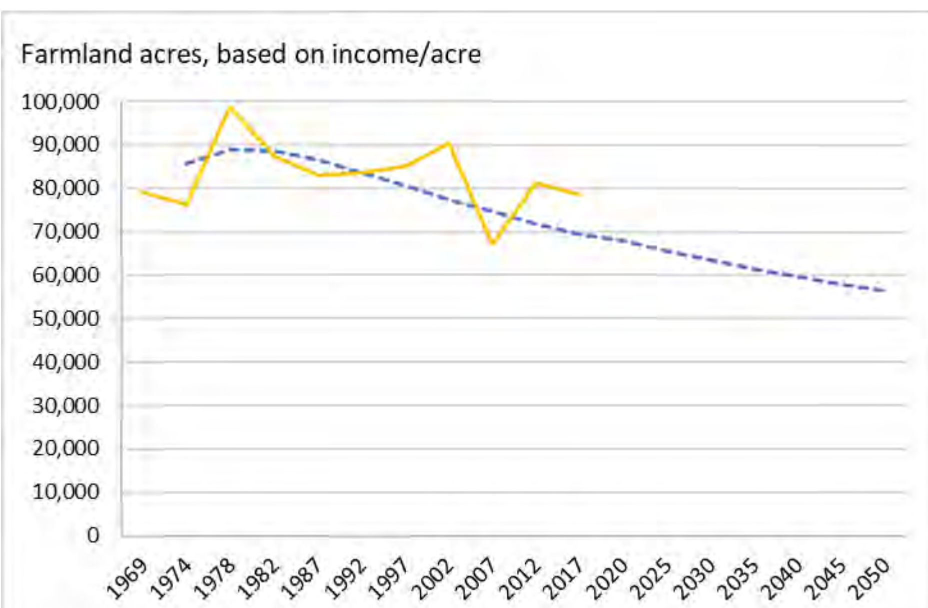
These projections combined the power function models for sales or income and the linear models for sales or income per acre. The combined models projected around 56,000 acres of farmland area in 2050 (Figures 20.22-20.23). Projected farmland area in the County in 2050 based on the combined models for USDOC-BEA farm employment and employment per acre was estimated at about 59,200 acres (Figure 20. 24).

Figure 20.22. Farmland area in Miami-Dade County projected to 2050 based on farm cash receipts trends (combined power and linear models).



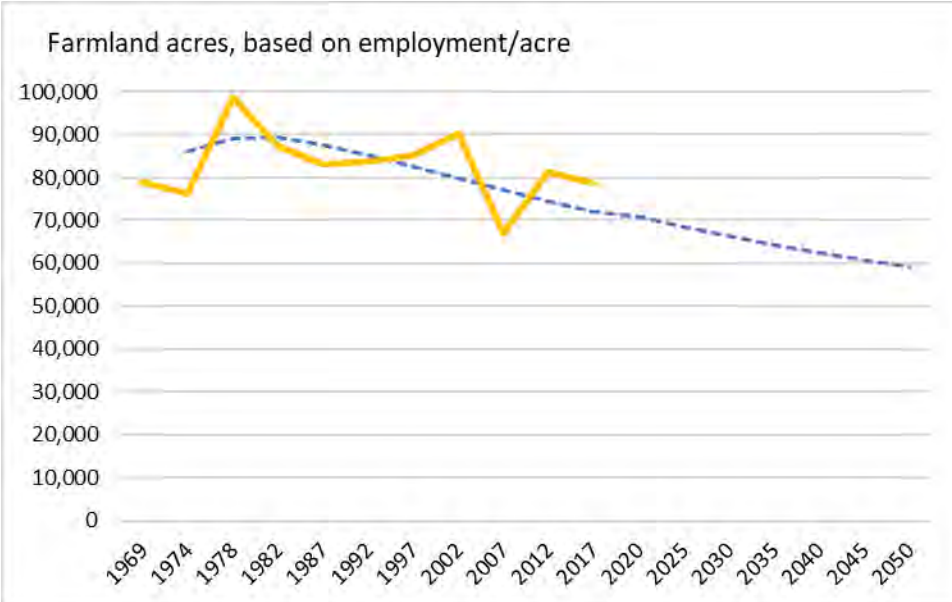
Source: USDOC-BEA, Farm Income and Expenses, USDA-NASS Census of Agriculture, and author's analysis.

Figure 20.23. Farmland area in Miami-Dade County projected to 2050 based on farm income trends (combined power and linear models).



Source: USDOC-BEA, Farm income and expenses, USDA-NASS Census of Agriculture, and author's analysis.

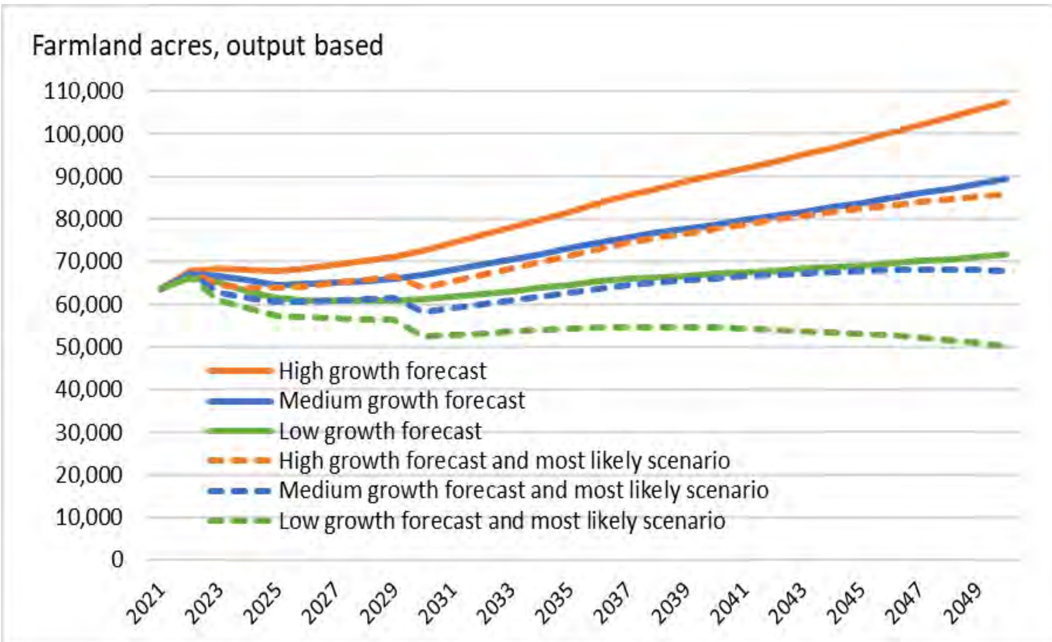
Figure 20.24. Farmland area in Miami-Dade County projected to 2050 based on farm employment trends (combined power and linear models).



Source: USDOC-BEA Regional Economic Information System, USDA-NASS Census of Agriculture, and author's analysis.

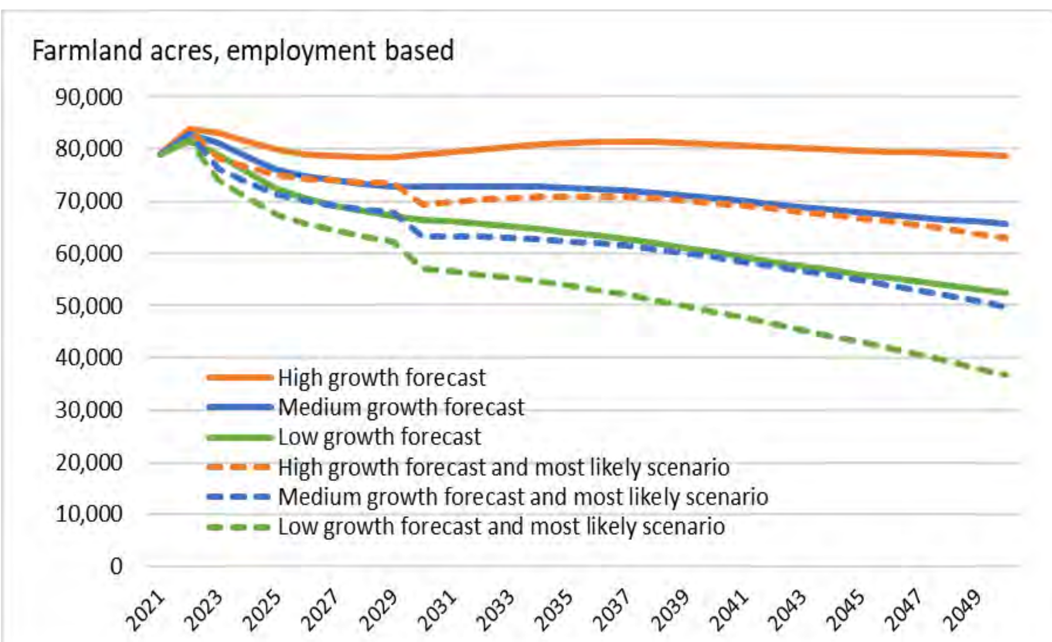
Farmland projections also were made using REMI model baseline forecasts of farm output and employment under high, medium, and low population growth baselines together with the "most likely" agricultural scenario. The REMI forecast of farm output under medium growth and most likely scenario gave a farmland projection of about 67,900 acres in 2050, while the high and low growth forecasts with the most likely scenario gave estimates of 85,800 and 50,000 acres, respectively (Figure 20.25). The REMI employment forecast for the medium growth forecast and most likely scenario provided a farmland projection of 49,800 acres in 2050, while the high and low growth plus most likely scenarios gave projections of 62,900 and 36,700 acres, respectively (Figure 20.26). The latter projection was the lowest of all projections.

Figure 20.25. Farmland area projections for Miami-Dade County based on REMI model farm output forecasts for population growth baselines and most likely agricultural scenarios, 2021-2050.



Source: REMI model for Miami-Dade County, and author's analysis.

Figure 20.26. Farmland area projections for Miami-Dade County based on REMI model farm employment forecasts for population growth baselines and most likely agricultural scenarios, 2021-2050.

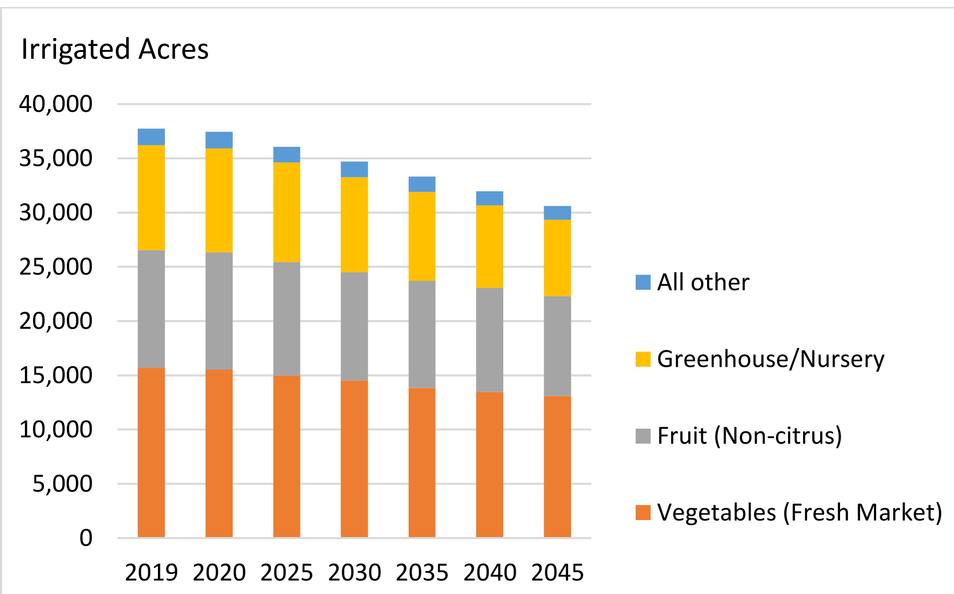


Source: REMI model for Miami-Dade County, and author's analysis.

Irrigated Cropland Projections

Irrigated agricultural land in Miami-Dade County is important to consider for future sustainability of the agricultural sector in view of the need for irrigation to produce reliable yields of specialty crops. A forecast of future irrigated agricultural land area and water use in the County was provided by the Florida Department of Agriculture and Consumer Services-Florida Statewide Agricultural Irrigation Demand (FDACS-FSAID) program, based on recent trends in land and water use, and global crop prices. These projections represent an independent third-party estimate of future agricultural land use. Irrigated cropland projections for major crops in the County to the year 2045 are summarized in Figure 20.27. Total irrigated crop acreage in Miami-Dade County was projected to decline from nearly 38,000 acres in 2019 to around 30,600 acres in 2045, representing a decrease of 18 percent, including large decreases for nursery/greenhouse (26%), vegetables (16%), and fruits (15%). According to the USDA-NASS Census of Agriculture, irrigated land in the County in 2017 was 36,801 acres, representing 47 percent of farmland area (USDA-NASS). Assuming that irrigated cropland continues to represent 47 percent of total cropland, these projections suggest that total cropland in the County in 2045 would be around 65,115 acres, which is comparable to other projections of future farmland area.

Figure 20.27. Irrigated cropland area in Miami-Dade County, 2019-2020 and projected 2025-2045



Source: Florida Department of Agriculture and Consumer Services, Florida Statewide Agricultural Irrigation Demand, 2021.

Summary of Farmland Projections

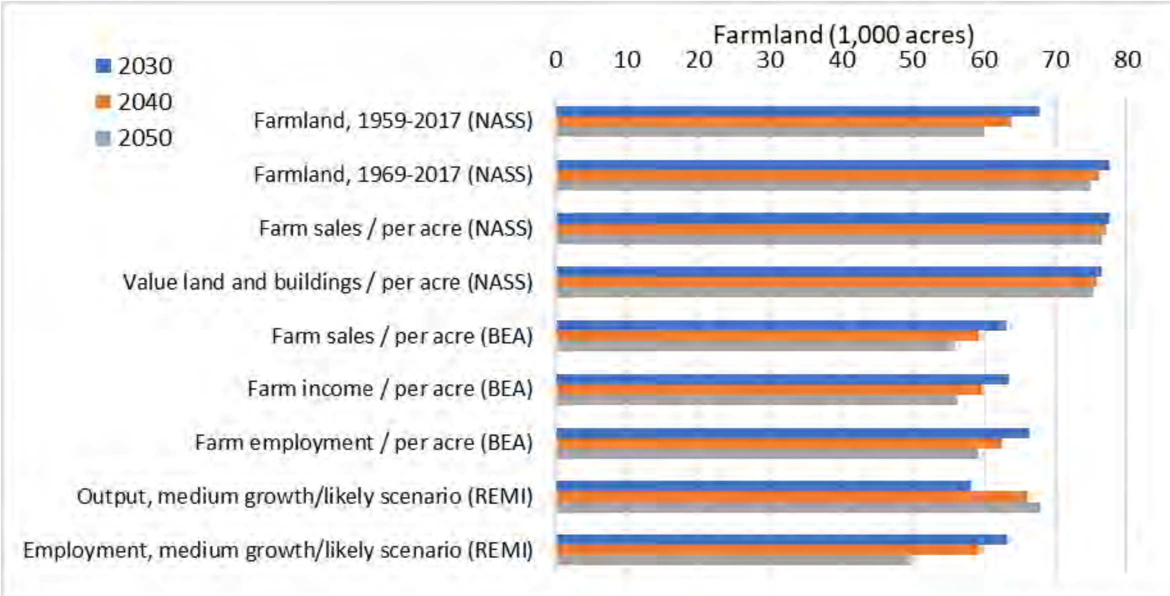
Farmland estimates for Miami-Dade County in 2030, 2040, and 2050 using nine (9) selected best-fitting statistical or forecast models are summarized in Table 20.8 and Figure 20.28. These selected results include the projections from the REMI model medium population growth and "most likely" scenario forecasts, but not the high or low population growth forecasts, which were deemed too optimistic or too pessimistic, respectively. The selected projections were based on trends in land use, farm sales, land value, cash receipts, income, land and building values, employment to show the amount of land needed to maintain economic benefits to the County comparable to the current level. Across the selected models, farmland area projections were lower than the 2017 benchmark of 78,543 acres in all years. Projections for the terminal year of 2050 ranged from a low of about 49,797 acres to a high of 76,607 acres. The lowest projection among selected models in 2050 would represent a 37 percent decrease of about 28,700 acres from the benchmark level in 2017. The median or midpoint projection in 2050 was 60,080 acres for the NASS farmland model for 1959-2017 data. The overall mean (average) of all projections was 64,008 acres, representing a 19 percent decrease from 2017. A trimmed mean of selected projections (i.e. dropping the maximum and minimum values) gives a similar estimate of 64,238 acres in 2050. Five of the model projections were from just under 50,000 acres to just over 60,000 acres in 2050: NASS farmland, 1959-2017; USDOC-BEA farm cash receipts; USDOC-BEA income; USDOC-BEA employment; and REMI employment/medium growth/most likely scenario. These five mid-range projections had a combined average of 56,284 acres in 2050, which is a 28.3 percent decrease of 22,259 acres from the 2017 benchmark, representing a -0.86 percent average annual change over the 33-year forecast period from 2017 to 2050.

Table 20.8. Summary of farmland area projections for Miami-Dade County, 2030, 2040, 2050, using selected statistical and economic forecasting models.

Basis, Model, Scenario	2030	2040	2050	Change 2017-50	Percent change 2017-50	Annual percent change
	Acres					
Farmland, exponential model (NASS, 1959-2017)	67,809	63,828	60,080	-18,463	-23.5%	-0.71%
Farmland, linear model (NASS, 1969-2017)	77,608	76,230	74,853	-3,690	-4.7%	-0.14%
Farm sales and sales per acre, logarithmic/linear models (NASS)	77,675	77,102	76,607	-1,936	-2.5%	-0.07%
Farm value land and buildings and value per acre, logarithmic/linear model (NASS)	76,561	75,868	75,279	-3,264	-4.2%	-0.13%
Farm cash receipts (sales) and receipts per acre, power/linear models (BEA, NASS)	63,145	59,336	56,006	-22,537	-28.7%	-0.87%
Farm income and income per acre, power/linear models (BEA, NASS)	63,502	59,689	56,360	-22,183	-28.2%	-0.86%
Farm employment and jobs per acre, linear models (BEA, NASS)	66,397	62,567	59,175	-19,368	-24.7%	-0.75%
Farm output, medium growth forecast most likely scenario, and sales per acre, linear model (REMI, BEA)	58,251	66,109	67,913	-10,630	-13.5%	-0.41%
Farm employment, medium growth forecast most likely scenario, and jobs per acre, linear model (REMI, BEA)	63,272	59,243	49,797	-28,746	-36.6%	-1.11%
Maximum	77,675	77,102	76,607	-1,936	-2.5%	-0.07%
Minimum	58,251	59,243	49,797	-28,746	-36.6%	-1.11%
Median	66,397	63,828	60,080	-18,463	-23.5%	-0.71%
Mean (all selected models)	68,247	66,663	64,008	-14,535	-18.5%	-0.56%
Trimmed mean (dropped max., min.)	68,328	66,232	64,238	-14,305	-18.2%	-0.55%
Mean of 5 mid-range projections: NASS farmland (1959-2017), BEA farm cash receipts, BEA income, BEA employment, REMI employment medium growth/most likely scenario	64,825	60,933	56,284	-22,259	-28.3%	-0.86%

Source: USDA-NASS Census of Agriculture, USDOC-BEA, REMI, and author's analysis.

Figure 20.28. Summary chart of farmland area projections using statistical and forecasting models for Miami-Dade County in 2030, 2040, 2050.



Source: USDA-NASS Census of Agriculture, USDOC-BEA, REMI, and author's analysis.

Discussion and Conclusions

This assessment of future agricultural land use in Miami-Dade County considered several economic and statistical model forecasts of agricultural sector activity to the year 2050. The best-fitting model for each predictor variable was selected as a set of nine alternative farmland acreage projections. All projections were in agreement that agricultural activity in the County will continue to increase significantly, although at lower rates than in the past. This is consistent with general trends in U.S. agriculture and specialty crop farming. In particular, the nursery/floriculture industry, the dominant agricultural sector in Miami-Dade County, has been the most rapidly growing major segment of U.S. agriculture for the past 30 years, but is now considered a mature industry with slower growth rates likely in the future (IbisWorld).

The models also indicated that space use intensity of agricultural production, measured as value per acre of land area for the different variables, will continue to grow, implying a greater demand for labor, technology, and material inputs, but somewhat lower demand for farmland as a factor of production. This too is consistent with global trends in agriculture, substituting higher inputs in the face of diminishing available land area. The joint effect of increasing agricultural output together with reduced land area per unit of production implies that farmland use may either increase or decrease depending upon the balance of these opposing factors.

The projections from models for USDOC-BEA farm cash receipts, total income, and employment comprised a group of mid-range estimates ranging from about 56,000 to 59,200 acres in 2050, which is reasonably close to the projection from the best-fitting statistical time series model of long-term trends in farmland itself

(60,080 acres, 2050) and the projection from data on farmland under irrigation (65,115 acres in 2045). As noted previously, the long time series of annual USDOC-BEA data on cash receipts, total income, and employment are considered very robust, and support high confidence in the results.

The consensus forecast of future agricultural land use in Miami-Dade County is a combined average of the five mid-range model projections giving the following point estimates, rounded to the nearest 100 acres: 64,800 acres in 2030; 60,900 acres in 2040; and 56,300 acres in 2050. The projected rate of change in farmland from 2017 to 2050 for this estimate (-0.86% per year) is slightly higher than the historic average decrease during 1959-2017 (-0.67% annually) and during the most recent 2012-2017 period of the USDA-NASS Census of Agriculture (-0.68% annually).

The higher estimates of 70,000+ acres in 2050 from some model projections were judged to be unlikely or less reliable. The estimates of 75,870 to 76,607 acres based on USDA-NASS information for farm sales and value of land and buildings were based on limited historical USDA-NASS Agricultural Census data (only every five years). The REMI model estimate of 67,913 acres in 2050 based on farm output under the medium population growth plus "most likely" agriculture scenario was driven by the expected overall strong growth in the County economy. This model also was the only one that indicated an increase in farmland from 2030 to 2050, which is considered improbable.

In cases where multiple divergent forecasts are available from different sources of information or methods, when there is high uncertainty about the forecasting situation, and when it is important to avoid large forecast errors, there is a strong precedent for using combined forecasts selected by academic and practicing economists (Armstrong, 2001). Combined forecasts have been demonstrated to reduce forecast error by 3 to 24 percent, or an average of 12.5 percent, determined by a review of 30 forecasts conducted between 1963 and 2000 dealing with macroeconomics, health care, company earnings, consumer products, construction, and commodity prices (Armstrong, 2001). Various techniques and calculations are used to combine forecasts, including a simple mean, trimmed mean, or weighted mean, with weighting factors applied to represent forecaster knowledge or experience, quality of the data, or other evidence. It is recommended to use combined forecasts when there are five or more separate competing forecasts, to use trimmed means to reduce bias from extreme forecasts, and to use equal weighting of components to avoid judgmental bias if there is no strong evidence to support unequal weights.

The future farmland projections in this report were made with due diligence and are believed to be the best estimates available; however, there is significant uncertainty in making projections 27 years into the future. It is possible that agricultural land use in Miami-Dade County could change more or less rapidly than indicated by these projections, depending upon unforeseen circumstances affecting the agricultural industry or the local economy in general.

The projections include the following assumptions and qualifications:

- Miami-Dade County economy will continue to grow and remain highly diversified.
- There are no catastrophic "tipping points," such as severe climate change/sea level rise, nuclear disaster, or global pandemic, that would overwhelm industry resilience to adapt to change.
- Agricultural industry output (revenues) will continue to grow and develop, although at less than historic rates due to market forces.
- The agriculture sector in Miami-Dade County is currently under significant financial stress with increasing production costs and declining net income and operation margins, as described in the Assessment of the Current Situation chapter of this report.
- Land use intensity (production per acre) will continue to increase similar to historic rates due to adoption of improved technology and change in crop mix toward more valuable nursery/greenhouse products, and specialty food products, leading to greater production per acre or reduced land requirements per unit of production.
- The agricultural industry in Miami-Dade County is becoming more concentrated in the nursery/floriculture sector, which is now dominated by one large firm, although many very small farms are starting to produce more specialized crops.
- More rapid adoption of new technologies or production practices that would accelerate land use intensification beyond the projected increases, and reduce demands for farmland per unit of production, are considered unlikely.
- Population density levels in the urban area of Miami-Dade County will remain stable or increase marginally to accommodate additional population growth and residential housing demand without conversion of agricultural lands.
- Labor market projections are highly uncertain due to current issues with foreign workers and immigration laws and policies.
- It was assumed that federal, state, and local policy will remain unchanged regarding labor, food safety, and international trade issues that affect agriculture in Miami-Dade County. In particular, we assumed that Quarantine 37, prohibiting importation of live plants in soil media for phytosanitary control, will remain in place and protect the nursery industry from foreign competition.
- The agricultural land use projections represent total farmland acreage, not only cropland, and may be higher than official agricultural property designations by the County Property Appraiser, because some properties used for agricultural purposes are not zoned Agricultural or may be used for necessary farm support services such as offices, parking, storage, repair shops, packing sheds, etc.
- The land use projections represent demand for farmland under market equilibrium conditions with the current County land use plan in place, including the Urban Development Boundary, which limits competition for land between agricultural and non-agricultural uses. Land use projections also assume that

property values continue to reflect agricultural use rather than speculative values for residential, commercial, and industrial development.

This research project was tasked with recommending the minimum farmland acreage needed to maintain a viable agricultural sector in Miami-Dade County through the year 2050, in support of policies for controlling urban development, limiting urban sprawl, and maintaining open space for agriculture and natural resources through the mechanism of the Urban Development Boundary (UDB). The agricultural land use estimates of 64,825 acres in 2030, 60,933 acres in 2040, and 56,284 acres in 2050 represent the minimum acreage required for agriculture without decreasing the availability of land, increasing land prices, and compromising the viability of agriculture in Miami-Dade County.

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Appendix A: Climate and Hydrology Modeling for Miami-Dade County

Appendix B: Emerging Agricultural Technologies

Appendix C: Agricultural Commodity Budgeting and Profitability Analysis

Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida

Final Report

Appendix A: Climate and Hydrology Modeling for Miami-Dade County

Contents

Executive Summary

Agricultural activity and production are vulnerable to climate change. Sea level rise is expected to bring additional challenges to agriculture in south Florida. This study investigated how projected changes in climate and sea level may affect groundwater quantity and quality in Miami-Dade County. A groundwater model, the Urban Miami-Dade (UMD) model developed by USGS, was used to represent mathematically the aquifer of Miami-Dade County—including agricultural areas—and its interaction with sea water. Two climate change scenarios and three sea level rise scenarios were fed to the UMD groundwater model to understand how groundwater flow and sea water intrusion process may look in the future. Under the most commonly used climate scenario of SSP2-4.5, the climate projection found that air temperature may increase by 1.5 to 1.8 degrees Celsius in the period of 2026 to 2050, compared to the historical period average. Precipitation was projected to slowly increase with large fluctuations and uncertainty. Under the NOAA Intermediate High sea level scenario combined with SSP2-4.5, the overall groundwater elevation was projected to increase by 0.25 m in the near future, compared to the elevation observed in the baseline period of 1996 to 2020. Areas that may be affected by brackish water would increase by 0.5 percent in the near future, while areas affected by seawater would increase by 3.7 percent for the same time frame. Groundwater elevation was expected to increase mainly due to projected sea level rise. Seawater and brackish water were projected to intrude into the fresh groundwater aquifer; however, the impacts might be limited to 15 to 20 km from the shoreline. The groundwater modeling results indicate that the groundwater level rises may be controlled mainly by the distance from the coastline rather than the land uses and covers and may be more sensitive to the projected sea level changes than the projected climate changes. Agricultural land uses might not be substantially affected by the saltwater intrusion processes as long as they do not expand to areas close to the shorelines or water areas in the southeastern part of Miami-Dade County. The groundwater modeling projected that seawater and brackish water would intrude into less than 1% of the agricultural land uses until 2100. The groundwater of agricultural areas was projected to increase by 0.24 m by 2050 and 0.75 m by 2100, compared to the baseline groundwater elevation. The groundwater elevation of agricultural areas was expected to be higher and increase faster than some other land uses and covers such as wetlands and upland natural. This modeling result implies that the agricultural land uses may experience root zone saturation more frequently due to the high groundwater table in the future, which may affect crop productivity and require adaptive agricultural management practices that can mitigate the impacts.

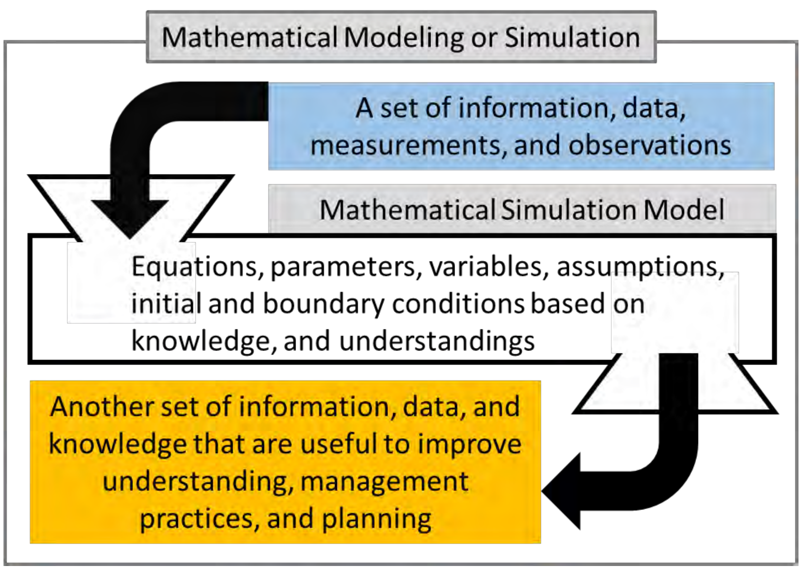
Methodology: Overview of Mathematical Modeling

Prediction is an everyday task for scientists and engineers. Mathematical modeling is one scientific way to predict the future and understand how something of interest reacts to internal and external stresses. Mathematical modeling is often simply called *modeling* or *simulation*.

Weather forecasting is a typical example of modeling. Warm and cold air masses meet and separate in the tropospheric layer of the atmosphere, and their dynamic movement creates weather phenomena and events such as wind, clouds, rain, snow, and fog. A group of warm and cold air masses is called a weather system. In a system, elements and entities such as warm and cold air bodies interact with each other; the manner of the interaction is called a *mechanism* that makes the system act as a whole.

A model is a representation of our understanding of reality that can be presented conceptually or in tangible form (e.g., a scale model of a car or a globe). Natural processes including air and water cycles are often too large in space to be represented in a tangible model. In such cases, mathematics becomes a useful tool to represent the ideas conceptually (Figure 2.1).

Figure 2.1. A schematic diagram of a mathematical model.



Models use equations and parameters to mathematically represent the mechanism of a system based on knowledge and information about the system (Figure 1). Our accumulated understanding and knowledge are embedded in the equations and parameters of a model. The mathematical equations and parameters enable the prediction of unknown variables based on known variables. The length of a chain of relationships between the knowns and unknowns can be short or long depending on the complexity of the system of interest.

There are many different types of models, from simple empirical models to complicated mechanistic models. The goal and required level of detail of modeling often determine the complexity of a model to be used. Empirical models are often relatively simple, relating variables of interest to other variables based on the historical relationship between them. Thus, empirical modeling heavily relies on observations showing how variables of interest changed in response to changes in others. The historical relationship does not explain the causality between them but only exhibits the statistical correlation. Empirical modeling can be good enough to predict something quickly if an in-depth understanding of the mechanism of a system is not required.

Mechanistic models describe the interactions between entities in a system of interest based on the understanding of the mechanisms. Mechanistic modeling tries to explain how and why a system of interest reacts to certain inputs. Mechanistic modeling tends to be more complicated, with many equations and parameters, compared to empirical modeling. Often, the values of mechanistic models' parameters are determined by comparing observed and modeled outputs to accurately represent the system, which is called parameter calibration. Thus, historical observations are also useful and critical for mechanistic modeling.

Prediction is not the only goal of using mechanistic models. Once mechanistic models are calibrated to observations, we can use them to explore how a system of interest reacts to different scenarios of internal and external stresses. Scenario analysis is useful especially when scenarios to be tested are not feasible to be implemented in reality. For instance, hydraulic models can describe what is going to happen to the downstream areas of a dam when the dam is broken. Models are also good educational tools. Students learn the history of theories and methodologies by investigating equations, parameters, constants, and assumptions employed in a model.

Modeling outputs are not free from errors. Modeling often requires assumptions for unknowns or simplifying the representation of a system and its mechanism. For instance, some climate models assume that the downward pull of gravity should be balanced by the upward force of an air mass so as to consider only the horizontal movement of the air mass. Assumptions are one of the major sources of errors and uncertainty; studies have developed scientific ways to reduce uncertainty in modeling results. Scientists combine simulations made using multiple models—which is called ensemble modeling—to increase accuracy.

The prediction of the future of a system is made based on the prediction of its past. Thus, prediction errors and uncertainty can accumulate in modeling processes, and prediction can become less accurate the farther the modeling gets into the future. Often, modeling can more accurately predict the overall status of a system at longer temporal scales such as years or decades. For example, hydrological models are good at predicting the overall amount of surface water and groundwater generated from rainfall (or precipitation) in a year, but it is still challenging to forecast the peak discharge of flooding.

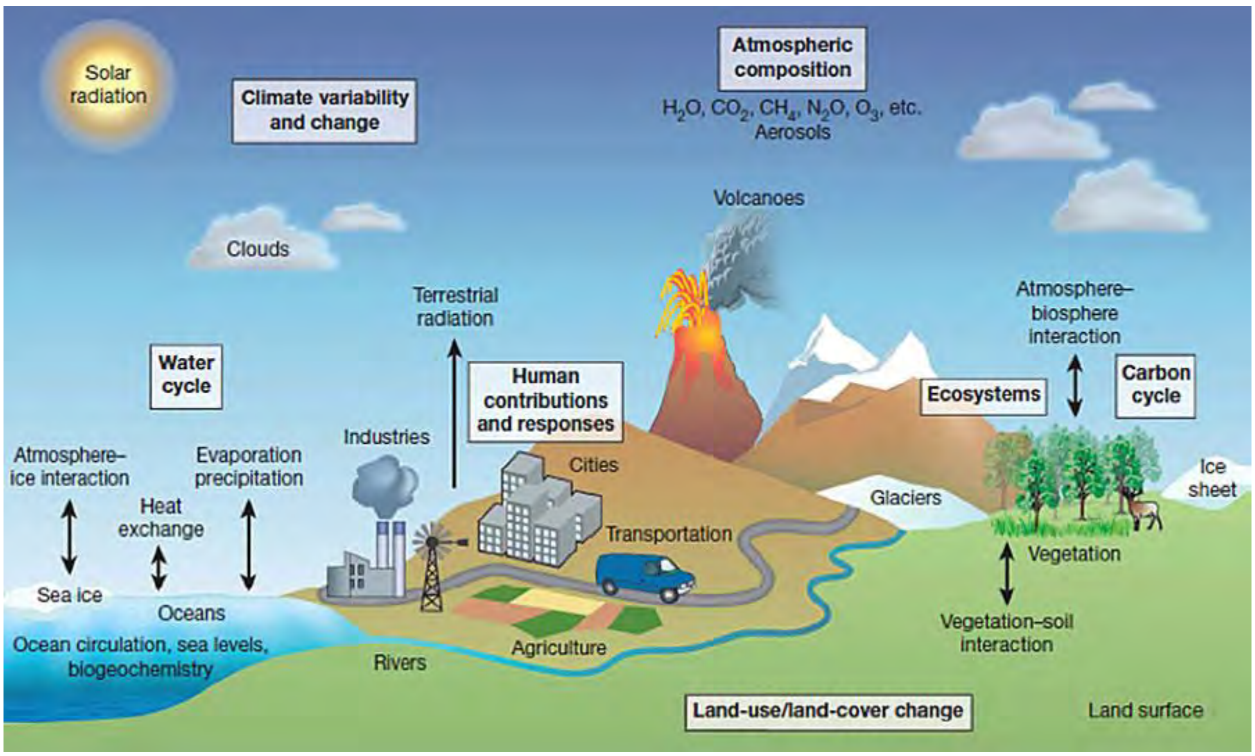
Although modeling outputs contain errors and uncertainty, they are still very useful. Mathematical modeling and prediction help better prepare for the future, at least showing how the future may look at the worst and best even when such modeling fails to forecast the future exactly. Scientists and engineers keep improving models with advances in methods and knowledge, which is then expected to increase modeling accuracy. Weather forecasting and hurricane tracking have become accurate enough to say that a hurricane is going to land at a specific place on the coastline. Advances in computing technology and resources will help further improve the efficiency and accuracy of modeling.

Climate Projections

Climate

Climate is long-term average weather, characterized by many factors including air temperature, precipitation, wind direction, and humidity. The variability in these physical features is expressed as weather and emerges as climate over long periods such as years, decades, and beyond (NOAA 2019; NASA 2019). Climate changes slowly over decades and centuries due to natural processes including volcanic activity, astronomical factors, and human activities such as greenhouse gas emissions (Figure 2.2).

Figure 2.2. Natural and anthropogenic processes in the climate system



Source: NOAA, 2017.

The climate of an area is determined by not only latitude but also elevation, topography, vegetation, land uses, proximity to the ocean, and ocean currents, all of which can make areas located at the same latitude exhibit different climate features. For instance, Florida’s climate is temperate and tropical, but Libya’s is mostly hot, even though Libya is located in similar latitude ranges (Florida lies between 24.5°N and 31°N, and Libya is between 19.5°N and 33°N). At large scales, astronomical factors, including solar variability and oscillations in the Earth’s axis of rotation, sometimes called external forcing, cause the climate to change (NRC 1982).

Climate Models

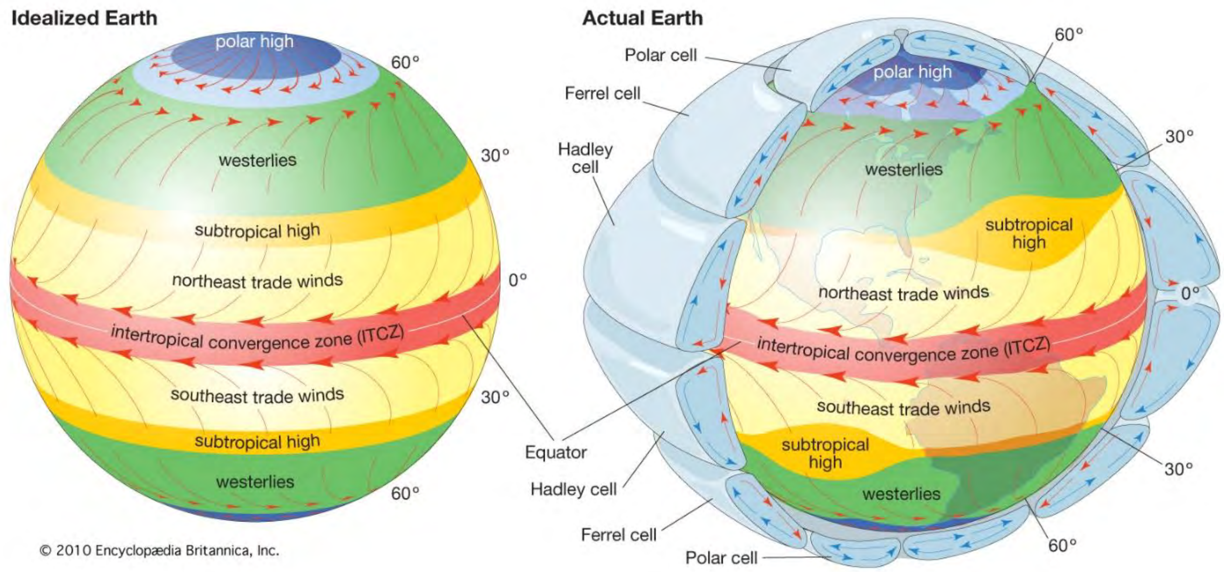
A climate model is a set of equations organized to simulate the relationship between the variables and climate forcings, such as changes in the average amount of solar energy absorbed and atmospheric greenhouse gas concentrations. Here the term *climate forcing* (often called *radiative forcing*) refers to the physical processes affecting the climate on the Earth through various factors. Climate scientists and modelers use climate models to numerically describe (or simulate) meteorological processes and project future climate. Here, the terms *project* or *projection* are commonly used to clarify the fact that predictions are made using climate models conditioned on the scenarios of future greenhouse gas emissions. An effective climate model takes into consideration all important variables, makes realistic assumptions, and reliably predicts climate outcomes before they occur.

Global Circulation Models

Global (or General) Circulation Models (GCMs) are a type of climate simulation model that describes the flows of air, water, and heat around the globe. Climate parameters and variables in the model represent the motion of air and water in the atmosphere (Figure 2.3). The patterns of air and water circulation are generalized and described mathematically in GCMs. There are also Regional Climate Models (RCMs) used to simulate climate processes in more detail at smaller spatial scales such as a country, state, or county.

Several national and international institutes make future climate projections using GCMs that were developed based on the current understanding of climate systems. Since 1995, the Working Group on Coupled Modelling (WGCM) of the World Climate Research Programme (WCRP) has implemented the Coupled Model Intercomparison Project (CMIP). The goal of CMIP is to obtain a better understanding of future climate variability caused by natural and man-made factors by assessing the performance and uncertainty of future climate projections made by multiple climate models (WCRP 2017). The CMIP has expanded in parallel with the Intergovernmental Panel on Climate Change (IPCC) scientific assessment (IPCC 2017). The IPCC is the United Nations body for regularly assessing the science related to climate change for policymakers (IPCC 2017). Now the CMIP and IPCC assessments are in their sixth phase (CMIP6) and assessment report cycle (AR6).

Figure 2.3. General atmospheric circulation patterns represented in climate models.



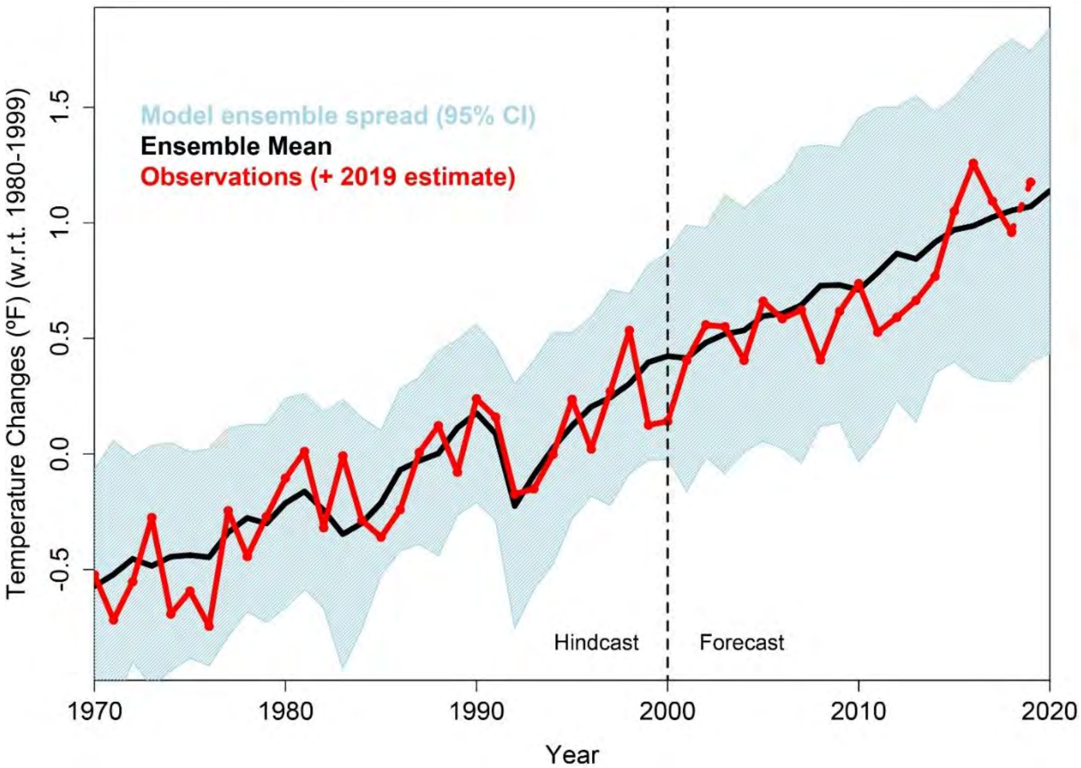
Source: Encyclopedia Britannica, 2018. Atmospheric Circulation: https://www.britannica.com/science/atmospheric-circulation.

As climate models and GCMs represent our understanding of reality, their outputs can include deviations from the real state of the system at any given point in space or time. These deviations are represented in the model as uncertainty, which is formally expressed as the range of possible deviation. Climate modelers try to reduce deviation and uncertainty by incorporating additional observations, knowledge, computing resources, and analytical techniques into climate modeling. Differences in future climate projections made by climate models are attributable to differences in the conceptual understanding of climate systems that are incorporated into climate models. Such differences can be regarded as part of the uncertainty but may also create improved models that lower uncertainty. Scientists often incorporate multiple models to make an ensemble projection that contributes to decision-making processes.

Different models would predict different futures, but they agree with global warming (Oreskes, 2004; Doran and Zimmerman, 2009; Anderegg, 2010; Lynas et al., 2021; Myers et al., 2021). For instance, climate predictions made using GCMs included in IPCC 4th Assessment Report (https://www.ipcc.ch/report/ar4/wg1/) in the early 2000s were found consistent with observations made between 2000 and 2020 (Figure 2.4). In addition, climate modeling results published between 1970 and 2007 were found generally accurate in predicting global warming in the years after publication (Hausfather et al., 2020).

Human-produced emissions of greenhouse gases and aerosols are a critical consideration of climate modeling. Much evidence, including climate modeling and long-term observations, indicates that "human influences have had an increasingly dominant effect on global climate warming observed since the mid-twentieth century" (APS, 2015). More than 97% of studies that investigated the cause of global warming agreed with the scientific consensus on anthropogenic warming (Anderegg et al., 2010; Cook et al., 2013, 2016). "The level of scientific agreement on AGW (anthropogenic global warming) is overwhelmingly high because the supporting evidence is overwhelmingly strong" (Cook et al., 2016). "The scientific consensus might, of course, be wrong. If the history of science teaches anything, it is humility, and no one can be faulted for failing to act on what is not known. But our grandchildren will surely blame us if they find that we understood the reality of anthropogenic climate change and failed to do anything about it" (Oreskes, 2004).

Figure 2.4. Comparison between the multi-GCM ensemble average forecasts made in 2004 and observed temperature.



Source: (Buis, 2020).

Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs)

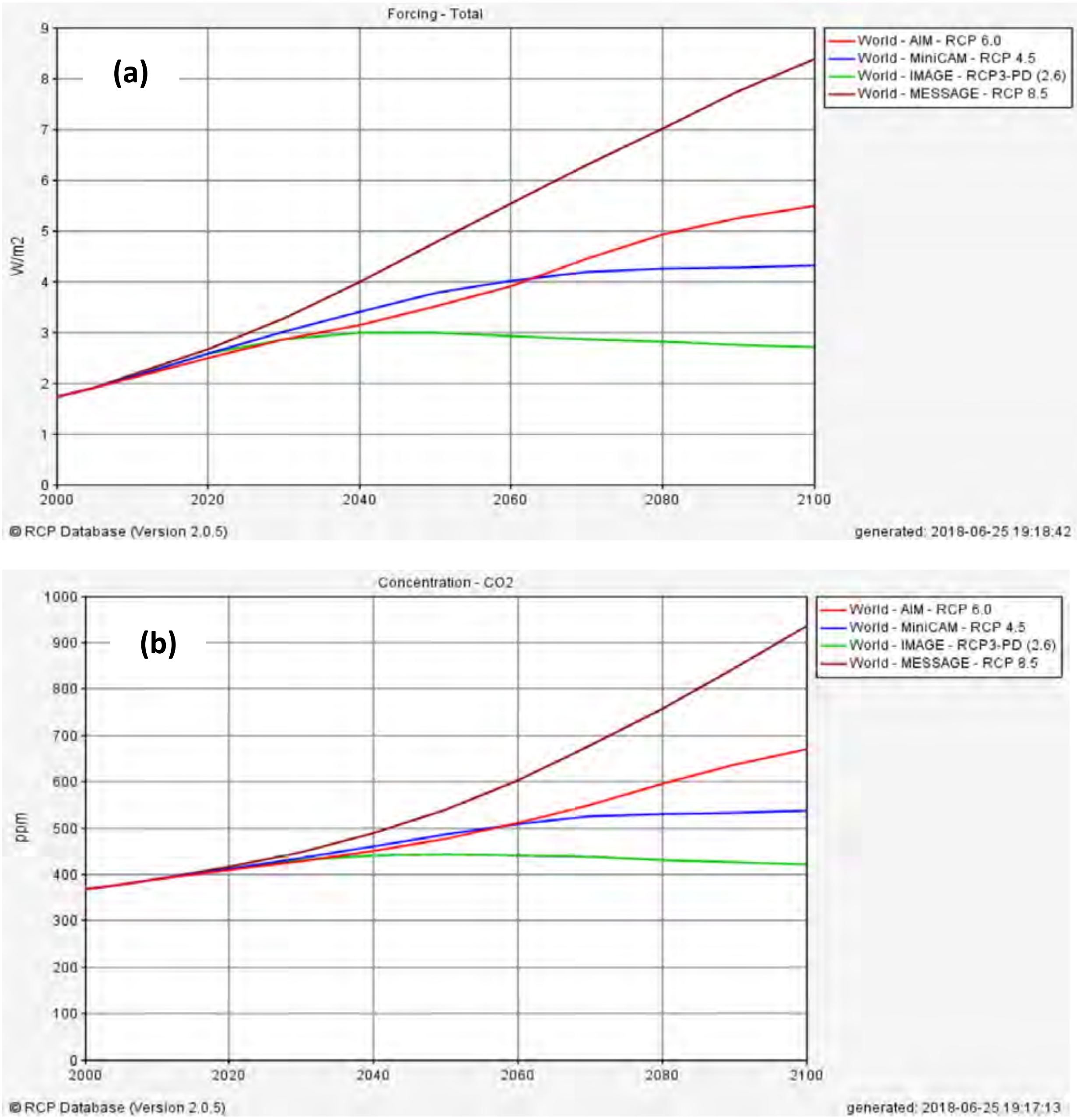
There are many factors that affect climate. Greenhouse gas concentrations are a critical factor that strongly influences the long-term state of Earth's energy balance. Greenhouse gases affect climate by changing the amount of energy from the sun coming in and going out of the Earth's atmosphere. The high concentrations of greenhouse gases in the atmosphere are largely due to human activities, including the burning of fossil fuels. When more energy remains in the environment due to increased greenhouse gas concentrations, the Earth will warm. Earth's temperature generally remains consistent over the long term as the Earth's energy budget has been historically in balance. Radiative forcing, the term used to describe this energy balance, is expressed in watts per square meter (W/m^2). A watt is a unit of power, such as 60 W of an incandescent light bulb and 10 W of a light-emitting diode (LED).

Climate scientists and modelers developed several climate scenarios related to greenhouse gas emissions based on different expectations of how people and societies may respond to changing climate in the future. Such expectations and resulting greenhouse gas concentrations are called *pathways* to certain future climate conditions. Four greenhouse gas concentration pathways were adopted by the IPCC for its fifth Assessment Report (AR5) in 2014 (Gettelman and Rood 2016). The pathways describe four possible climate scenarios, depending on the amount of greenhouse gas emitted in the future, and each scenario is expressed in the unit (W/m^2) of radiative forcing in Earth's energy budget: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (Figure 2.5). For instance, RCP4.5 represents a greenhouse gas concentration pathway that reaches the radiative forcing of 4.5 W/m^2 in 2100 (Figure 2.5a). The radiative forcing of 4.5 W/m^2 means that the Earth receives the net energy gain of 4.5 W per m^2, which is analogous to the situation where we have a lightbulb of 4.5 W in every square meter on the Earth's surface. The higher radiative forcing of the RCP 8.5 scenario means more severe future global warming.

The radiative forcings can be interpreted by the corresponding carbon dioxide (CO2) concentrations (Figure 2.5b). The current concentration of CO2 is around 400 parts per million (ppm), and the most pessimistic scenario (RCP8.5) says that it may reach around 950 ppm by 2100. On the other hand, the most optimistic scenario (RCP2.6) projected that the wide use of bioenergy, carbon capture, and storage technologies, and reduced use of fossil fuels might eventually decrease CO2 concentrations in the late 21st century (Table 2.1). Details of the RCPs can be found in Moss et al. (2010) and van Vuuren et al. (2011).

Climate scientists, economists, and modelers have created a set of new pathways that describe how global society and economies may change in the future, and the new pathways are called *Shared Socioeconomic Pathways* (SSPs). SSPs were adopted by the IPCC for its Sixth Assessment Report (AR6) in 2021. The previous pathways (i.e., RCPs) did not include socioeconomic narratives to go alongside them. The SSPs represent alternative storylines about how the world might develop over the coming century under climate policy (Table 2.2). SSPs were incorporated into the latest climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6).

Figure 2.5. Radiative forcing and the corresponding CO2 concentration pathways of the four RCPs. The horizontal axes represent years, and the vertical axes represent radiative forcings in Watts per square meter (a) and CO2 concentrations in parts per million (b).



Source: RCP Database (2018).

Table 2.1. Characteristics of Relative Concentration Pathways.

Scenarios	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
Greenhouse gas emissions	Very low	Medium-low mitigation Very low baseline	Medium baseline, high mitigation	High baseline
Agricultural area	Medium for cropland and pasture	Very low for both cropland and pasture	Medium for cropland but very low for pasture (total low)	Medium for both cropland and pasture
Air pollution	Medium-Low	Medium	Medium	Medium-high

Source: Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2020.

Table 2.2. Shared Socioeconomic Pathways.

SSP	Descriptions
SSP1	**Sustainability**: Low challenges to mitigation and adaptation
	• The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries.
SSP2	**Middle of the road**: Medium challenges to mitigation and adaptation
	• The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns.
SSP3	**Regional rivalry**: High challenges to mitigation and adaptation
	• A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues.
SSP4	**Inequality**: Low challenges to mitigation, high challenges to adaptation
	• Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries.
SSP5	**Fossil-fueled development**: High challenges to mitigation, low challenges to adaptation
	• This world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development.

Source: Riahi et al. (2017). For more details, see https://climate-scenarios.canada.ca/?page=cmip6-overview-notes.

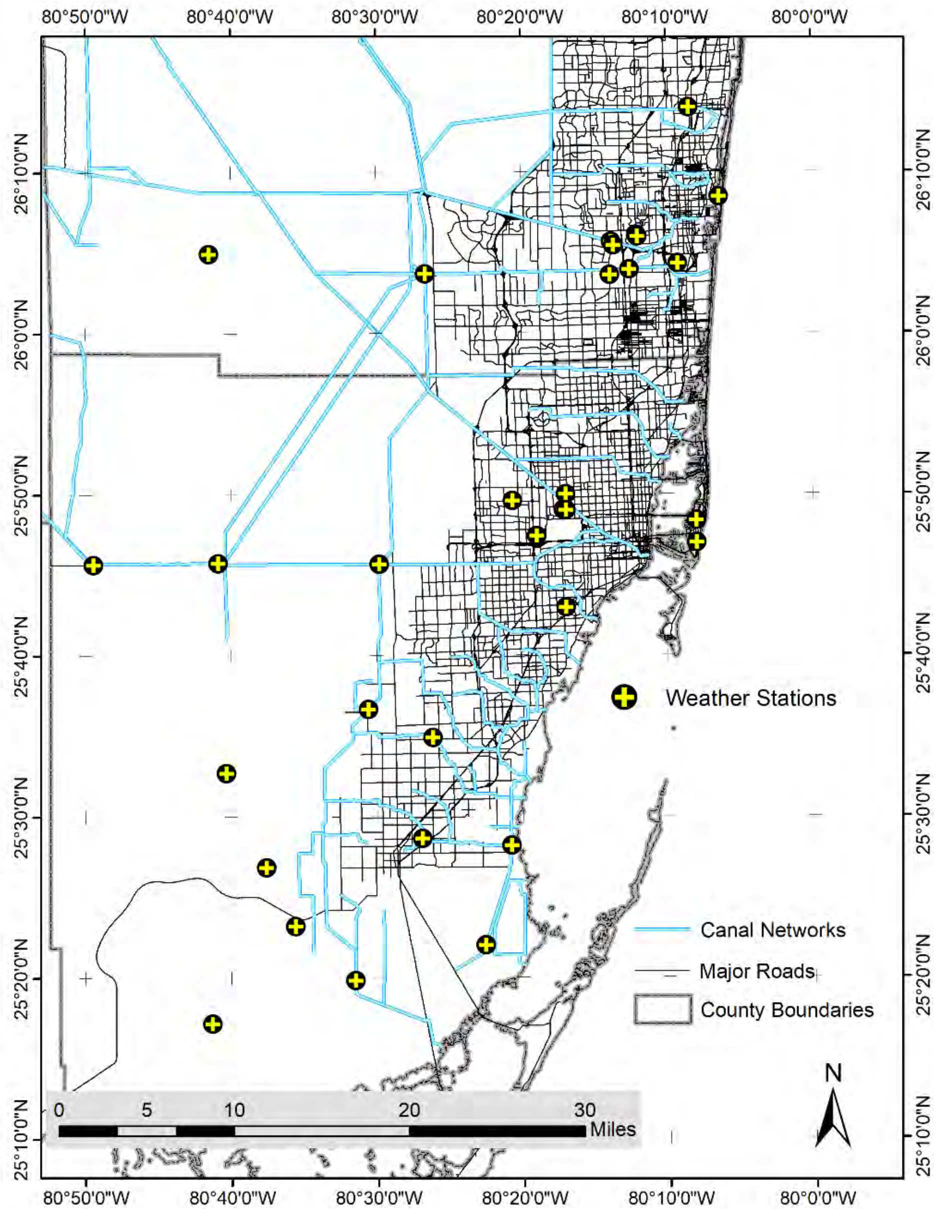
Climate Projections for the Miami-Dade County Study

This study compiled the outputs of climate modeling conducted with 29 models available (Table 2.3) and their variants with different initial conditions and assumptions (Table 2.2) from the CMIP6 in the Earth System Grid Federation (ESGF) platform (https://esgf.llnl.gov/) supported by several U.S. agencies including NSF, NOAA, NASA, and DOE. This study adopted two priority scenarios: SSP2-4.5 and SSP5-8.5 (Tables 1 and 2). Biases in the global-scale climate modeling outputs were corrected using the empirical quantile mapping method (Gudmundsson et al., 2012) and historical weather (daily precipitation, minimum and maximum air temperature) records from 35 weather monitoring stations associated with Miami-Dade County (Figure 2.6). It is well known that the raw outputs of GCMs are limited in their direct application for climate change impact assessment because their spatial resolutions are not consistent and do not match with those of hydrological/hydraulic modeling. Thus, the raw GCM outputs are usually downscaled or interpolated to smaller resolutions or local weather stations. Various methodologies have been developed in this regard, and each method has distinct advantages and disadvantages. This study downscaled the raw GCM outputs to the 35 local weather stations while correcting their biases using the empirical quantile mapping method. Then, the bias-corrected and downscaled weather data were interpolated using the nearest neighbor method (Figure 2.6).

Table 2.3. List of GCMs and their variants considered in this study.

ID	Modeling center	Institution	Model	Res. Lon. × Lat.
1	NCAR	National Center for Atmospheric Research	CCSM4	1.25° × 0.94°
2	NSF-DOE-NCAR	National Science Foundation, Department of Energy, National Center for Atmospheric Research	CESM1_BGC	1.25° × 0.94°
3			CESM1_CAM5	1.25° × 0.94°
4	CMCC	Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC_CM	0.75° × 0.75°
5			CMCC_CMS	1.88° × 1.86°
6	CNRM-CERFACS	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	CNRM_CM5	1.41° × 1.40°
7	CSIRO-QCCCE	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence	CSIRO_Mk3.6.0	1.88° × 1.86°
8	CCCma	Canadian Centre for Climate Modelling and Analysis	CanESM2	2.81° × 2.79°
9	LASG-CESS	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University	FGOALS-g2	2.81° × 3.05°
10	LASG-IAP	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	FGOALS-s2	2.81° × 1.66°
11	NOAAGFDL	Geophysical Fluid Dynamics Laboratory	GFDL-CM3	2.50° × 2.00°
12			GFDL-ESM2G	2.50° × 2.00°
13			GFDL-ESM2M	2.50° × 2.00°
14	NIMR/KMA	National Institute of Meteorological Research/Korea Meteorological Administration	HadGEM2-AO	1.88° × 1.25°
15	MOHC (additional realizations by INPE)	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HadGEM2-CC	1.88° × 1.25°
16			HadGEM2-ES	1.88° × 1.25°
17	IPSL	Institut Pierre-Simon Laplace	IPSL-CM5A-LR	3.75° × 1.89°
18			IPSL-CM5A-MR	2.50° × 1.27°
19			IPSL-CM5B-LR	3.75° × 1.89°
20	MIROC	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5	1.41° × 1.40°
21			MIROC-ESM	2.81° × 2.79°
22			MIROC-ESM-CHEM	2.81° × 2.79°
23	MPI-M	Max Planck Institute for Meteorology (MPI-M)	MPI-ESM-LR	1.88° × 1.86°
24			MPI-ESM-MR	1.88° × 1.86°
25	MRI	Meteorological Research Institute	MRI-CGCM3	1.13° × 1.12°
26	NCC	Norwegian Climate Centre	NorESM1-M	2.50° × 1.89°
27	BCC	Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1	2.81° × 2.79°
28			BCC-CSM1.1 (m)	1.13° × 1.12°
29	INM	Institute for Numerical Mathematics	INM-CM4	2.00° × 1.50°

Figure 2.6. Locations of 35 weather stations used when developing projections of future climate for the study.



Source: NOAA, National Centers for Environmental Information – Climate Data Online: https://www.ncdc.noaa.gov/cdo-web/; SFWMD, DBHYDRO: http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu.

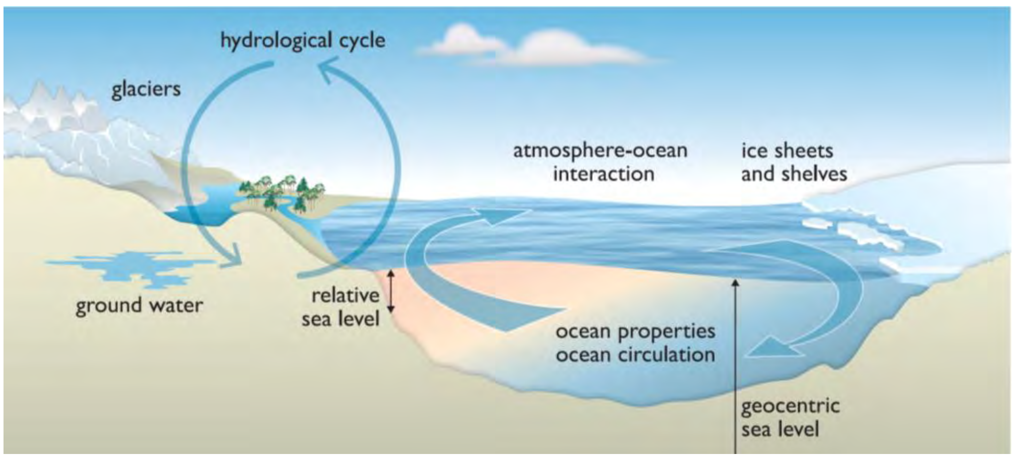
Sea Level Projections

Sea Level Models

Mathematical atmosphere-ocean models describe physical processes contributing to sea level change, rising under global warming conditions. Global sea levels can change due to three fundamentally different mechanisms. First, the volume of ocean water can change in response to changes in its temperature. For example, the volume of a water mass increases with an increase in its temperature, which is called *thermal expansion*. The mass of water melted from glaciers also can increase ocean water mass. However, the impacts of melting sea ice on global sea level are relatively small compared to thermal expansion because it already floats on the sea displacing water corresponding to its weight. The movement of Earth's crust can change the depths of the global ocean. Such a geological process happens slowly over thousands of years; thus, it is less relevant to the century time scale of interest.

The global scale mechanisms, thermal expansion and ice/glacier melting are directly associated with climate change (Figure 2.7). An increase in air temperature will increase the temperature of ocean water and promote the melting of glaciers, which will then increase the sea level. Thermal expansion can be modeled with three-dimensional ocean circulation models. The melting of glaciers is difficult to calculate using models because there is a large number and variety of glaciers; thus, semi-empirical scaling laws are used instead. Overall, the IPCC report (IPCC 2007) projected a sea level contribution from the ice sheets to be close to zero, due to Greenland losing some mass and Antarctica gaining a similar amount. Sea level modeling does not consider the movement of Earth's crust yet.

Figure 2.7. Climate-sensitive processes and components that can influence global and regional sea level.

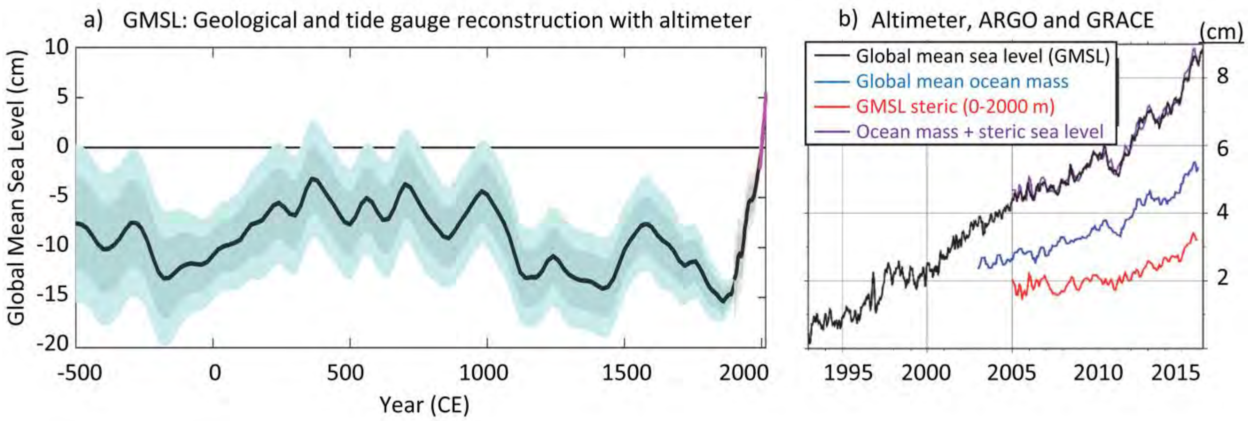


Source: Church et al. (2013).

Due to the complexity of ocean water dynamics, semi-empirical models are often used to explore the linkage between sea level increases and air temperature increases observed in the past. The fundamental assumption of the semi-empirical models is that the sea level rises faster as it gets warmer. Several refinements have been suggested for the semi-empirical models, and it has been shown that a semi-empirical model fits sea level proxy data for the past millennium. Semi-empirical models are used to project future sea level rise from a scenario of future global temperature rise. A fundamental limitation is that one cannot be sure that the simple empirical connection found in the past will continue to hold in the future. Hence, they can only be a temporary projection until comprehensive physically-based modeling has matured enough to provide more robust projections. Physically-based models also have the advantage of, in principle, allowing regional sea level projections.

Sea level change is a long-term response to climate change. Thus, the relatively small projected sea level rise by the year 2100, as compared to the changes measured in tens of meters that occurred in earth's history. The rise by 2100 is only a small beginning of a much larger, multi-century response of ocean and ice sheets to elevated global temperatures (Figure 2.8).

Figure 2.8. a) Global Mean Sea Level (GMSL) rise from -500 CE (500 BCE) to 2010; b) GMSL rise from 1992 to 2015.



Source: Sweet et al. (2017).

The Intergovernmental Panel on Climate Change (IPCC) employed simulation models, called Atmosphere-Ocean General Circulation Models (AOGCMs), to predict sea levels at a global scale (Church et al., 2013). AOGCMs are a kind of climate model that explicitly considers the dynamics of the ocean and its interaction with the atmosphere, known as “coupling”. Local sea level change can deviate from the global mean sea level change for many reasons. Ocean water can be driven by winds. Changes in ocean dynamics, heat content, and salinity can be ununiform. There are vertical land movements that make the sea level change locally relative to the land. In addition, the gravitational pull of land ice is reduced as the ice melts, which has a surprisingly large effect on the sea surface. All these local factors can be considered in sea level modeling, but uncertainties are large. A list of geophysical processes that can affect sea levels is summarized in Table 2.4.

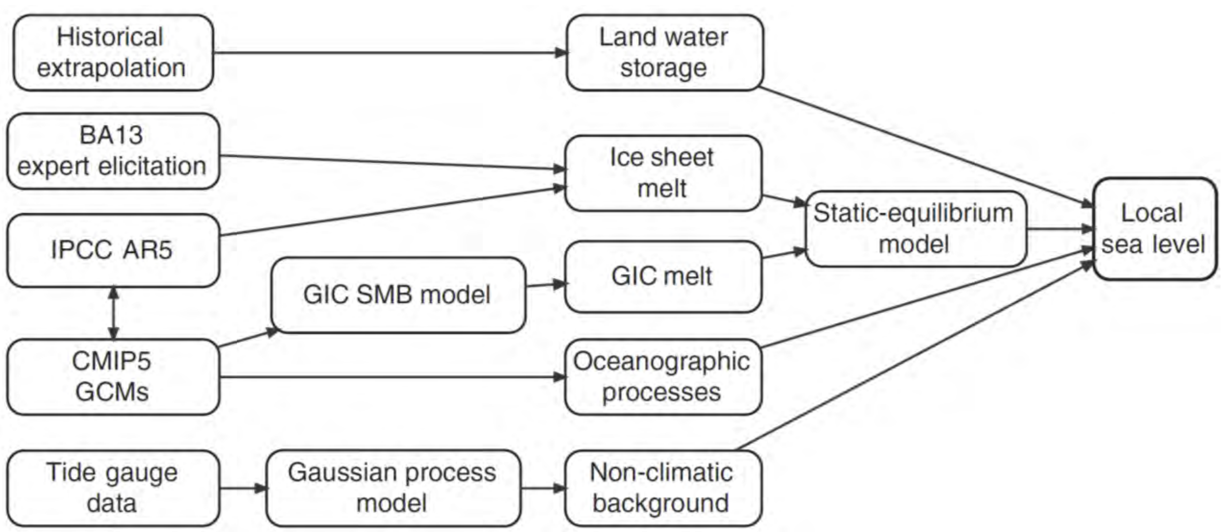
Studies have attempted to translate global scale sea level projections at a local scale (Kopp et al., 2014; Hall et al., 2016; Sweet et al., 2017, 2022). For example, Kopp et al. (2014) considered global thermal expansion, ice sheets (Greenland, West and East Antarctica), land water storage, regional ocean steric and dynamic effects (or oceanographic processes), and long-term, local, non-climate sea level change due to tectonics and sediment compaction to project future sea levels at tide-gauge sites. NOAA’s sea level predictions were made based on the IPCC global sea level projections considering the major mechanisms including thermal expansion, glaciers, ice sheets, and water storage on land, together with regional and local factors such as oceanographic processes and tectonics (Figure 2.9).

Table 2.4. Spatial and temporal scales of geophysical processes affecting sea levels.

Physical Process	Spatial Scale			Temporal Scale	Potential Magnitude (yearly)
	Global	Regional	Local		
Wind Waves (e.g., dynamical effects, runup)			X	seconds to minutes	< 10 m
Tsunami		X	X	minutes to hours	< 10s of m
Storm Surge (e.g., tropical storms or nor'easters)		X	X	minutes to days	< 15 m
Tides			X	hours	< 15 m
Seasonal Cycles		X	X	months	< 0.5 m
Ocean/Atmospheric Variability (e.g., El Niño Southern Oscillation, ENSO)		X	X	months to years	< 0.5 m
Ocean Eddies, Planetary Waves		X	X	months to years	< 0.5 m
Ocean Gyre and Over-turning Variability (e.g., Pacific Decadal Oscillation, PDO)		X	X	years to decades	< 0.5 m
Land Ice Melt/Discharge	X	X	X	years to centuries	< 0.1 m
Thermal Expansion	X	X	X	years to centuries	< 0.1 m
Vertical Land Motion		X	X	minutes to centuries	< 0.1 m

Source: Sweet et al. (2017).

Figure 2.9. Flow of sources of information used in local sea level projections. GCMs: global climate models, GIC: glaciers and ice caps, SMB: surface mass balance.



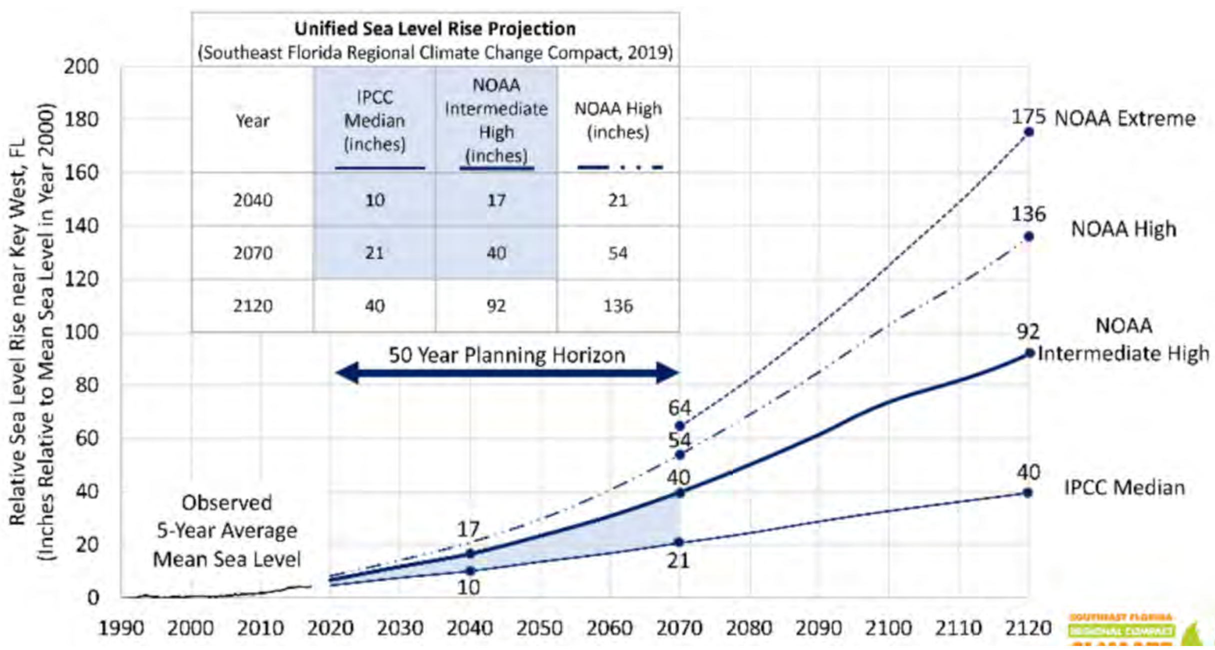
Source: Sweet et al. (2017).

Sea Level Prediction Considerations for the Miami-Dade County Study

This study directly adopted three sea level rise projections recommended by the Unified Sea Level Rise Projection of the Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (2020; hereafter the Compact): IPCC Median, NOAA Intermediate High, and NOAA High. These sea level projections were prepared based on the projections of NOAA and IPCC (Church et al., 2013; Sweet et al., 2017). Here, some details of the sea level rise projection are briefly introduced to provide a background of the projections employed in the groundwater modeling of this study. The Compact selected the year 2000 as the initial year of the sea level rise projection as it was used as the reference year for the latest regional sea level projections of NOAA (Sweet et al., 2017). The Key West tidal gauge (NOAA Station ID 8724580) that has historical tidal elevation records since 1913 was selected as the reference gauge for the calculation of the regional sea level projection.

The regional sea level projections available from NOAA (Sweet et al., 2017) were used to create the NOAA Intermediate High and High curves (Figure 2.10 and Table 2.5). One of the previous curves, USACE High was replaced by NOAA Intermediate High in 2022 (Table 5). The global-scale IPCC Median sea level projection was modified for the Key West station using the NOAA methodology to create the regional IPCC Median curve (Sweet et al., 2017). The NOAA Virginia Key tidal gauge station was used as the reference point for sea level along the coastline of Miami-Dade County in the groundwater modeling. The relative sea level rise scenarios (or the relative change of sea level to the mean sea level) for the Key West station were directly applied to the Virginia Key station for the future groundwater projection in this study.

Figure 2.10. Unified sea level rise projections for the Key West station.



Source: Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (2020).

Table 2.5. Summary of unified sea level rise projections at the Key West station in 2030, 2060 and 2100.

Year	IPCC Median Regional (inches)	NOAA Intermediate High (inches)	NOAA High (inches)
2030	8	12	14
2060	17	31	41
2100	33	74	103

Source: Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (2020).

Groundwater Projections

Groundwater model

Groundwater moves within the aquifer, and its movement is driven by differences in the elevation of the water table. Many different factors control the direction and rate of the movement such as topography (elevation and slope), weather events (precipitation), the hydraulic properties of the soil located above the aquifer, and the geological characteristics of the aquifer rocks. The mathematical representation of groundwater movement necessarily requires simplifying assumptions, which are embodied in the governing equation describing the mechanism. For example, the governing equation for groundwater flow is often derived by combining Darcy's law with an equation of continuity. Darcy's law states that the groundwater flow rate is proportional to the difference in the water table elevations at two different locations. In addition, the continuity equation represents the idea that water is conserved in a flow, i.e., water can neither be created nor annihilated when moving from one place to another place.

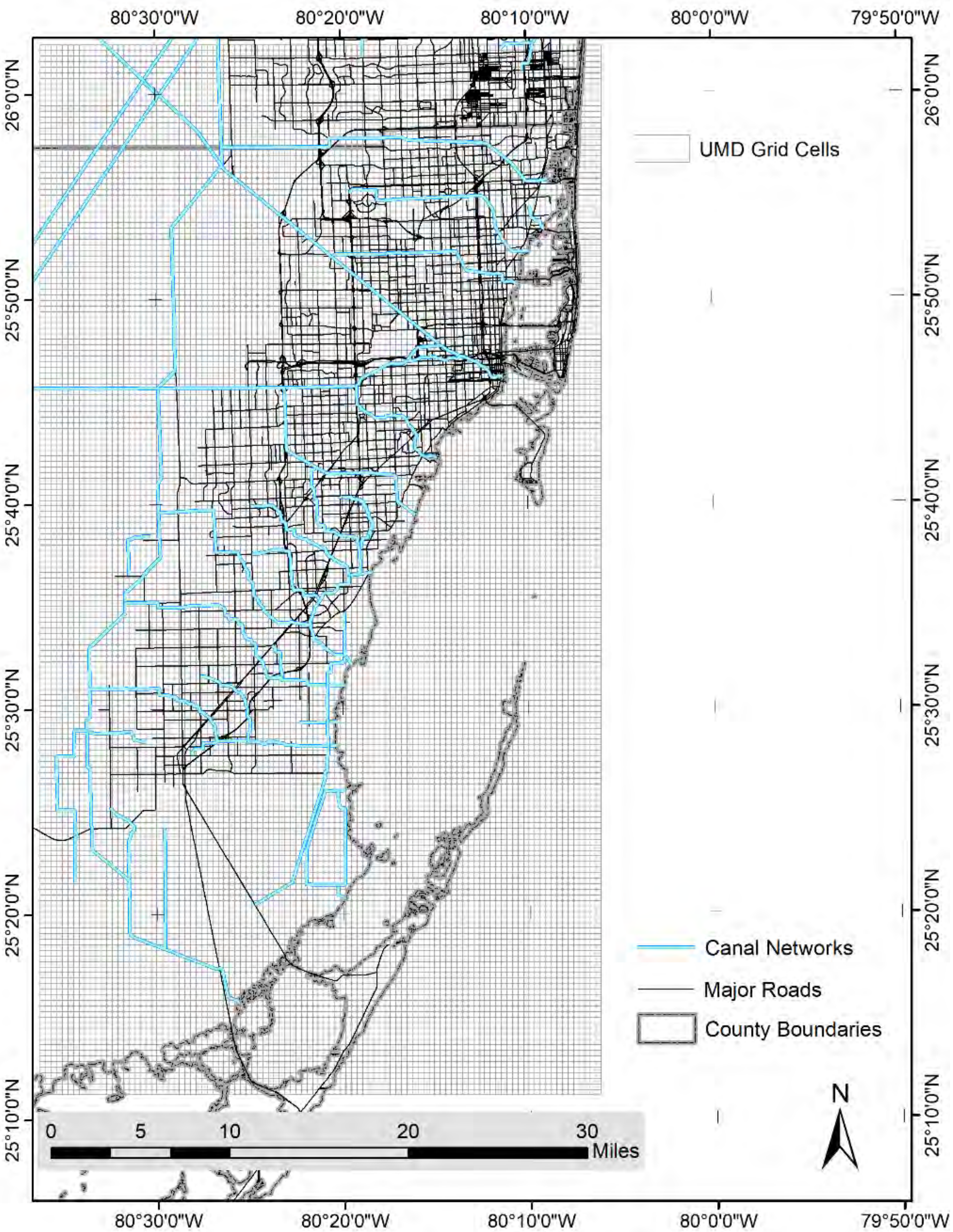
There are many different models developed to mathematically describe groundwater flow. The modular three-dimensional finite-difference ground-water flow model (MODFLOW) is one of the groundwater models most widely used and regarded as a standard for groundwater simulation (USGS, 2022a, 2022b). MODFLOW was first developed and released by the U.S. Geological Survey (USGS) in 1984, and many updates and advancements have been made to MODFLOW since then. MODFLOW uses the finite differences method to solve the governing equation in the form of a partial differential equation. The modeling domain is divided into square cells to represent the spatial variations of landscape, soils, aquifer rocks, and management practices. For example, the domain of the groundwater modeling was split into 500 m X 500 m cells in this study, and the size of a cell was determined considering modeling efficiency, the spatial variability of the landscape, and the geological features of the aquifer (Figure 2.11). The model domain contains a total of 15,853 active cells, covering an area of 3,963.2 km^2 (1,530.2 mi^2), to be considered in groundwater modeling.

Urban Miami-Dade (UMD) model

South Florida hydrology is dominated by canal networks that are managed to provide flood protection, water supply, and environmental protection. The landscape varies widely across South Florida, with corresponding differences in the way water is managed. The evaluation of planning, regulation and operational issues requires a simulation model that captures the effects of both regional and local hydrology.

Miami-Dade County is underlain by the shallow, unconfined to semiconfined, highly permeable Biscayne aquifer, which is the primary source for municipal water supply and irrigation. The surface water system, including the canal networks in Miami-Dade County, is hydraulically and hydrologically connected to the groundwater system; thus, the management of the surface water system can affect groundwater resources and vice versa.

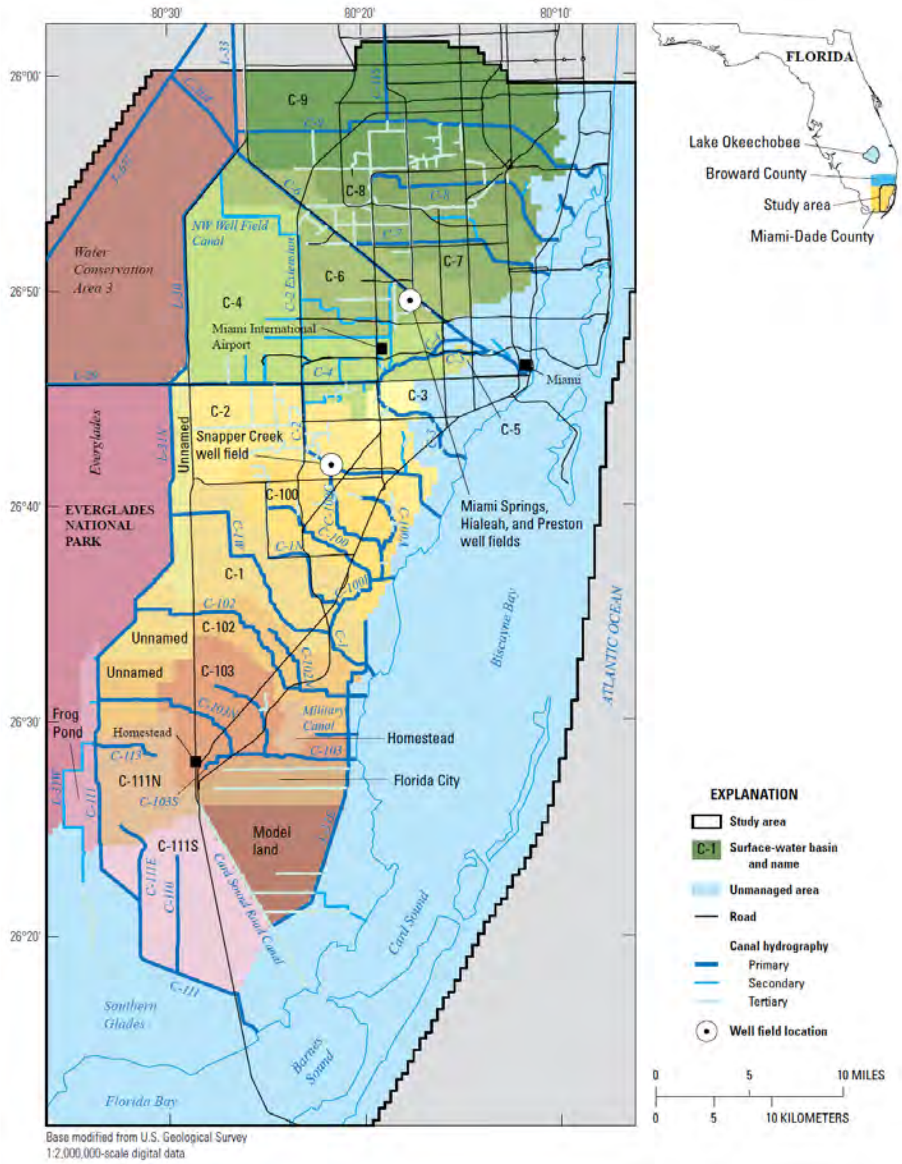
Figure 2.11. Map of grid cells within the modeling domain of the USGS MODFLOW model used for the Urban Miami-Dade (UMD) model.



Source: Hughes and White (2016).

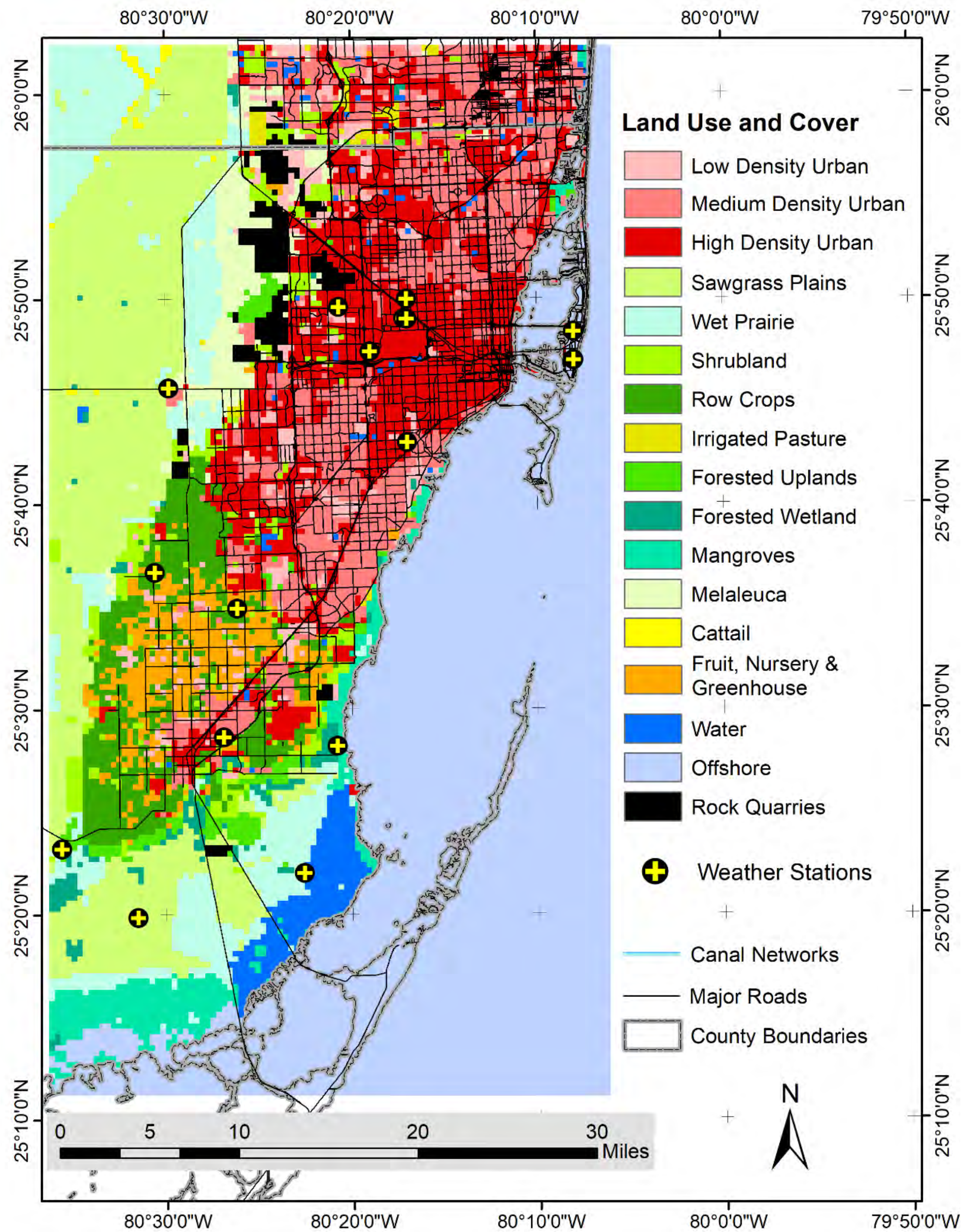
In 2008, USGS, in cooperation with the Miami-Dade County Water and Sewer Department, initiated a hydrologic analysis to improve the understanding of the contribution of various components to the water supply at the county scale. One of the objectives of the collaboration was to create a modeling tool that would allow various components of the complex hydrologic system to be quantified, and to evaluate the effects of historical and potential system stresses on the coupled surface-water/groundwater system and hydrologic budget. The tool created is a coupled surface-water/groundwater flow model of the urban areas of Miami-Dade County that can quantify canal leakage and groundwater inflow from the Everglades, as well as simulate changes in surface-water stage and discharge, groundwater levels, and the position of the freshwater-seawater interface (Hughes and White, 2016; Figures 2.11, 2.12, and 2.13).

Figure 2.12. Water control structures and facilities within the spatial domain of the UMD groundwater model.



Source: Hughes and White (2016).

Figure 2.13. Map of land uses/covers used for the UMD modeling, weather stations, canal networks, and major roads within the modeling domain.



Source: Hughes and White (2016).

USGS created the MODFLOW model to describe groundwater flow in the aquifer in the early 1980s (McDonald and Harbaugh, 2003). MODFLOW has been much improved with modules for additional functionality since then (Harbaugh, 2005; Langevin et al., 2008; Niswonger et al., 2011). The UMD model was developed on the basis of the MODFLOW model with additional modules including the Surface-Water Routing (SWR1) Process (Hughes et al., 2012) and the Seawater Intrusion (SWI2) Package (Bakker et al., 2013). The SWR1 Process was developed to simulate surface-water stage, surface-water discharge, and surface-water/groundwater interaction. The SWI2

Package was created to simulate variable-density flow in the interface between fresh groundwater and saltwater by solving the advective-dispersive transport equation so that saltwater intrusion processes can be simulated.

This study used a numerical model that Hughes and White (2016) developed to evaluate the impacts of climate changes and sea level rise on the groundwater system of Miami-Dade County. The model is often called the Urban Miami-Dade (UMD) model. The UMD model is one of the variants of MODFLOW with enhanced capacity of representing and simulating surface water stage, surface water discharge, surface water and groundwater interaction, and seawater intrusion into the Biscayne aquifer.

The simulation domain of the UMD model covers the part of Miami-Dade County, from the eastern parts of Everglades National Park (the west boundary) and Water Conservation Area 3 (the northwest boundary) to the coastline (the south and east boundaries), and some southern parts of Broward County (the C-9 surface-water basin; the north boundary). Thus, the model domain covers all agricultural areas in Miami-Dade County (Figures 2.12 and 2.13). The land uses and covers of Miami-Dade County have changed substantially, and the UMD model employs a representative land use and cover map derived from the investigation of historical changes in land use data developed by the South Florida Water Management District (SFWMD) for 1995, 2000, 2004, and 2008 and aerial photographs from 1999 (Hughes and White, 2016). The Florida Land Use and Cover Classification System attributes in the land use data of the SFWMD were simplified to 20 basic land use categories of the South Florida Water Management Model (SFWMM) (Figure 2.13; MacVicar et al., 1984; SFWMD, 2005; Hughes and White, 2016). Surface water deliveries through the canal network and groundwater seepage from the water conservation areas and Everglades are simulated as the boundary condition in the groundwater modeling.

The UMD model was constructed by using existing hydraulic and hydrogeologic data and the estimated position of the freshwater-seawater interface. The model is based on a number of the previous groundwater-flow and solute-transport models designed to (1) investigate groundwater flux into Biscayne Bay (Langevin, 2001), (2) evaluate the factors contributing to hypersalinity events in Biscayne Bay (Lohmann et al., 2012), and (3) estimate time-based capture zones and drawdown contours for two well fields in Miami-Dade County (Brakefield et al., 2013). These previous studies were expanded by specifically simulating surface-water stage and discharge in the managed canal system, dynamic canal leakage to the Biscayne aquifer, and discharge from the Biscayne aquifer to the canal system. The model also includes estimates of agricultural water use, recreational (lawn) irrigation (e.g., common public areas, parks, playgrounds, athletic fields, cemeteries, and golf courses), and septic tank return flows.

Observation data collected from January 1997 through December 2010 were used to calibrate and verify the model, and includes periods of below-average, average, and above-average rainfall. The model was calibrated with surface-water stage and discharge observations, net surface-water subbasin discharge, and groundwater level observations.

Groundwater projections for Miami-Dade County

The future daily climate and sea level scenarios projected for the modeling domain were input into the UMD model prepared by USGS (Hughes and White, 2016). As described before, the global-scale climate and sea level projections were downscaled into the local weather and tidal observation stations associated with the groundwater modeling domain. From two shared socio-economic pathways (SSP2-4.5 and SSP5-8.5), five climate modeling outputs, and three sea level rise curves (IPCC Median, NOAA Intermediate High, and High), a total of 30 different climate and sea level scenario combinations were considered in the groundwater modeling. The multiple projections give us an idea of the range of possible results and degree of uncertainty in the projections.

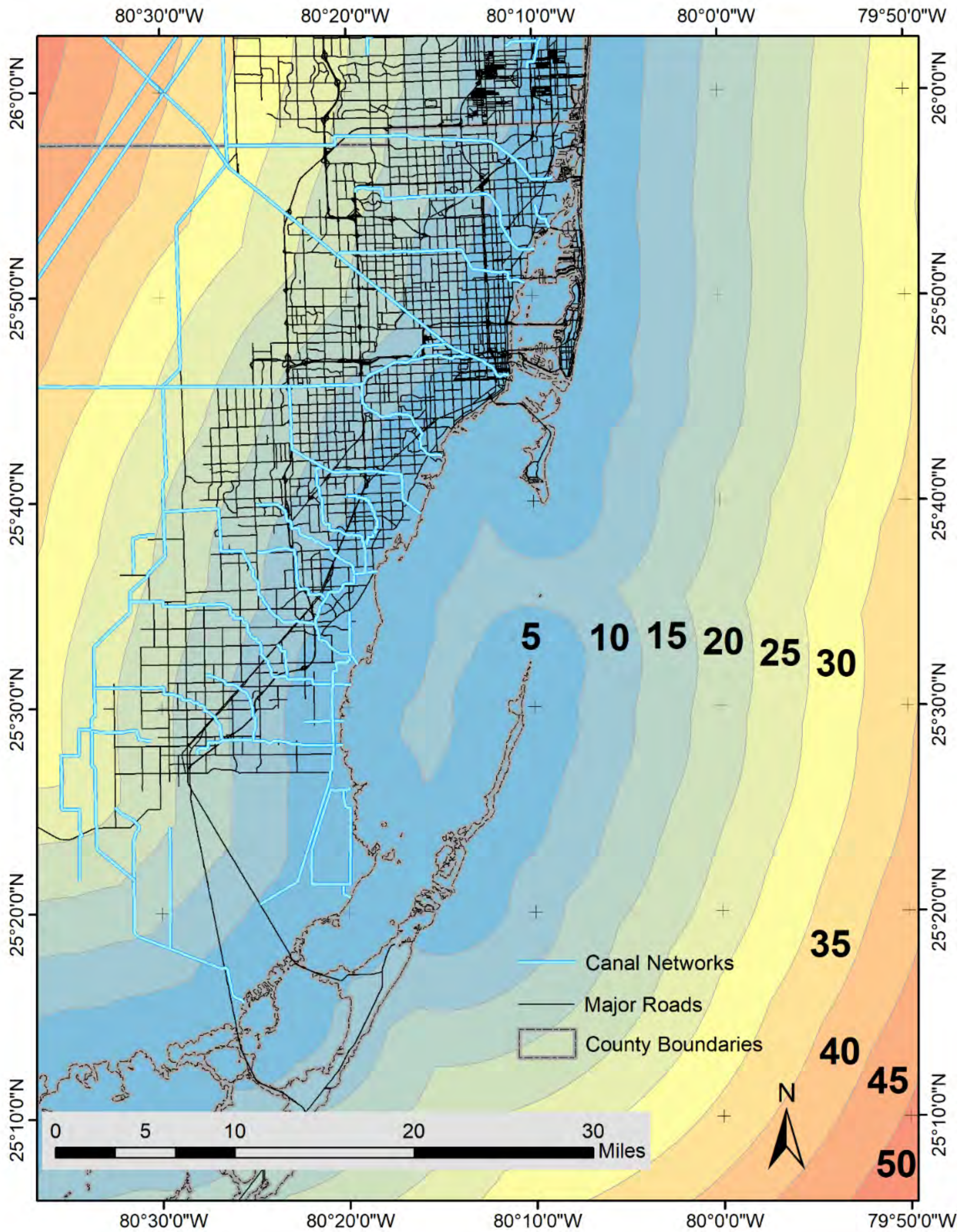
Sea level observations made at the Virginia Key (NOAA Station ID: 8723214) from January 1, 1996, to December 31, 2020, were used to represent the daily variations of the projected future sea levels as the boundary conditions of the UMD modeling. It was assumed that the sea level may increase linearly between the years 2040, 2070, and 2120 for which the projected sea level rises are specifically described in the latest (2019 Update) report of Unified Sea Level Rise Projection Southeast Florida (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2020). In the case of sea level projections for the period from 2026 to 2040, for example, the time series of historical sea level observations made at the Virginia Key station from 1996 to 2010 were linearly increased so that the projected sea level would increase by 17 inches by the end of 2040 under the NOAA Intermediate High sea level scenario.

Results

This report presents the results of climate and hydrology projections made under future climate change and sea level rise scenarios. For brevity, this report details projections made under the climate scenario SSP2-4.5 (Table 2.2) and the sea level scenario of NOAA Intermediate High (Table 2.5) which is considered the most likely scenario, then, these results are compared with other climate and sea level scenarios. The climate change scenario of SSP2-4.5 represents "a central pathway in which trends continue their historical patterns without substantial deviations," and it has been used as a representative climate scenario in many other studies (Boer et al., 2016; Gillett et al., 2016; Kravitz et al., 2015; O'neill et al., 2016). The IPCC Median and NOAA Intermediate High scenarios are regarded as the lower and upper boundaries for short-term use until 2070, respectively (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2020).

Future climate (precipitation and air temperature) and hydrology (groundwater level and salinity) projections were summarized by land use classes and 5-km distance zones from the shorelines of Miami-Dade County (Figure 3.1). The UMD model employs a land use and cover map based on historical land use and cover changes from 1995 to 2008 and aerial photos (Figure 2.13; Hughes and White, 2016). Summaries of the UMD groundwater modeling results were made according to the land use and cover classes. The land uses and covers used in the UMD model may not represent the current land uses and covers but do represent land uses and covers in the recent past. The land uses and covers keep changing dynamically over time, and it is impractical to update the maps in a real-time manner.

Figure 3.1. Map of five-kilometer (3.1-mile) distance zones from the shoreline of Miami Dade County.



Climate Projections

This study compiled the outputs of climate modeling conducted with 29 different climate models (Table 2.3) and their variants with different initial conditions and assumptions from the CMIP6 in the Earth System Grid Federation (ESGF) platform (https://esgf.llnl.gov/) supported by several U.S. agencies including NSF, NOAA, NASA, and DOE.

Climate and groundwater modeling using the 29 climate models and the UMD model projected the future precipitation, air temperature, groundwater elevation, and areas affected by saltwater intrusion within the UMD modeling domain from 2026 to 2100. A total of 174 (29 climate models × 2 climate scenarios × 3 sea level rise scenarios) future groundwater flow (elevation and saltwater intrusion) projections were generated using the 29 climate models under each of the combinations of the two climate and three sea level rise scenarios.

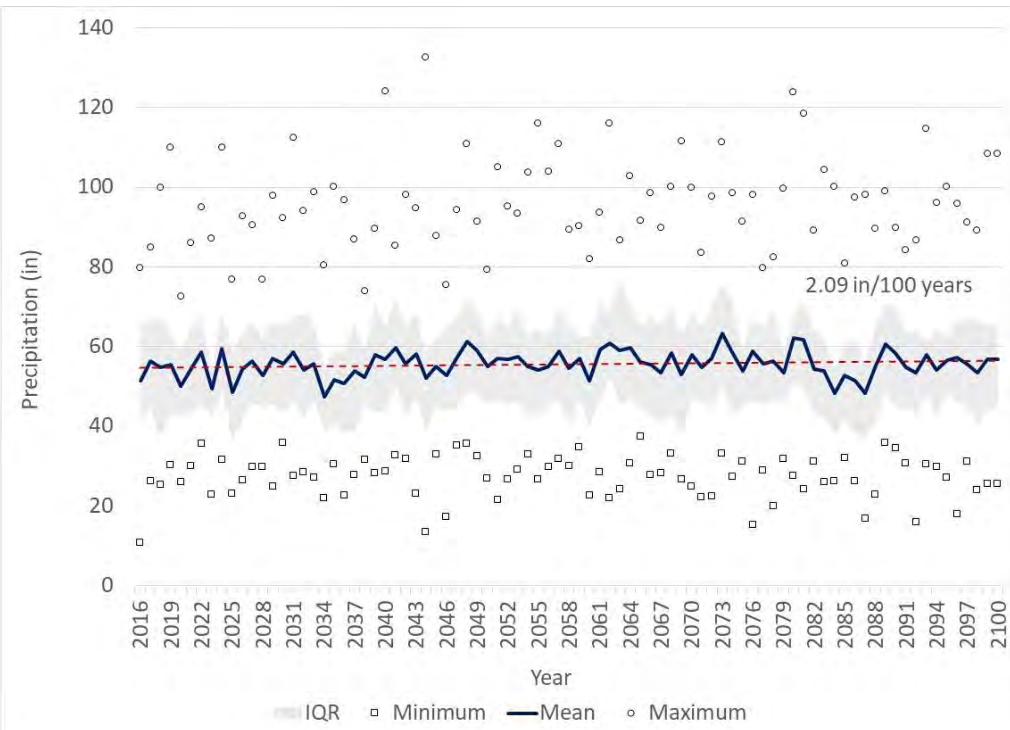
For the brevity of presentation, projections made using the 29 climate models were often averaged to create representative projections for each of six (2 climate scenarios × 3 sea level rise scenarios) scenario combinations. Projections made for the entire future period, from 2026 to 2100, are presented in this report, however, we summarize results for the near future period from 2026 to 2050, mid future period from 2051 to 2075, and far future period from 2076 to 2100 for purposes of this study. The future projections of variables of interest were compared with the reference or historical values for the baseline period of 1996 to 2020. Variations in the projections made using the 29 climate models were quantified and summarized using the range (maximum and minimum) and interquartile range (IQR), i.e. the difference between the 75th and 25th percentiles of the data. Relatively larger variations mean higher uncertainty in the projections. Such variations can be regarded as the amount of uncertainty due to climate modeling as well as the future climate and sea level rise scenarios, which are highly uncertain because they are sensitive to many socioeconomic factors, including population, education, economic growth, policy changes, urbanization, technological development, and their complicated interactions (Table 2.2). This report presents the groundwater projections made under the six different climate and sea level rise scenario combinations to show the overall range and uncertainty of the projections.

Precipitation

Annual precipitation was projected to increase in the future at the rate of 3.9 mm per 10 years under the SSP2-4.5 scenario (Figures 3.2 and 3.3). The 29 climate models did not have good agreement with each other on precipitation as expected, creating an uncertainty band shown as the interquartile range (IQR) in the plot of the future precipitation projections. The average annual precipitation was projected to be 1,304 mm (51.3 inches) between 2026 and 2050, which represented a decrease of 2.3% compared to the historical average of 1,334 mm (52.9 inches) from 1970 to 2014. Annual precipitation fluctuates over time within the uncertainty band width of 514 mm. Under the worst-case SSP5-8.5 scenario, average annual precipitation was projected at 1,381 mm (54.4 inches), which represents an increase of 3.5% compared to the historic average, although the uncertainty was slightly lower (464 mm or 18. inches). For the entire future period from 2026 to 2100, the worst-case climate scenario (SSP5-8.5) projected the annual average precipitation of 1,354 mm (53.3 inches), which was slightly less than 1,377 mm (54.2 inches) for the moderate climate scenario (SSP2-4.5), which might be attributed to differences in the projected air temperature (Figures 3.4 and 3.5). The relatively hotter airmass projected under SSP5-8.5 can hold more water vapor before saturation, resulting in less precipitation than a relatively cold airmass. The precipitation projection results indicate that the rainwater input to the aquifer may not be substantially changed in the future. The results imply that total freshwater input to the aquifer also may remain unchanged if the amount of water delivered to the canal systems such as L-67C, L-33, and C-11S from the upstream areas does not change in the future.

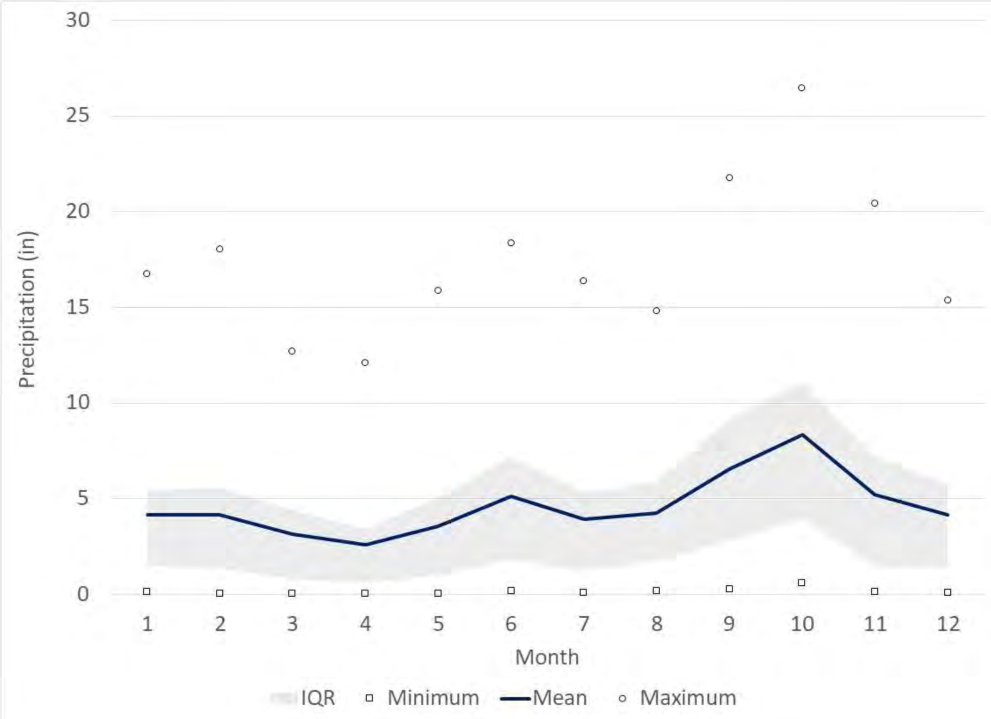
Some of the plots included in this report present the amount of uncertainty with uncertainty bands, which were created under the SSP2-4.5 climate scenario. The uncertainty bands in grey color represent the inter-quartile range (IQR), i.e., the difference between the 3rd quartile and 1st quartiles of climate or groundwater projections. The maximum and minimum values of the projections are represented with empty circles and boxes, respectively. The IQR was considered a measure of the uncertainty or spread of the data in the projections and is less sensitive to extreme values and outliers compared to the range between the maximum and minimum values, and it has been commonly employed to quantify uncertainty.

Figure 3.2. Projected annual precipitation amounts in Miami-Dade County, 2016-2100.



The average projected monthly precipitation is shown in Figure 3.3. The level of disagreement between models was greater at the monthly scale than at the annual scale, which is expected. The uncertainty band of the precipitation projections was wider during the wet season from September to November than the dry seasons from March to May. Some of the models provided unrealistic projections, demonstrating the limitations of global-scale climate modeling applied to local areas (Her et al., 2019; Lee et al., 2021; Meresa et al., 2022). However, the projections can be still useful when they are processed to improve their reliability using statistical methods such as a multi-model ensemble, which was employed in this study. In the near future from 2026 to 2050, monthly precipitation was projected to peak in October, which agrees with the historical patterns in the local area.

Figure 3.3. Projected monthly precipitation for the near future period under the SSP2-4.5 climate scenario.



Air Temperature

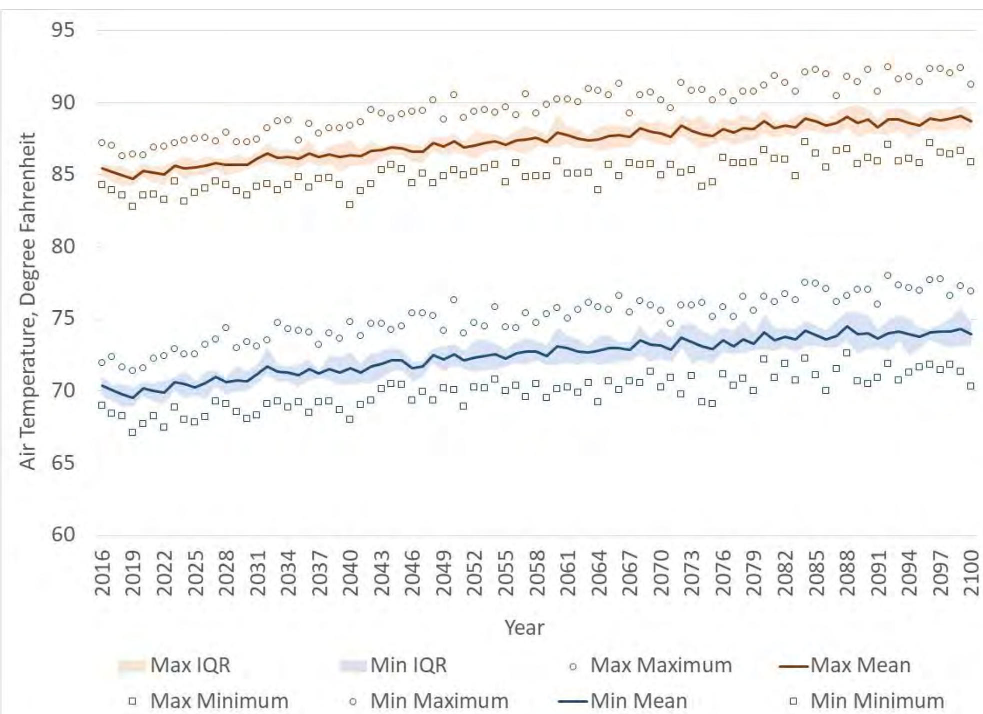
The annual average daily maximum and minimum air temperatures were projected to increase in the future under the SSP2-4.5 climate scenario (Figures 3.4 and 3.5). The average daily maximum and minimum air temperatures were projected to be 30.2 degrees Celsius (86.4 Fahrenheit) and 21.9 degrees Celsius (71.4 Fahrenheit) during 2026 to 2050, and to increase to 31.4 degrees Celsius (88.5 Fahrenheit) and 23.3 degrees Celsius (73.9 Fahrenheit) from 2076 to 2100. Historical records from 1970 to 2014 showed the average daily maximum and minimum air temperatures were 28.7 degrees Celsius (83.7 Fahrenheit) and 20.1 degrees Celsius (68.2 Fahrenheit), respectively. Compared to the historical period averages, the maximum and minimum air temperature may increase by 1.5 degrees Celsius (2.7 Fahrenheit) and 1.8 degrees Celsius (3.2 Fahrenheit) from 2026 to 2050. Under the worst case scenario, the average daily maximum and minimum air temperatures were expected to increase by 1.7 degrees Celsius (3.1 Fahrenheit) and 2.0 (3.6 Fahrenheit) degrees Celsius respectively for the near future (from 2026 to 2050) and by 4.7 degree Celsius (8.5 Fahrenheit) and 5.3 degree Celsius (9.5 Fahrenheit) respectively for the far future (from 2076 to 2100).

The annual average increase in daily minimum air temperature of 0.0287 degrees Celsius (0.052 Fahrenheit) was expected to be faster than the daily maximum air temperature (0.0261 degrees Celsius /year or 0.047 Fahrenheit /year). Such a finding agrees with other studies about future air temperature projections (Karl et al., 1993; Caesar et al., 2006; Her et al., 2019). The degree of agreement between the 29 climate models was much higher in the air temperature projections than in the precipitation projections (Figures 3.2 and 3.4). For example, the average width of the uncertainty band of the daily maximum air temperature (Figure 4) was only as much as

2.4% (0.75 Celsius degree) of the overall average for the entire future period, which is much smaller than 37.6 % for annual precipitation (Figure 3.2).

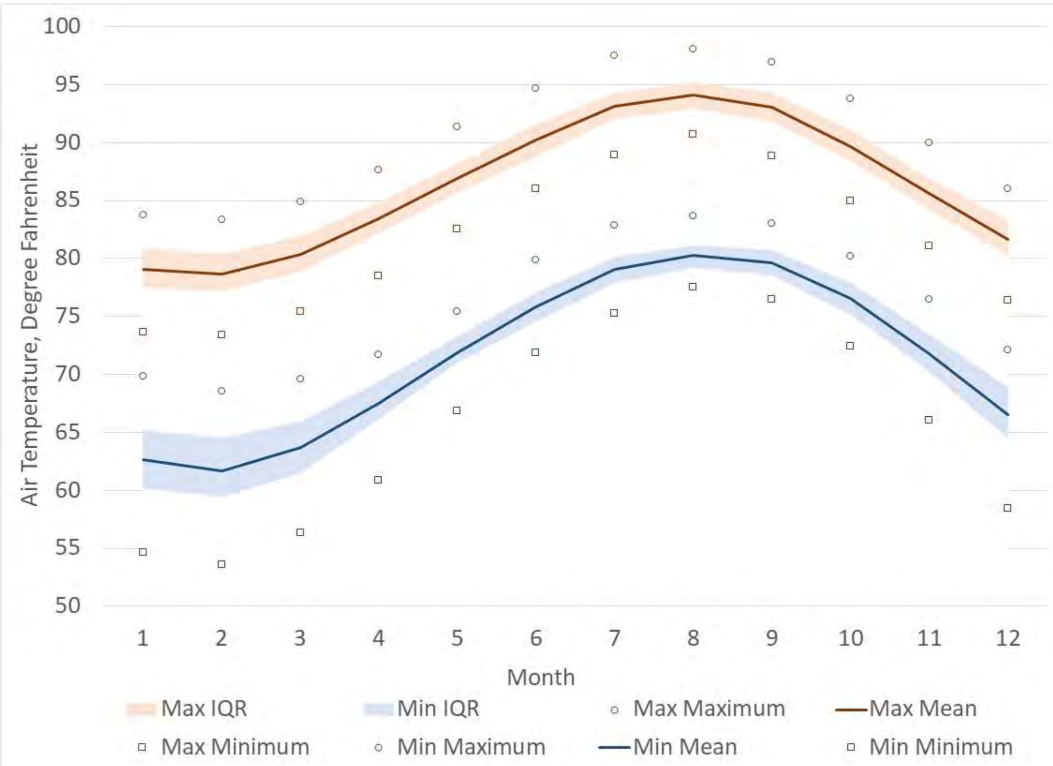
The air temperature projection results indicate that the rate of evaporation and evapotranspiration by plants may increase in the future, which may then increase the frequency and/or severity of drought events and subsequently require more irrigation water to maintain crop health. An increase in air temperature may help certain types of plants and crops grow well, but others may experience heat stress more frequently and/or severely depending on the growing seasons. Increased air temperature was known to help improve winter growth and plant crops earlier but can increase heat stress and water use of crops and decrease crop production (Her et al., 2017). In addition, increase in air temperature can decrease the nutrient quality of feed, feed intake of livestock, milk and meat production, and reproduction (Her et al., 2017). Some crops now grown in Miami-Dade County may no longer be adapted to the higher temperature regime. In addition, increased air temperature is known to promote the spread of pests and diseases. For example, global warming could lead to an expansion of the geographic distribution of agricultural insect pests and an increase in the number of their generations (Skendžić et al., 2021). Changes in air temperature and precipitation may favor or limit pest species depending on local climate and ecology (Schneider et al., 2022). Farmers have managed to adapt to the variations of weather and climate in South Florida, but the projected climate change may bring additional challenges to local agriculture.

Figure 3.4. Projection of annual average minimum and maximum air temperature.



Monthly variations of average daily maximum and minimum air temperature were projected using the climate models as shown in Figure 3.5. Similar to the case of the precipitation projection, the level of disagreement between models was greater at the monthly scale than at the annual scale, however, outliers were not large, compared to the precipitation projections (Figures 3.3 and 3.5). The uncertainty bands tend to be relatively wider in the winter season from December to March and narrower in the summer season from June to September. Thus, more temperature variability may be experienced during the important winter season for vegetable crops in the County.

Figure 3.5. Projection of monthly average minimum and maximum air temperatures.



Sea Level Projections

This study adopted three sea level rise projections recommended by the Unified Sea Level Rise Projection of the Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (2020): IPCC Median, NOAA Intermediate High, and NOAA High. These sea level rise projections were first prepared for regional planning purposes in 2011, then updated in 2015 and 2020 (Table 3.1, Figures 3.6 to 3.8).

Table 3.1. Sea level rise projections at the Key West station, 2030-2120.

Year	IPCC Median Regional (IM)		NOAA Intermediate High (NI)		NOAA High (NH)	
	Inches	Meters	Inches	Meters	Inches	Meters
2030	8	0.20	12	0.30	14	0.36
2040	10	0.25	17	0.43	21	0.53
2060	17	0.43	31	0.79	41	1.04
2070	21	0.53	40	1.02	54	1.37
2100	33	0.84	74	1.88	103	2.62
2120	40	1.02	92	2.34	136	3.45

Source: Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2020.

Sea level changes continuously. Short-term, hourly and daily, variations are usually caused by waves and tides attributed to changes in local current, sustained wind, and/or the gravitational pull of the moon (Figure 3.6). Sea level also varies seasonally mainly due to seasonal changes in sea water temperature and resulting sea water volume (Figure 3.7). In the Northern Hemisphere, for example, air temperature is relatively high in summer, which leads to increase in sea water temperature. The warmed sea water expands and raises sea level. It takes time for sea water to warm up, which creates a time delay between the peaks of air temperature (e.g., August in Figure 3.5) and sea water temperature (e.g., October in Figure 3.7). Long-term variations generally occur due to global scale changes such as thermal expansion and ice/glacier melting, which are closely associated with climate changes. The overall trend of the sea level projections recommended by the Compact are described in Figure 3.8. The baseline scenario assumes that the historical sea level variation may continue in the future without any long-term increasing or decreasing trend. The daily and monthly variations observed in the past were assumed to be repeated with projected long-term trend (or increase, Table 3.1) in the other scenarios, including IPCC Median, NOAA Intermediate High, and NOAA High.

Figure 3.6. Daily sea level projections for the Virginia Key station.

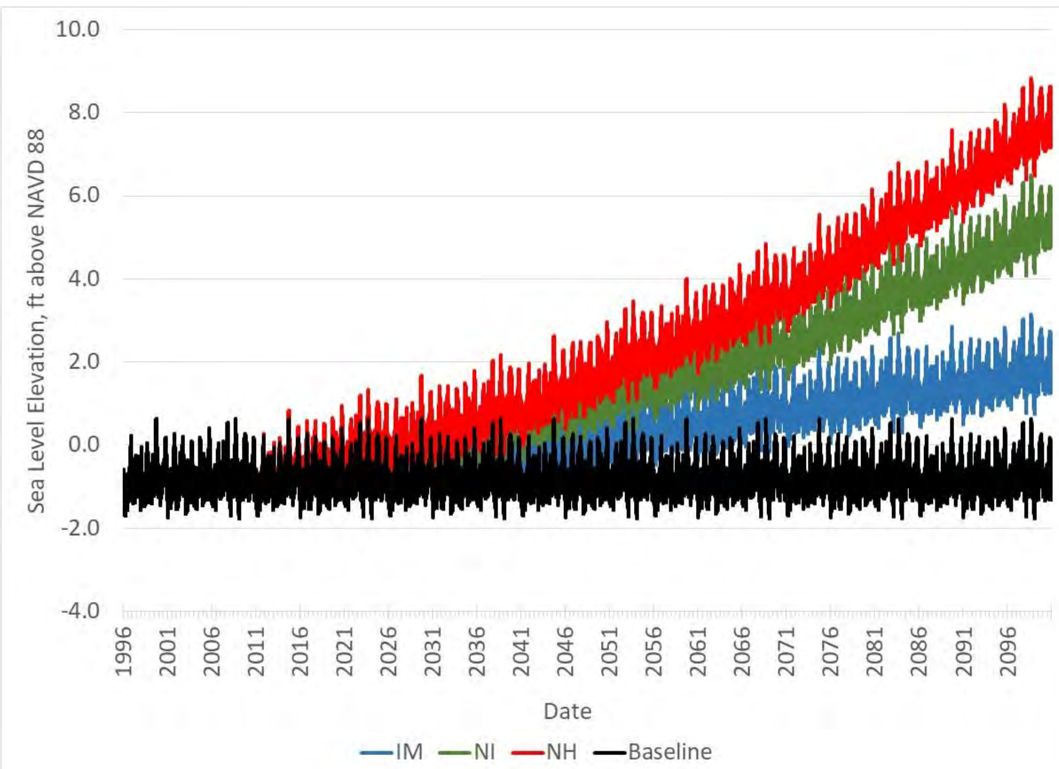
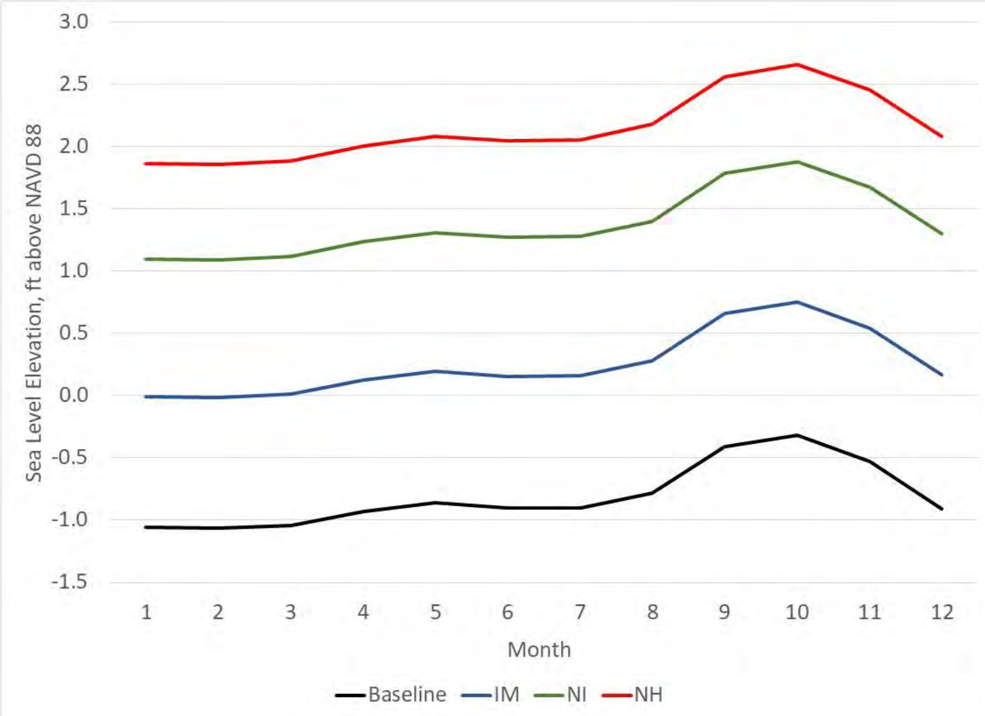
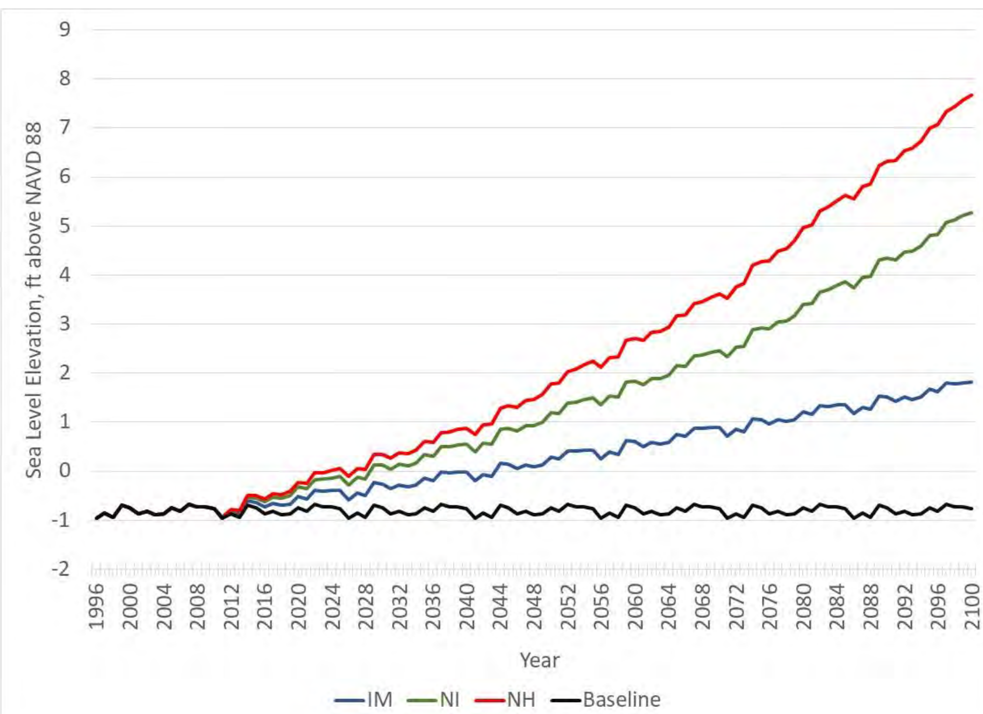


Figure 3.7. Monthly average sea level projections for the Virginia Key station.



Source: Unified Sea Level Rise Projection Southeast Florida.

Figure 3.8. Annual average sea level projections for the Virginia Key station.



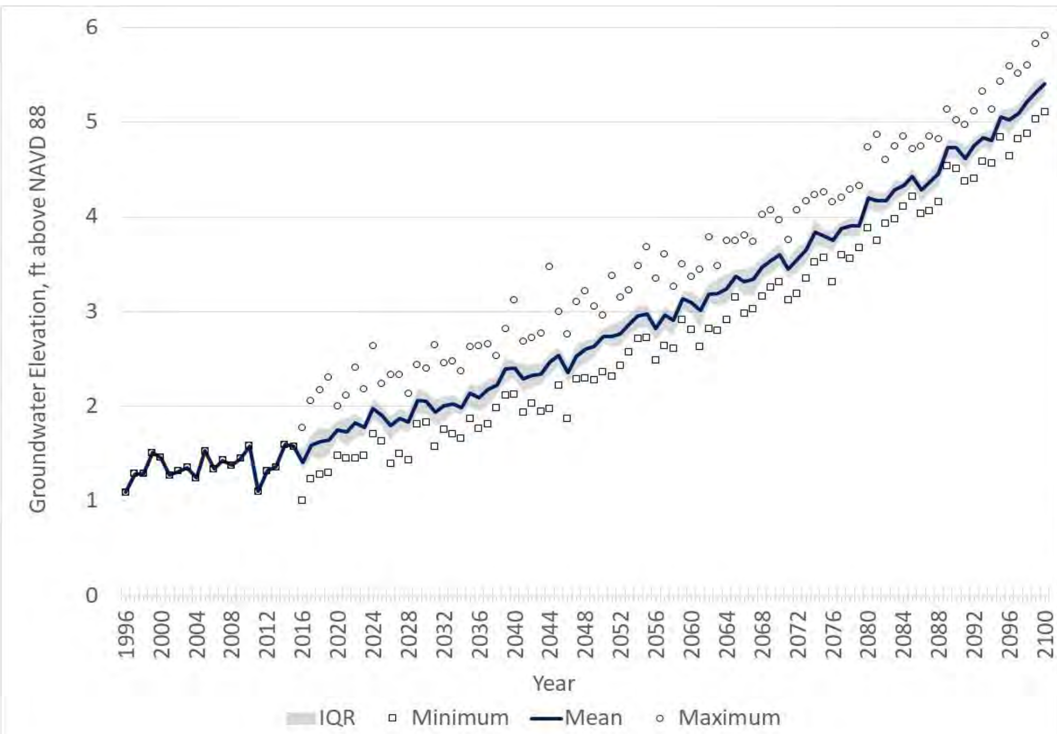
Source: Unified Sea Level Rise Projection Southeast Florida and historical daily sea level variations observed at the Virginia Key station.

Groundwater Projections

Groundwater level

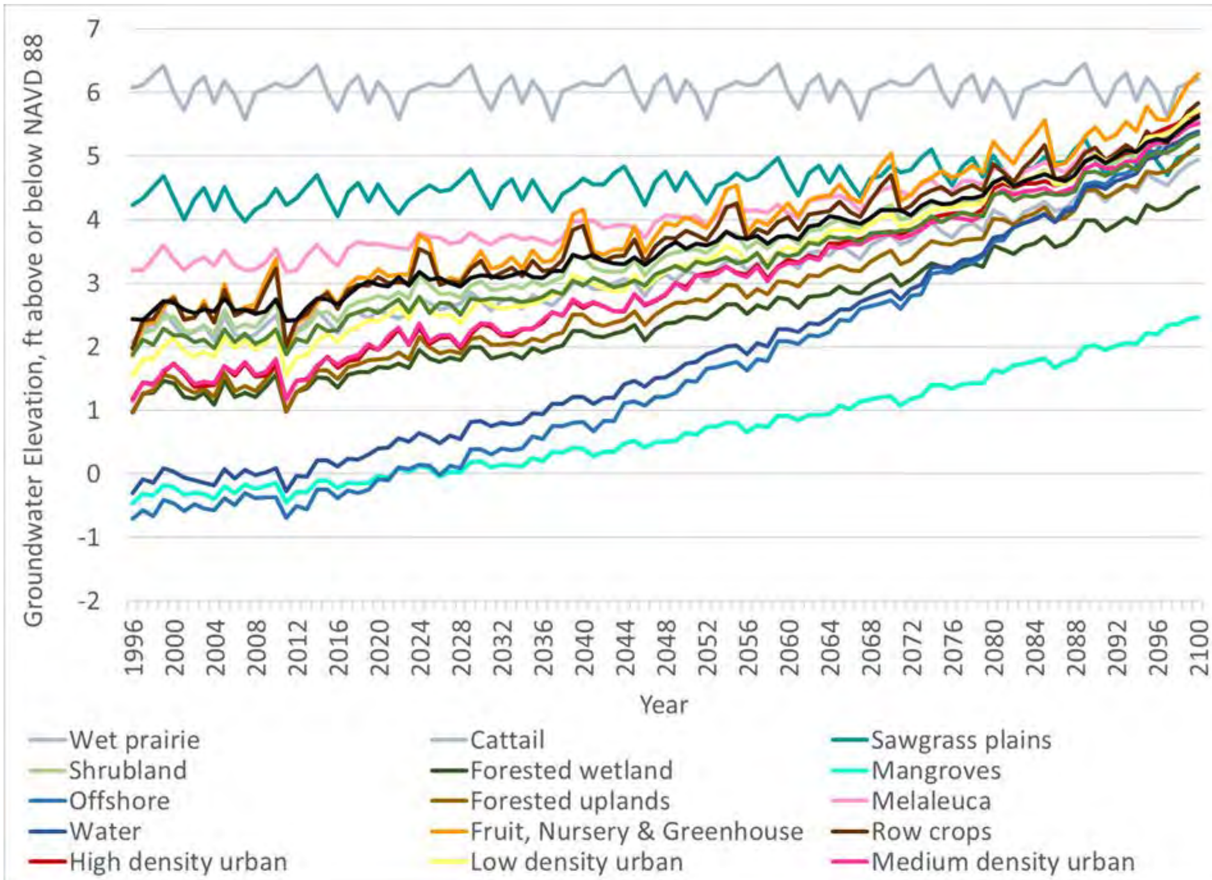
The overall groundwater elevation was projected to increase by 0.25 m in the near future period of 2026 to 2050 and 0.95 m in the far future period of 2076 to 2100, compared to the elevation observed in the baseline period of 1996 to 2020, within the UMD modeling domain under the NOAA Intermediate High (NI) sea level and SSP2-4.5 climate scenarios (Figure 3.9). The groundwater elevation projections vary across sea level and climate scenarios, locations, and seasons. The NOAA High (NH) and SSP5-8.5 scenario combination projected groundwater elevation to increase by 0.31 m in the near future and 1.31 m in the far future periods. Groundwater elevation projections with respect to land use and cover classes, distance from the shoreline, and month are described in Figures 3.10 to 3.16.

Figure 3.9. Projected groundwater elevation under the NOAA Intermediate High sea level scenario.



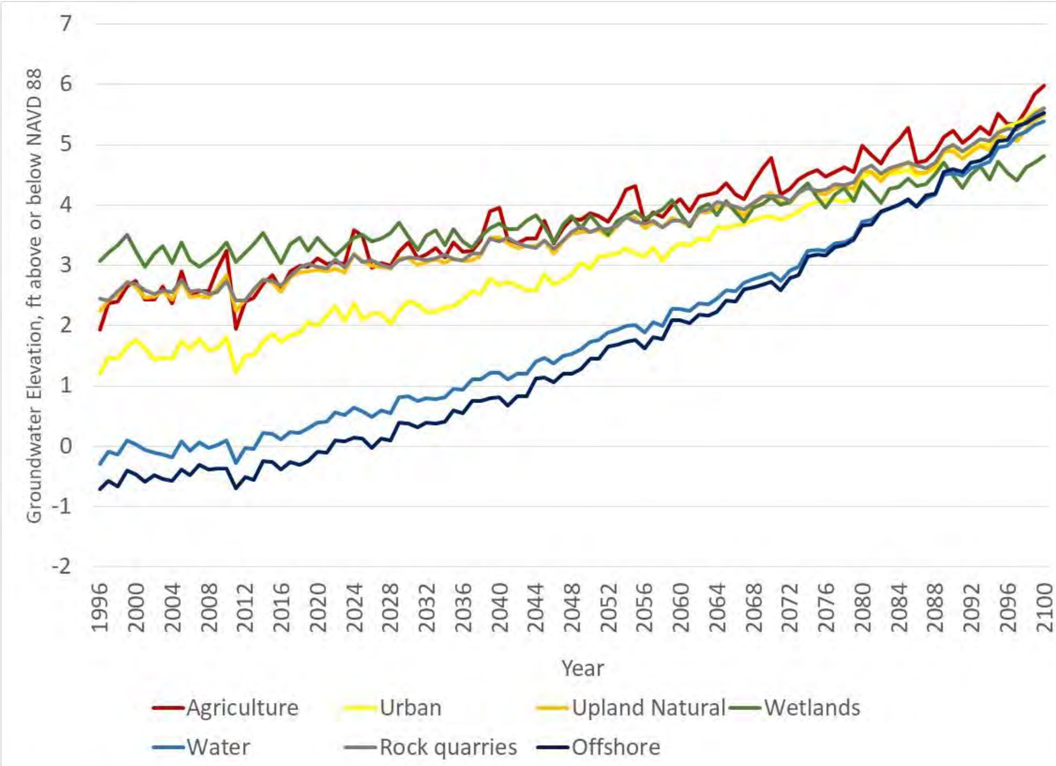
The groundwater elevations of water and offshore areas (Figure 2.13) were projected to most rapidly increase under the NI sea level and SSP2-4.5 climate scenarios (Figure 3.10). On the other hand, groundwater elevation was projected to remain relatively unchanged in cattail and sawgrass plains areas. For example, groundwater elevations of offshore and cattail areas were projected to increase by 1.46 m and 0.00 m, respectively, in the far future period compared to the baseline period. In addition, the groundwater elevation of high density urban areas was projected to increase by 0.98 m, from 0.48 m to 1.47 m above the NAVD 88 in the far future period.

Figure 3.10. Projected groundwater elevation by the land uses/covers under the NOAA Intermediate High sea level scenario.



For an understanding of groundwater impacts, the 17 land uses and covers used in the UMD modeling were consolidated into seven classes, including agriculture (row crops including vegetables, other fruit, nursery, and greenhouse crops, and irrigated pasture), urban (low, medium, and high density), upland natural areas (forested upland, shrubland, and Melaleuca), wetlands (wet prairie, cattail, mangroves, sawgrass plains, and forested wetland), water, rock quarries, and offshore (Figure 3.11). Similar to the case of the detailed land uses and covers, the groundwater elevation was projected to rapidly increase in water, offshore, and urban areas that are close to the coastline. The groundwater elevation of agricultural areas was expected to increase faster than some other land uses and covers such as wetlands and upland natural, and it can be higher than those of the others in the far future. This modeling result implies that the agricultural land uses may experience root zone saturation more frequently due to the high groundwater table in the future, which may affect crop productivity and require adaptive agricultural management practices that can mitigate the impacts. For example, Zhang et al. (2019) estimated the occurrence and spatial distribution of root zone saturation potential in the C111 canal areas based on historical groundwater level observations and groundwater modeling results. They found that root zone saturation durations were positively associated with rainfall amount, antecedent groundwater elevation, and canal water stages. In the dry season, the antecedent groundwater elevation and canal water stage played a more important role in determining the root zone saturation.

Figure 3.11. Projected groundwater elevation for consolidated land use/cover classes under the NOAA Intermediate High sea level scenario.



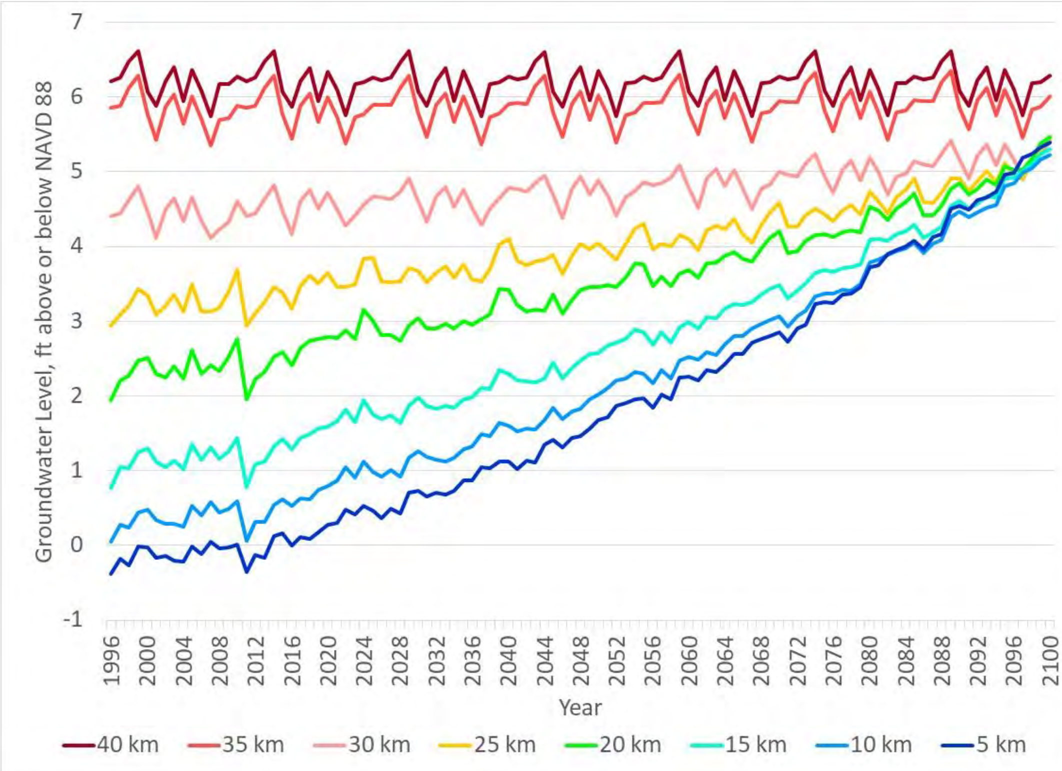
Under the most likely sea level and climate scenarios, the groundwater elevation of agricultural land uses was projected to increase by 0.37 m during the period of 2046 to 2055, compared to the baseline period elevation (Table 3.2). The projected groundwater elevation increase of 0.37 m for agricultural land uses is smaller than the projected sea level increases shown in Table 3.1 because the effect is attenuated at a distance from the coastline.

Table 3.2. Projected groundwater elevations and their increases for agriculture land uses under the NOAA Intermediate High sea level and SSP2-4.5 climate scenarios.

Year or Period	Groundwater Elevation (meters/feet above NAVD 88)		Groundwater Increase, from baseline (meters/feet)	
	Meters	Feet	Meters	Feet
1996 to 2020 (baseline)	0.80	2.62	-	-
2026 to 2035	0.97	3.18	0.17	0.56
2036 to 2045	1.07	3.51	0.27	0.89
2046 to 2055	1.17	3.84	0.37	1.21

The projected increase in groundwater elevation is greater closer to the shoreline (Figure 3.12). In the far future, for instance, groundwater elevations of areas located 35 to 40 km from the shoreline were actually projected to decline by 0.01 m, while areas 0 to 5 km from the shoreline were projected to increase by 1.33 m, under the most likely sea level and climate scenarios. Groundwater elevation of areas 30 km or more from the shoreline may not be affected at all.

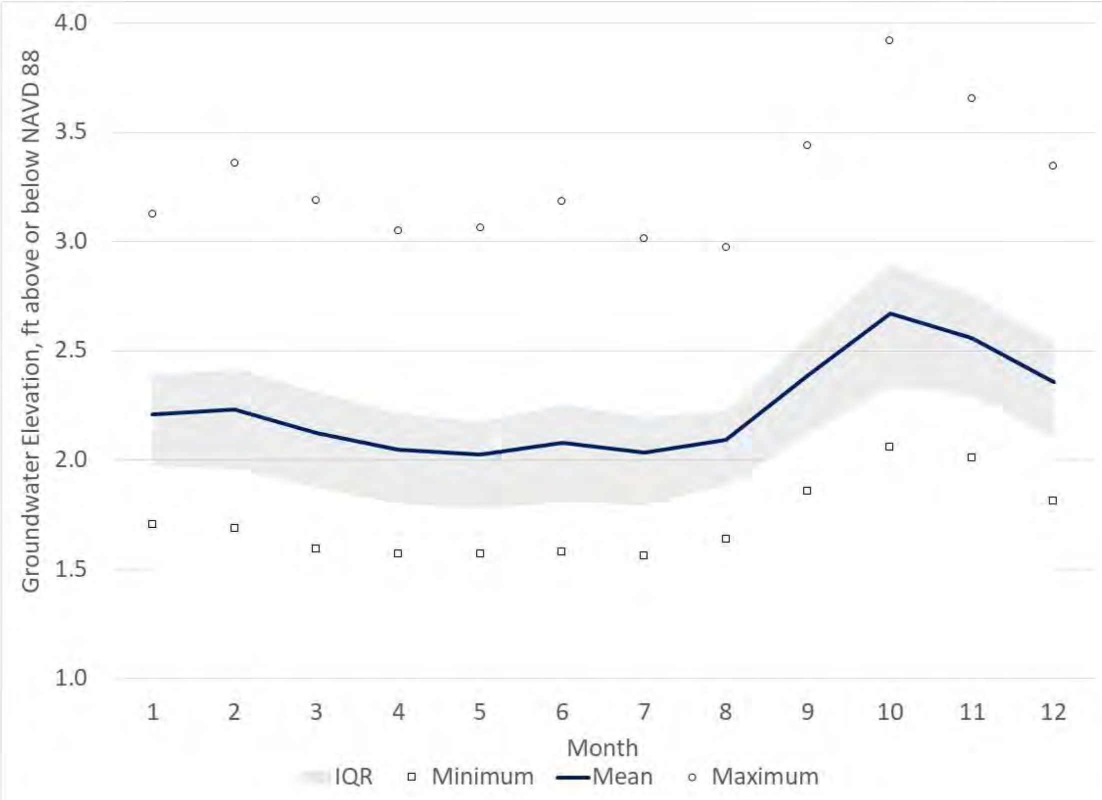
Figure 3.12. Projected groundwater elevation by distance from the shorelines under the NOAA Intermediate High sea level scenario.



The trend in groundwater elevations projected in relation to distance from the shoreline can help explain the relatively rapid groundwater elevation increases projected for areas with water land cover (Figures 3.10 to 3.12). The Water land cover class is located relatively close to the shoreline (Figure 2.13) where groundwater elevation is more responsive to sea level variations than areas far from the shorelines. For example, the majority (84%) of water is located in the 5-km zone, while cattail and sawgrass area are mainly distributed in the 30-km or further zones. This finding indicates that the groundwater level rises may be controlled mainly by the distance from the coastline rather than the land uses and covers and may be more sensitive to sea level changes than climate changes.

The projected changes in the groundwater elevation vary seasonally (Figure 3.13). Groundwater elevation is highest in October, followed by November, September, and December. Such a result corresponds with the projected precipitation peak in October (Figures 3.3 and 3.13). Groundwater elevation rises were projected to be relatively small from April to July. The difference between the projected monthly maximum rise (0.81 m in October) and minimum rise (0.62 m in April) is 0.19 m. The average width of the uncertainty band is 0.13 m, and the average differences between monthly maximum and minimum projections (empty circles and squares) is 0.47 m. Such a finding indicates that the disagreement between climate projections is large enough to substantially affect the groundwater elevation projections.

Figure 3.13. Projected groundwater elevation for 2026 to 2050 by month under the NOAA Intermediate High sea level scenario.



The monthly variations of the projected groundwater elevations for the near future were compared by the land uses and covers (Figures 3.14 and 3.15). The cattail and sawgrass plains areas located the farthest from the shoreline showed the greatest monthly variations in the near future period; cattail: 2.02 m in October and 1.66 m in May; sawgrass plains: 1.56 m in October and 1.20 m in May. The relatively high seasonal variation might be attributed to the distance from the shorelines and seasonal changes in weather and hydrology.

Figure 3.14. Projected monthly groundwater elevation variation during 2026 to 2050 by land use and cover under the NOAA Intermediate High sea level scenario.

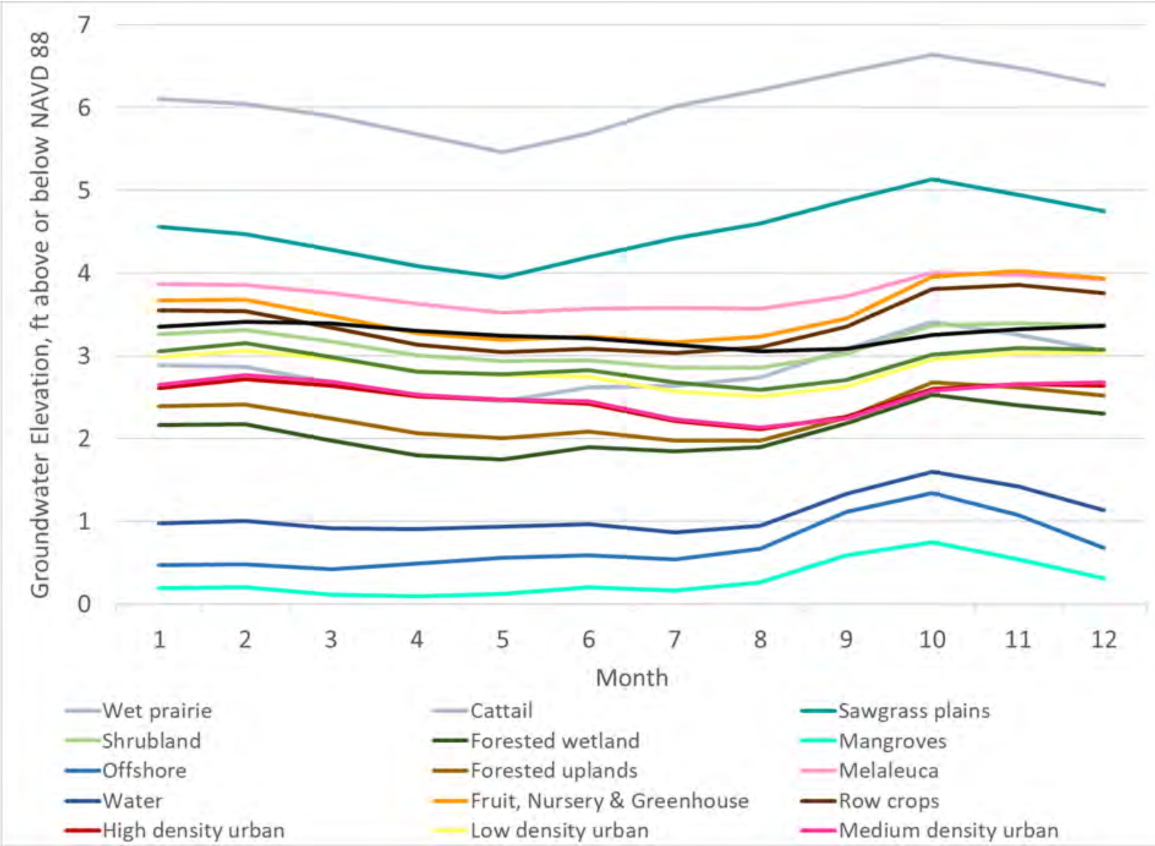
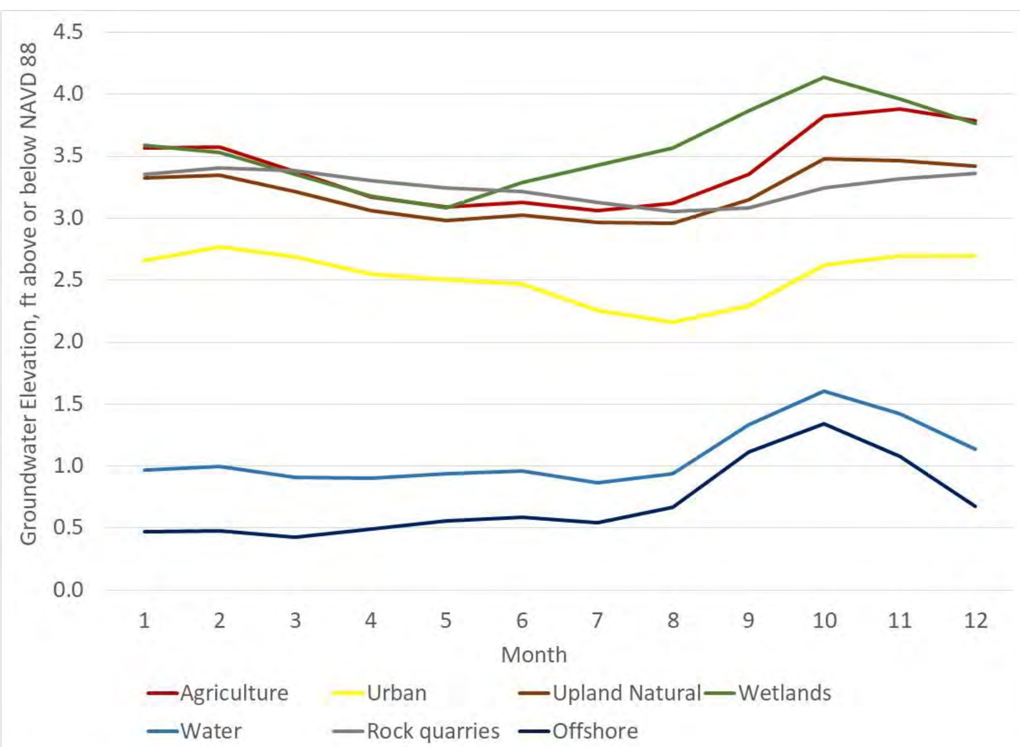
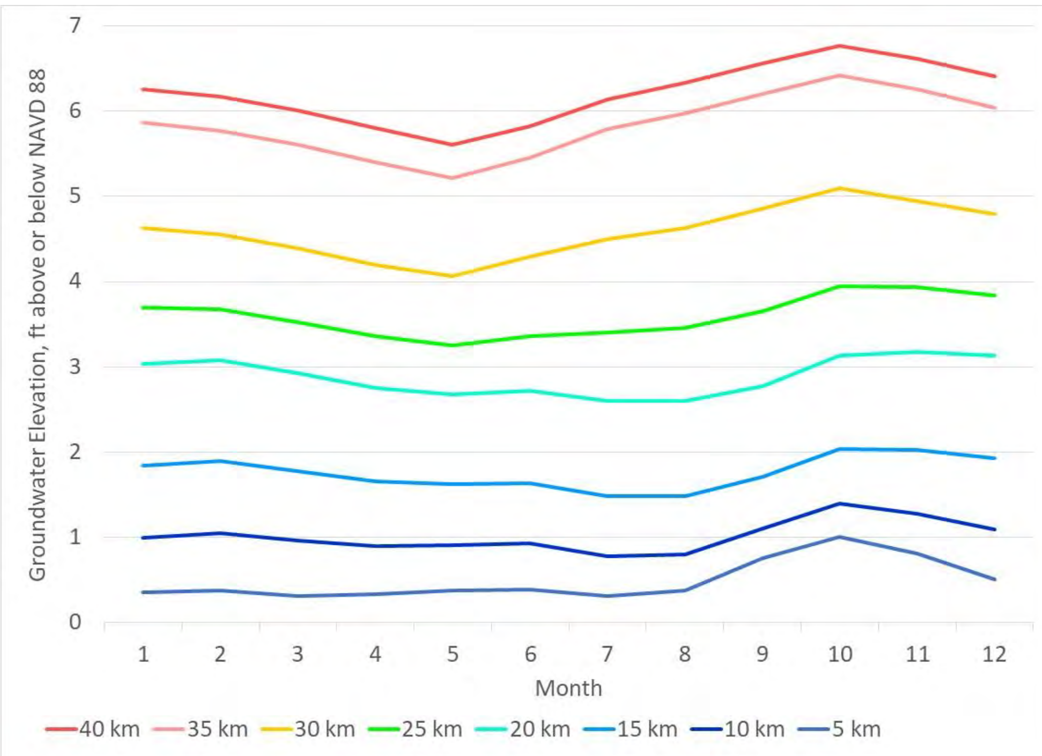


Figure 3.15. Projected monthly groundwater elevation variation during 2026 to 2050 by consolidated land use and cover under the NOAA Intermediate High sea level scenario.



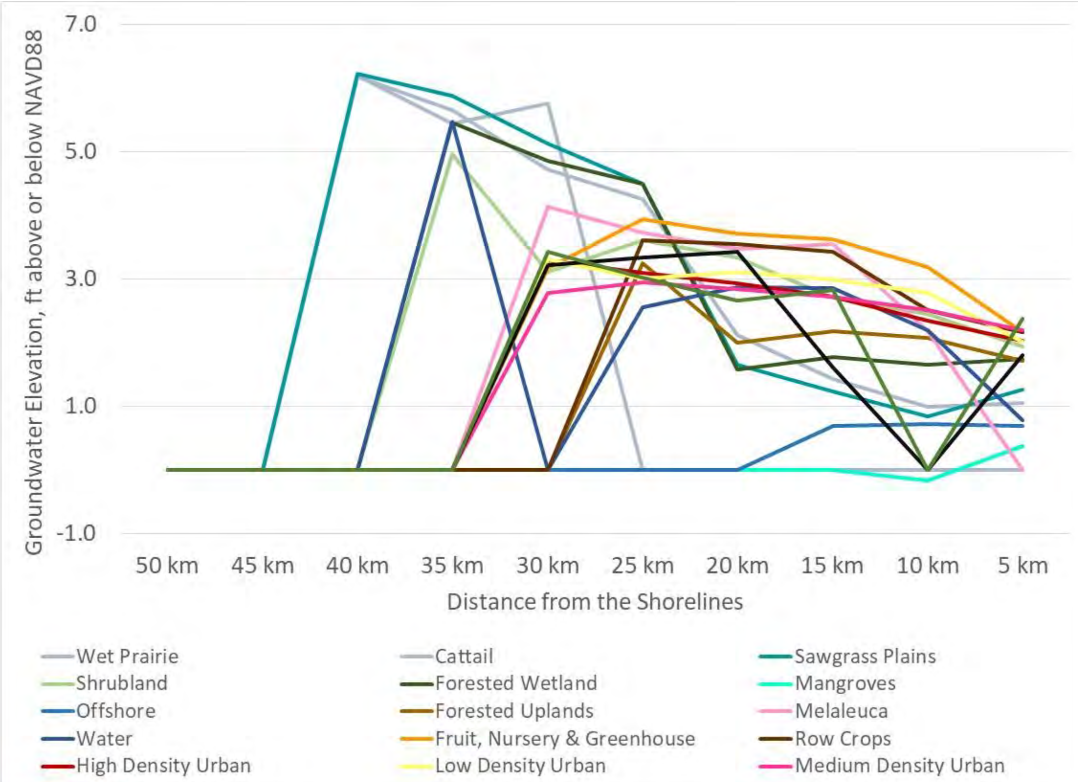
The monthly variations of projected groundwater elevation are compared by distance from the shoreline in Figure 3.16. The projected groundwater elevations peaked in October or November regardless of distance from the shoreline. However, the minimum groundwater elevations appeared in different months depending on the distance. For example, groundwater elevation was lowest in May in the 40 km zone and in July in the 5 km zone. Considering the fact that the lowest precipitation was projected for April (Figure 3.3), this finding implies that areas far from the shorelines may be more responsive to changes in precipitation and corresponding hydrological processes compared to the coastal areas, which is expected. On the other hand, monthly variations of groundwater elevation projected for water, mangrove, and offshore areas more closely follow sea level projections(Figures 3.3, 3.8, and 3.16).

Figure 3.16. Projected monthly groundwater elevation during 2026 to 2050 by distance from the shoreline under the NOAA Intermediate High sea level scenario.



Overall, groundwater elevations were projected to increase with distance from the shorelines (Figure 3.17). The gradient of groundwater elevation makes groundwater flow from the northeast to the southwest in Miami-Dade County. For example, sawgrass plains, cattail, and wet prairie areas located farthest from the shoreline have relatively high groundwater elevation, compared to mangroves, offshore, and water areas.

Figure 3.17. Projected groundwater elevation during 2026 to 2050 by land use/cover and distance from the shoreline under the NOAA Intermediate High sea level scenario.



Groundwater Quality

The impacts of projected climate and sea level changes on groundwater quality were quantified for areas in the UMD modeling domain whose aquifers are intruded by brackish and seawater. Brackish water has more salinity than freshwater but not as much as seawater. Salinity is defined as the total amount of dissolved salts in water. The salinity of brackish water ranges from 0.5 to 30 grams per liter while the salinity of seawater ranges between 33 and 37 grams per liter. Areas affected by brackish or seawater for at least one day a year were counted in the evaluation. This approach shows the maximum spatial extent of the impacts.

The area affected by seawater was expected to increase substantially within the UMD modeling domain (Figure 3.18). Areas affected by seawater were projected to increase from 25.8% in the baseline period to 33.9% in the far future period. The area affected by brackish water was projected to decrease in the future (Figure 3.19). Specifically, the average size of brackish-water areas might decrease from 12.7% of the UMD modeling domain area in the baseline period (from 1996 to 2020) to 10.3% in the far future period (from 2076 to 2100). Thus, areas affected by seawater would increase by 8.1% while areas affected by brackish areas would decrease by 2.4% for the same time frame. This indicates that the interface or transition areas where brackish water exists between the salt water and fresh groundwater in the aquifer may get narrowed, and the gradient of salinity may get steeper in the future. In addition, fresh groundwater may recede back to the west or the land side.

Figure 3.18. Projected area affected by seawater under the NOAA Intermediate High sea level scenario.

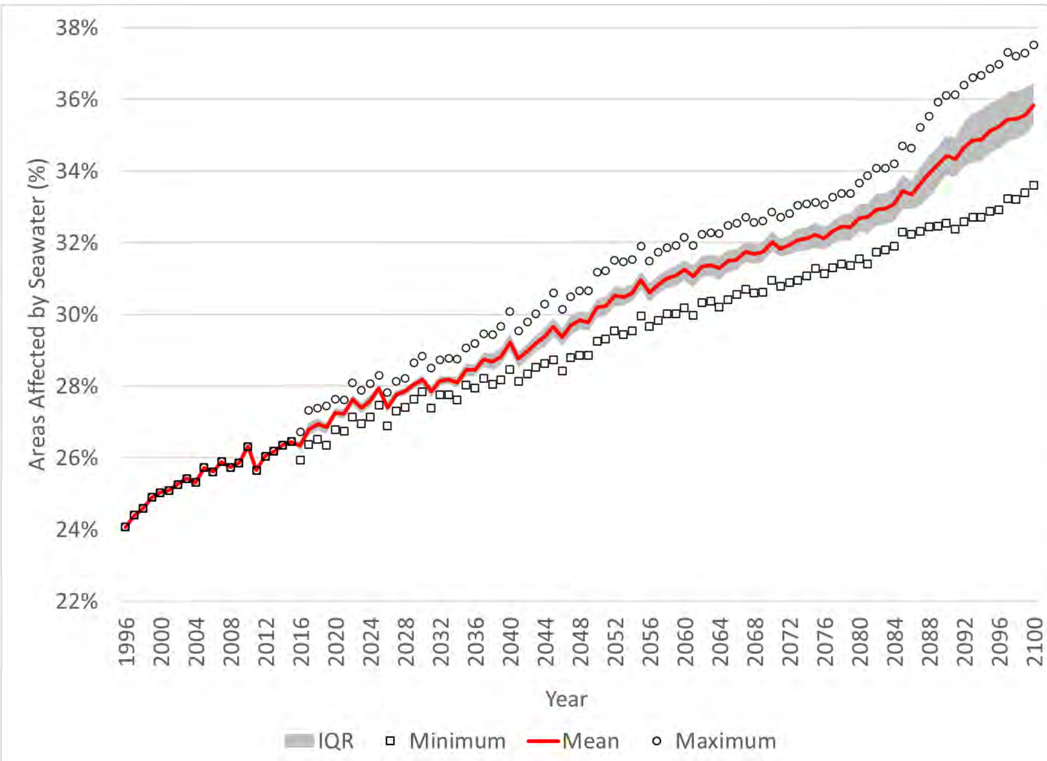
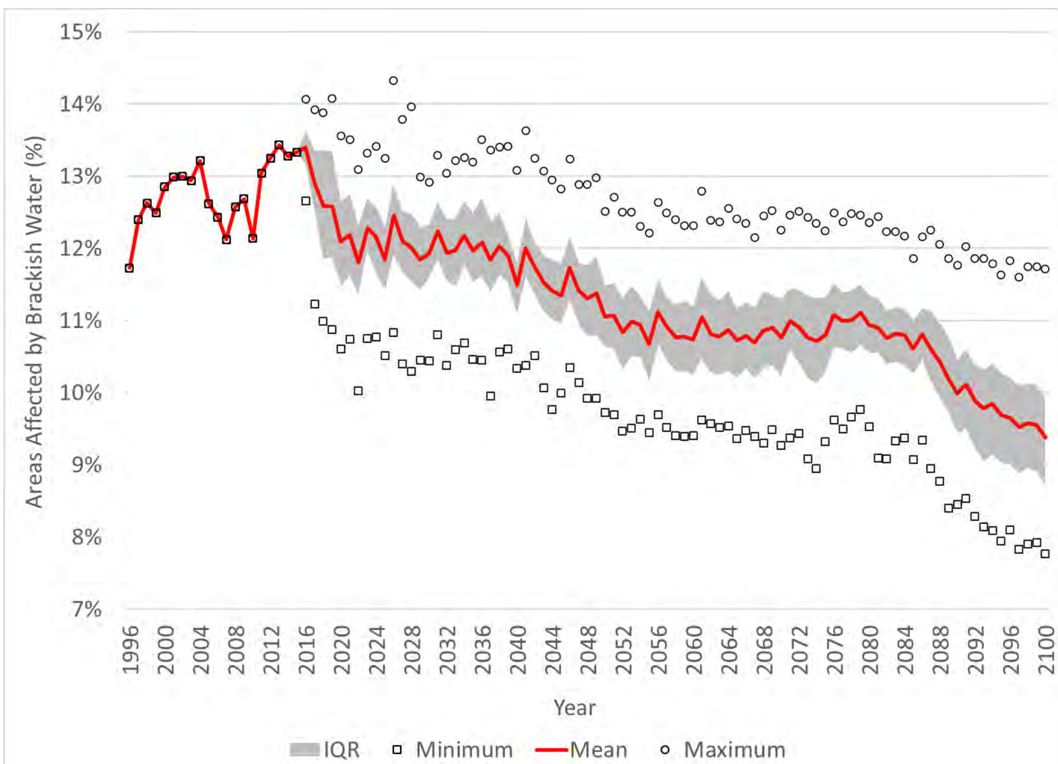


Figure 3.19. Projected area affected by brackish water under the NOAA Intermediate High sea level scenario.



The land use and cover of water was projected to experience the most substantial changes in the salinity of groundwater, followed by mangroves and wet prairie areas (Figures 3.20 and 3.21). In 2020, for example, 75% and 5% of water areas were affected by seawater and brackish water, respectively. The sizes of the seawater and brackish water areas were expected to change to 16% and 64% in 2100, respectively. The majority of water, mangrove, and wet prairie areas are distributed along the shorelines in the southeast corner of Miami-Dade County. On the other hand, the aquifer below high and medium density urban areas located right next to the shorelines were projected to be much less affected by climate and sea level change scenarios compared to those of water, mangroves, and wet prairie. Such a difference in the sensitivity to projected sea level rise might be attributed to the geological characteristics of the local aquifers. For instance, the transmissivity or flow rate of groundwater in the aquifer is much higher (250 to 500 vs. 750 to 1000 thousand square feet per day) in the southeast part of the County than in the urban areas (Hughes and While, 2016: Figure 2.13).

Figure 3.20. Projected area affected by seawater for land uses/covers under the NOAA Intermediate High sea level scenario.

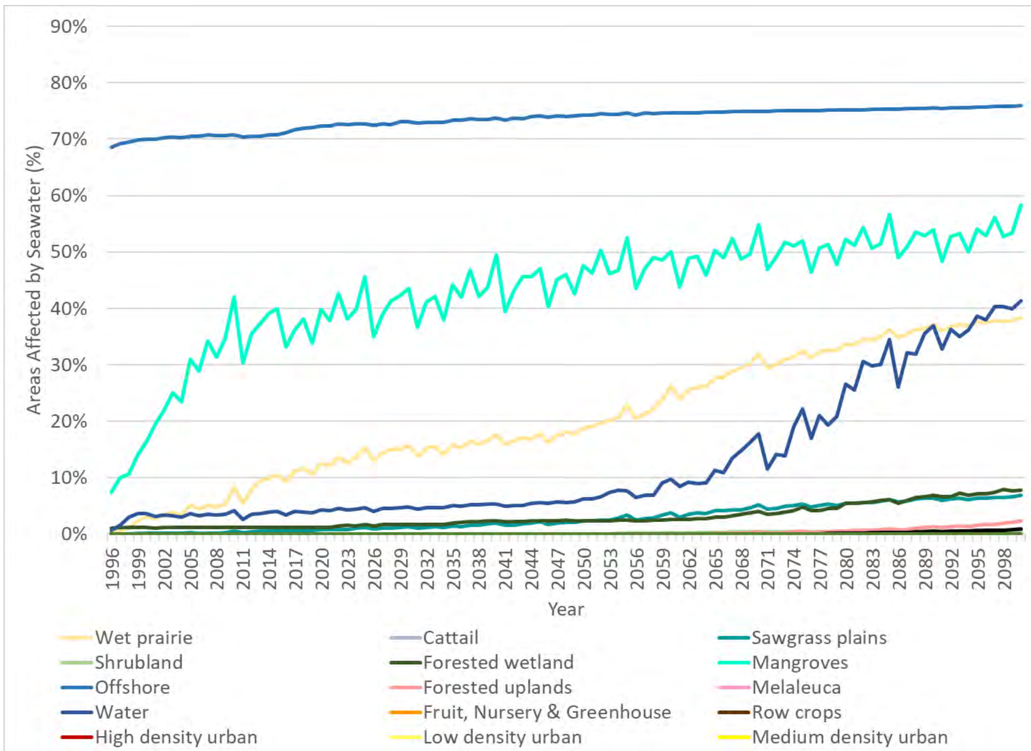
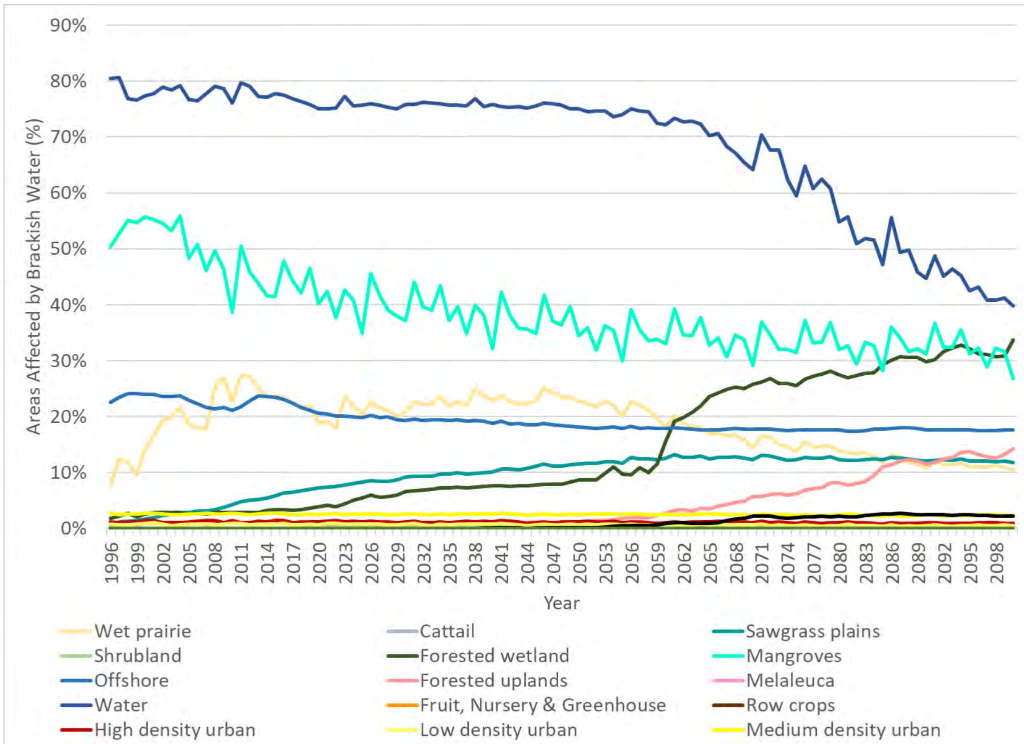


Figure 3.21. Projected area affected by brackish water for land uses/covers under the NOAA Intermediate High sea level scenario.



When the 17 land use and cover classes were simplified to the seven categories, it becomes clear that most areas other than water, offshore, and wetlands may not be substantially (less than 3%) affected by seawater or brackish water (Figures 3.22 to 3.25). For example, seawater and brackish water would intrude into less than 1% of the agricultural land uses until 2100. In the cases of urban and upland natural land uses, the areas affected by seawater or brackish water until are less than 1.5% and 3.2%, respectively. The area of urban land uses intruded by seawater or brackish water were expected to remain relatively constant.

Figure 3.22. Projected area affected by seawater for consolidated land uses/covers under the NOAA Intermediate High sea level scenario.

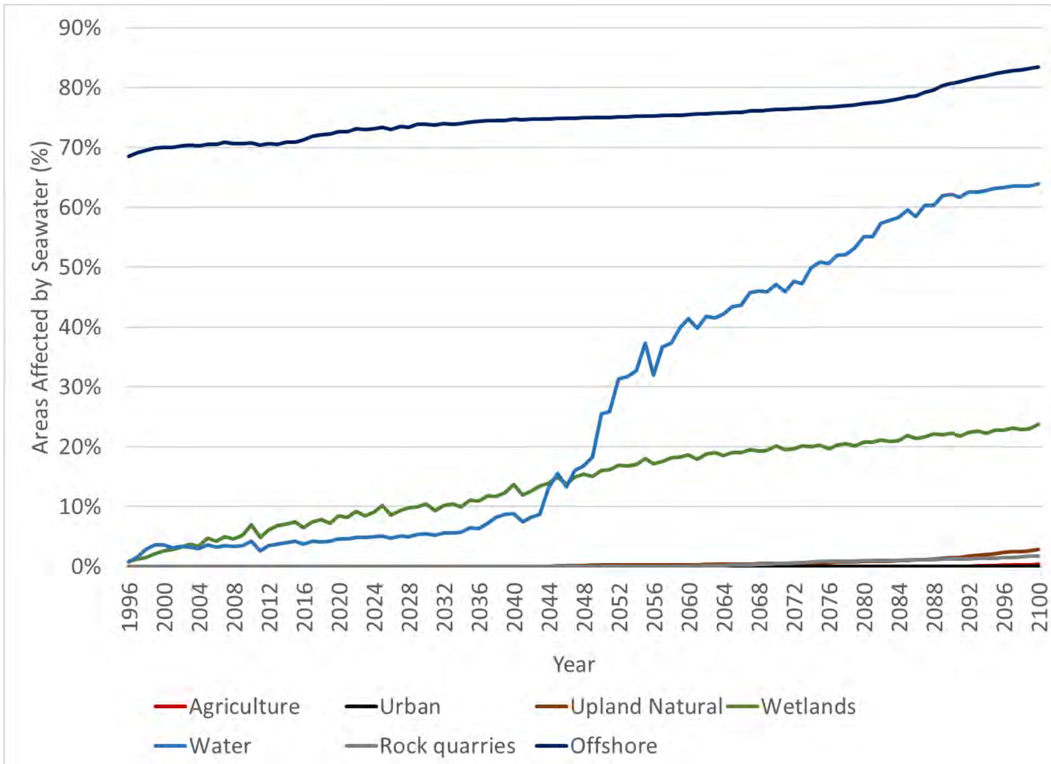


Figure 3.23. Projected area affected by seawater for selected land uses/covers under the NOAA Intermediate High sea level scenario.

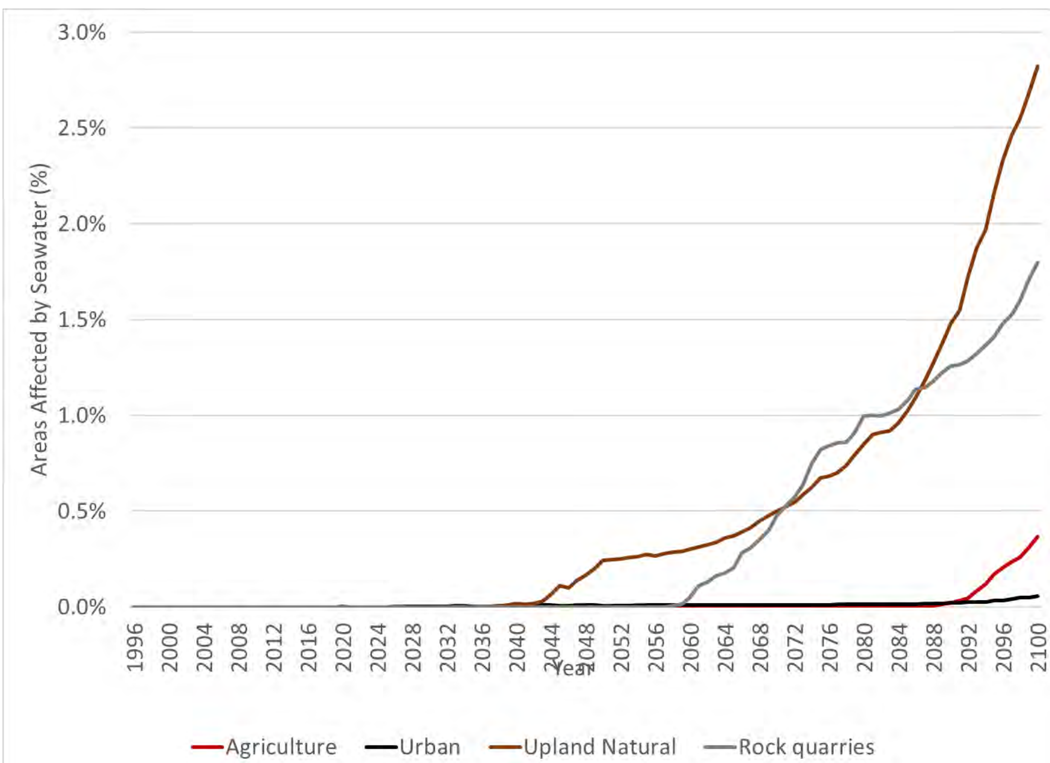


Figure 3.24. Projected area affected by brackish water for selected land uses/covers under the NOAA Intermediate High sea level scenario.

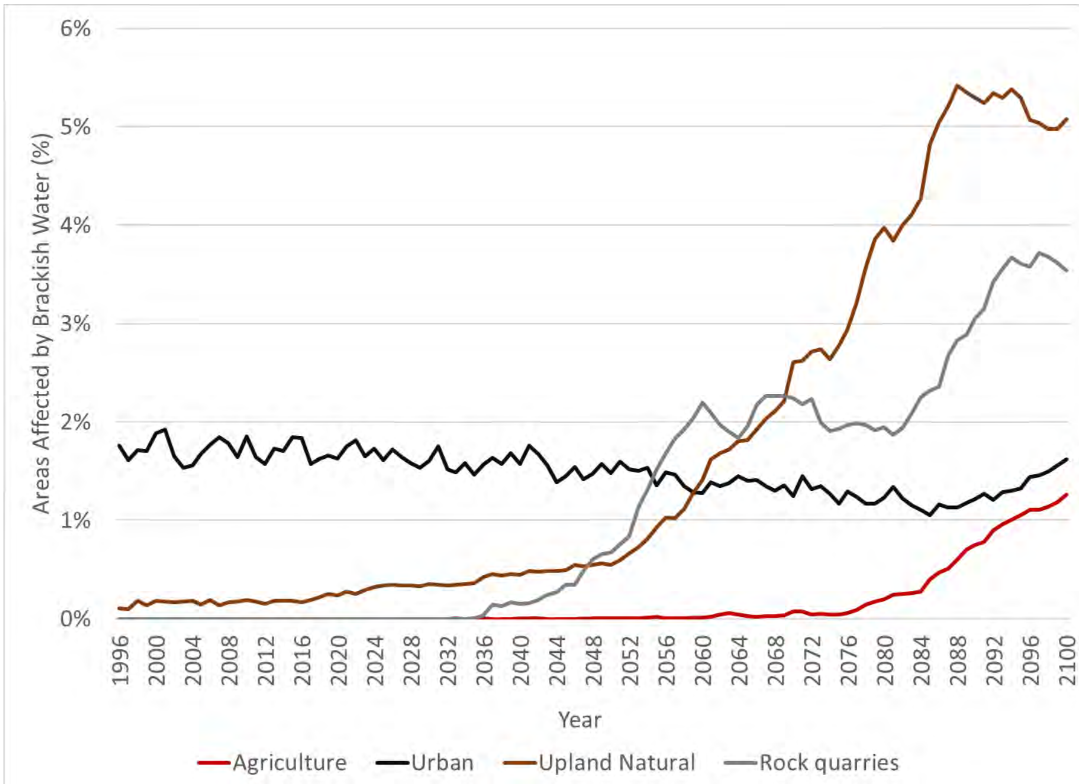
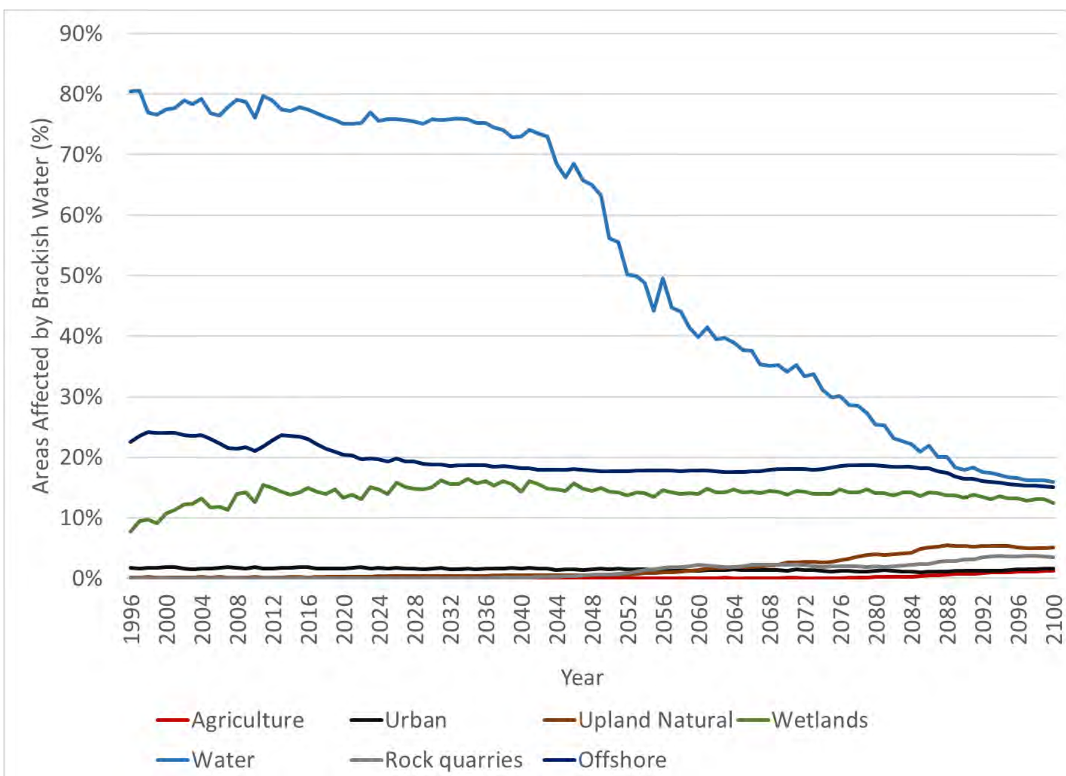


Figure 3.25. Projected area affected by brackish water for consolidated land uses/covers under the NOAA Intermediate High sea level scenario.



Seawater has already started replacing brackish water in the aquifer of mangrove and wet prairie areas (Figures 3.20 and 3.21). The seawater intrusion into the aquifer of water areas was projected to accelerate around 2040 when sea level was expected to rise at a higher rate (Table 1, Figures 2.10 and 3.21). Overall, the UMD modeling showed that the aquifer of the south and southeast parts of Miami-Dade County might be the most sensitive to the projected sea level rise. The impact of sea level rise on the saltwater intrusion process of agricultural areas was projected to be minimal in the near future. Zero percent of agricultural areas was projected to be affected by brackish or seawater in the aquifer. This may be due to the inland location of most agricultural areas.

Seawater was expected to intrude into areas within 15 km of the shorelines at relatively constant rates until 2100 (Figure 3.26). Brackish water was projected to be replaced with seawater within 10 km of the shorelines, but it might intrude into the aquifer of further inland areas (Figure 3.27). Areas 25 km away from the shoreline might not be substantially affected by seawater and brackish water intrusion until 2100 under the NOAA Intermediate High sea level scenario (Figures 3.25 and 3.26).

Figure 3.26. Projected area affected by seawater in relation to distance from the shoreline under the NOAA Intermediate High sea level scenario.

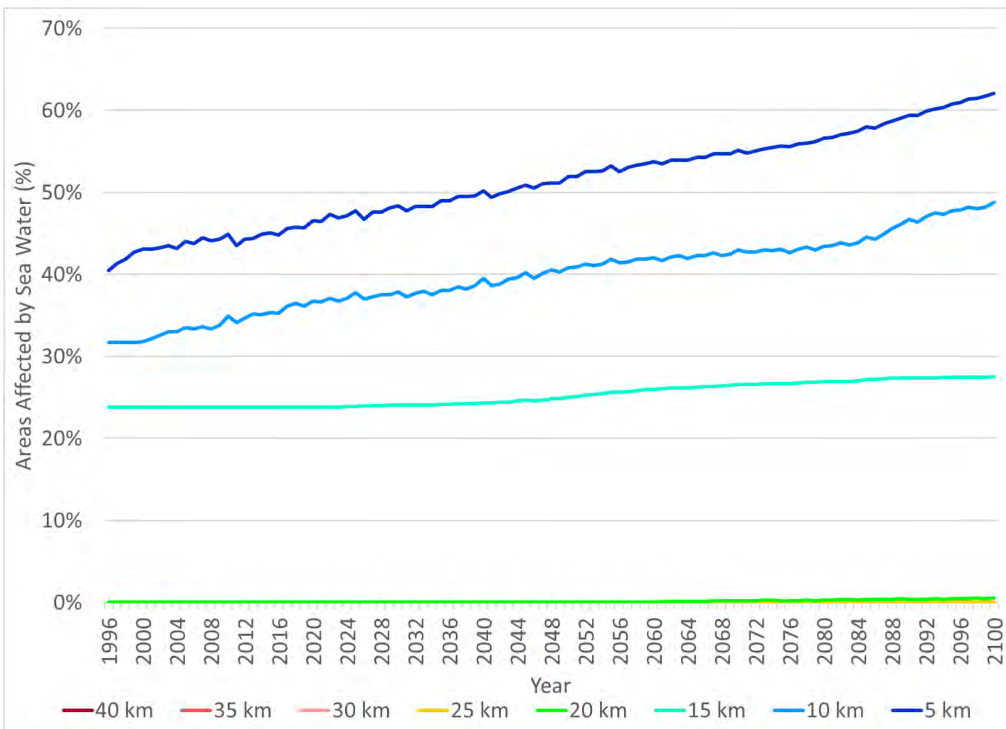
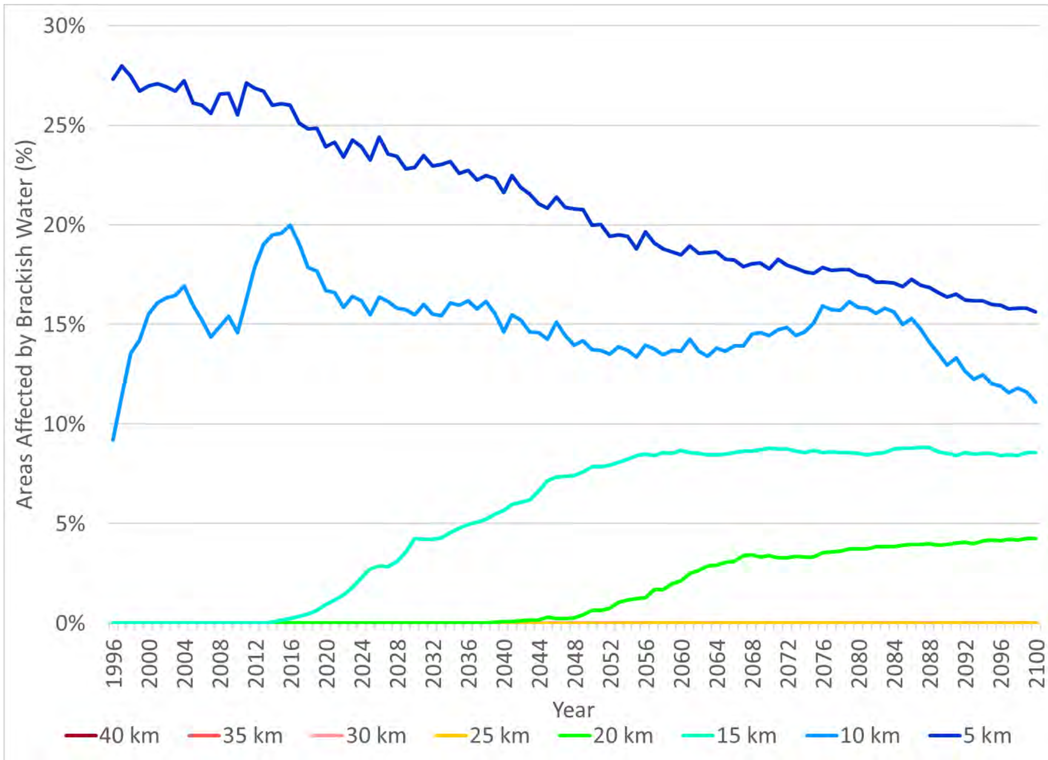


Figure 3.27. Projected area affected by brackish water in relation to distance from the shoreline under the NOAA Intermediate High sea level scenario.



The sizes of areas affected by seawater and brackish water were projected to change seasonally (Figures 3.28 and 3.29). The size of areas intruded by seawater was expected to peak in October and be minimized in May (Figure 3.28). This is similar to that of the projected monthly sea level variations. On the other hand, the brackish water areas may peak in April and May, which corresponds to the seasonal patterns of precipitation (Figures 3.3 and 3.29). This implies that the intrusion process of brackish water may be more responsive to precipitation and hydrology rather than sea level.

Figure 3.28. Projected monthly variation in area affected by seawater in 2026 to 2050 under the NOAA Intermediate High sea level scenario.

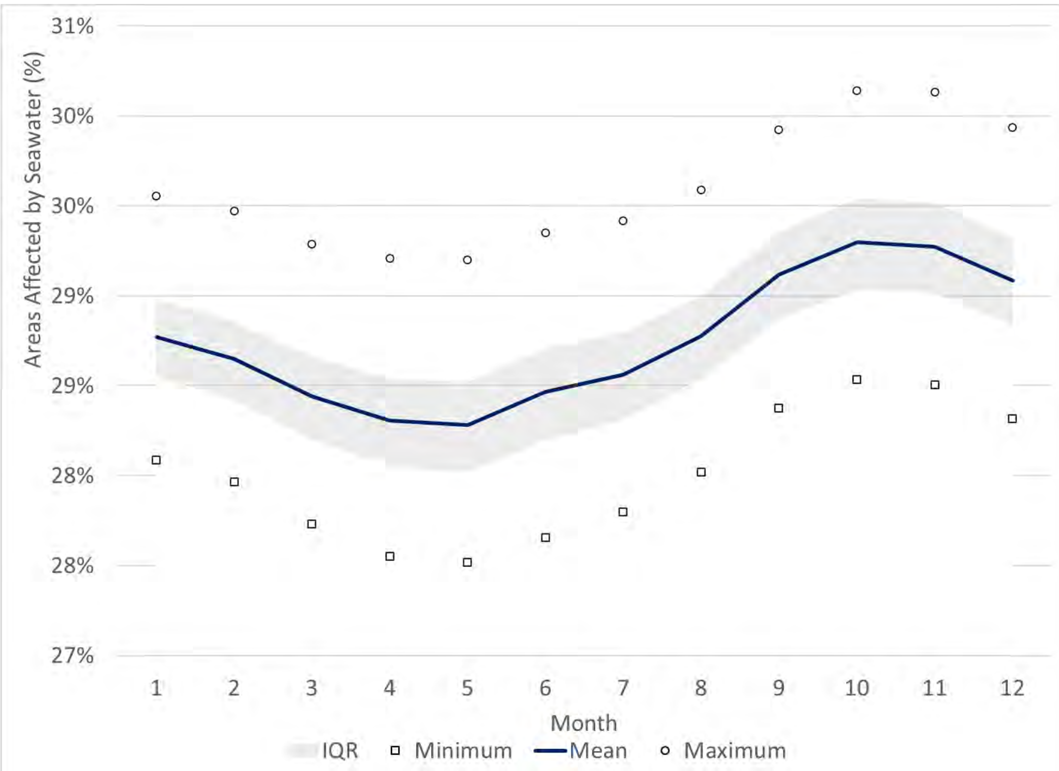
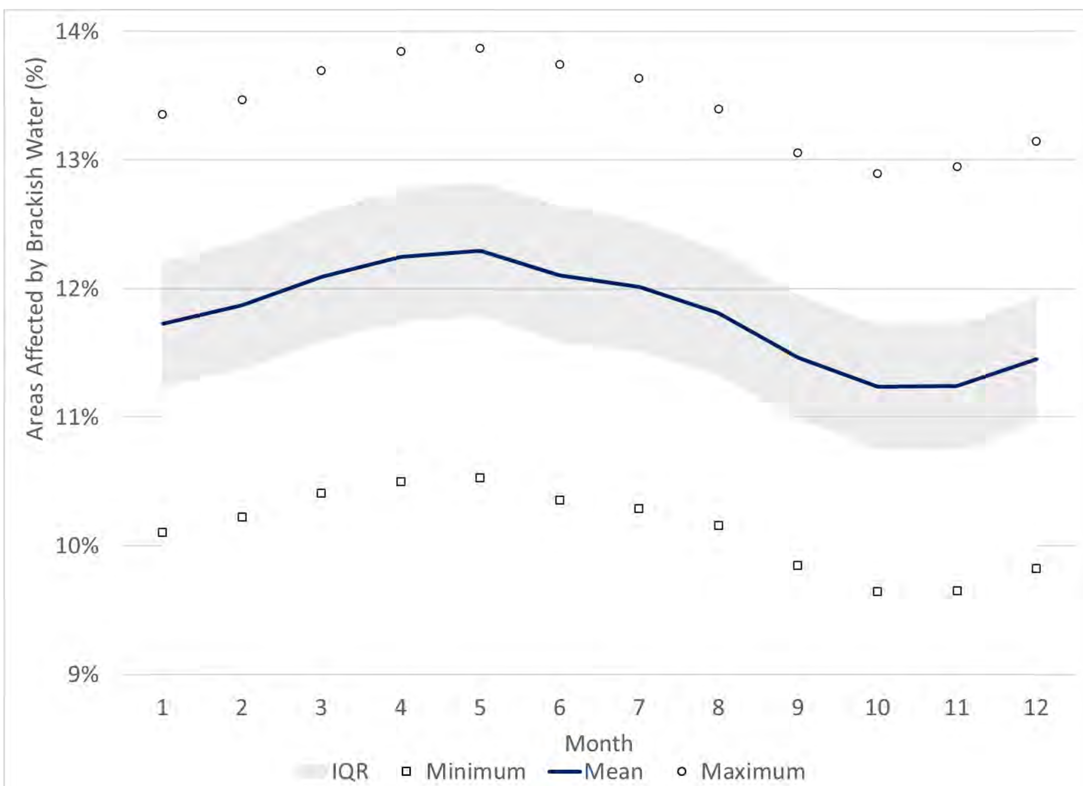


Figure 3.29. Projected monthly variation in area affected by brackish water in 2026 to 2050 under the NOAA Intermediate High sea level scenario.



The seasonal variations of the sizes of brackish and seawater areas were expected to be noticeable only within 10 km of the shorelines (Figures 3.30 and 3.31). The sizes of brackish and seawater areas were projected to be relatively sensitive to the seasonal patterns of precipitation and sea level, respectively.

Figure 3.30. Projected monthly variation of area affected by seawater in the near future by distance from the shorelines (2026 to 2050) under the NOAA Intermediate High sea level scenario.

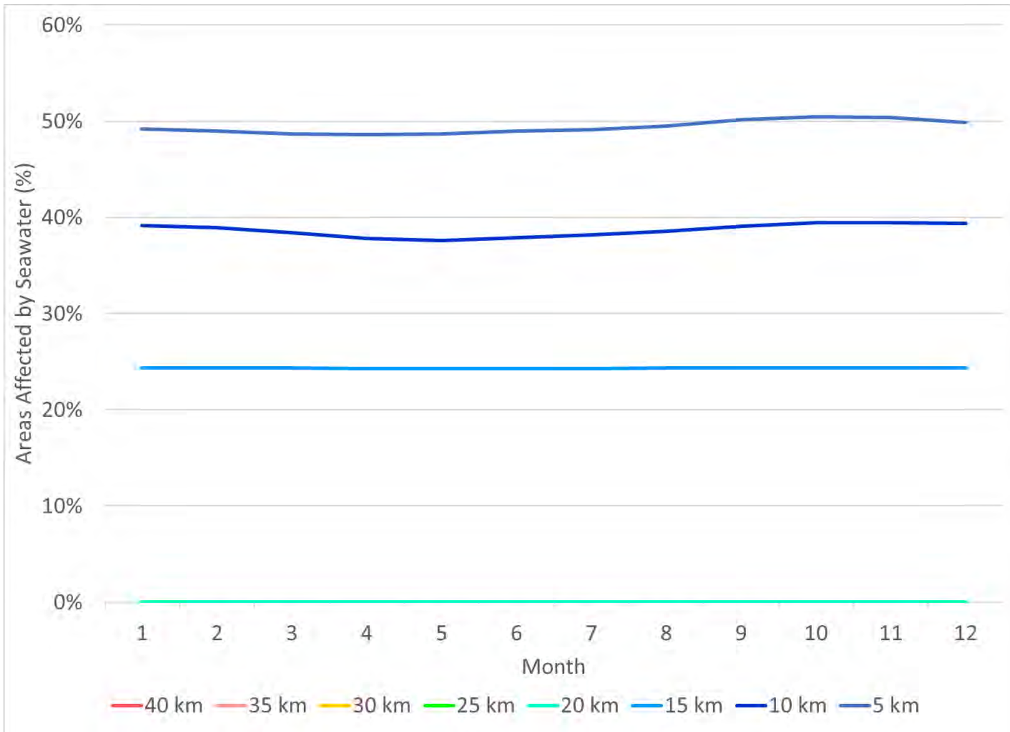
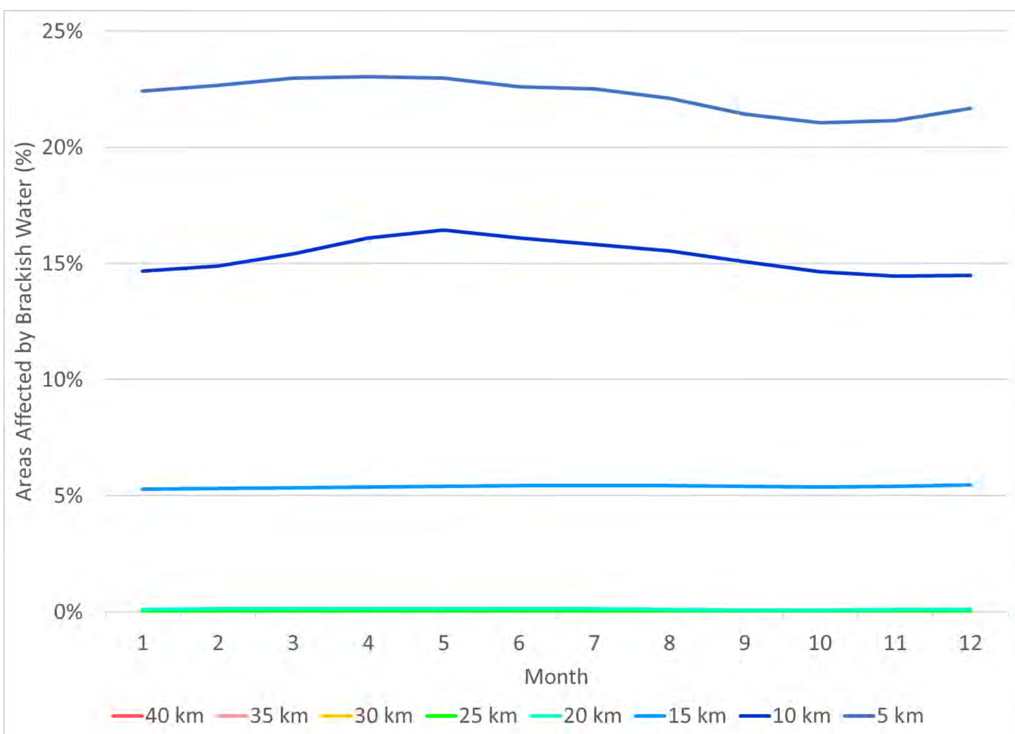


Figure 3.31. Projected monthly variation of area affected by brackish water by the distances from the shorelines (2026 to 2050) under the NOAA Intermediate High sea level scenario.



As described previously, in summary, the intrusion of brackish water and sea water was projected not to go beyond 15 km from the shorelines (Figures 32 and 33). Within the potential intrusion zone, areas relatively close to the shorelines and located in the southeast part of Miami-Dade County were found to be more sensitive to the SSP2-4.5 climate change and NOAA Intermediate High sea level rise scenarios. Compared to the groundwater elevation projections, the impacts of the scenarios for potential changes in climate and sea level on groundwater salinity or intrusion processes were projected to be more localized in the vicinity of the shorelines or ocean water. For example, the groundwater elevations were projected to increase within 30 km of the shorelines, but brackish water was expected to intrude only into 15 km from the shorelines (Figure 3.12).

Figure 3.32. Projected area affected by seawater in 2026 to 2050 by land use/cover and distance from the shorelines under the NOAA Intermediate High sea level scenario.

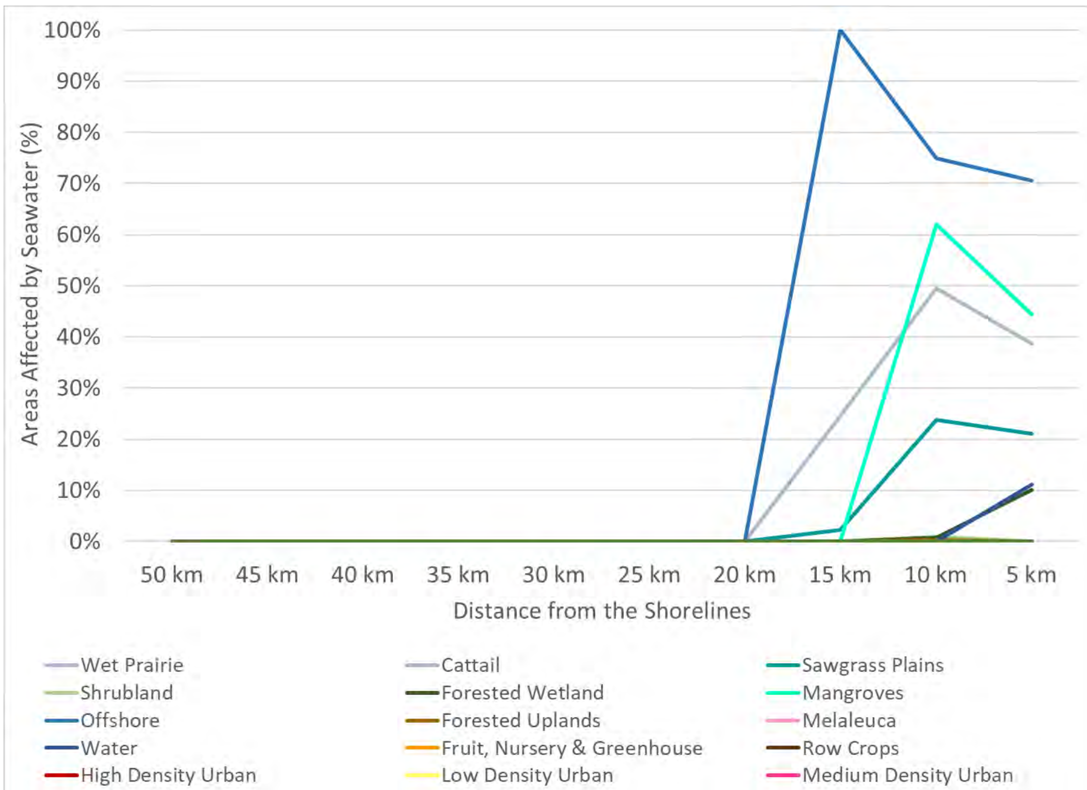
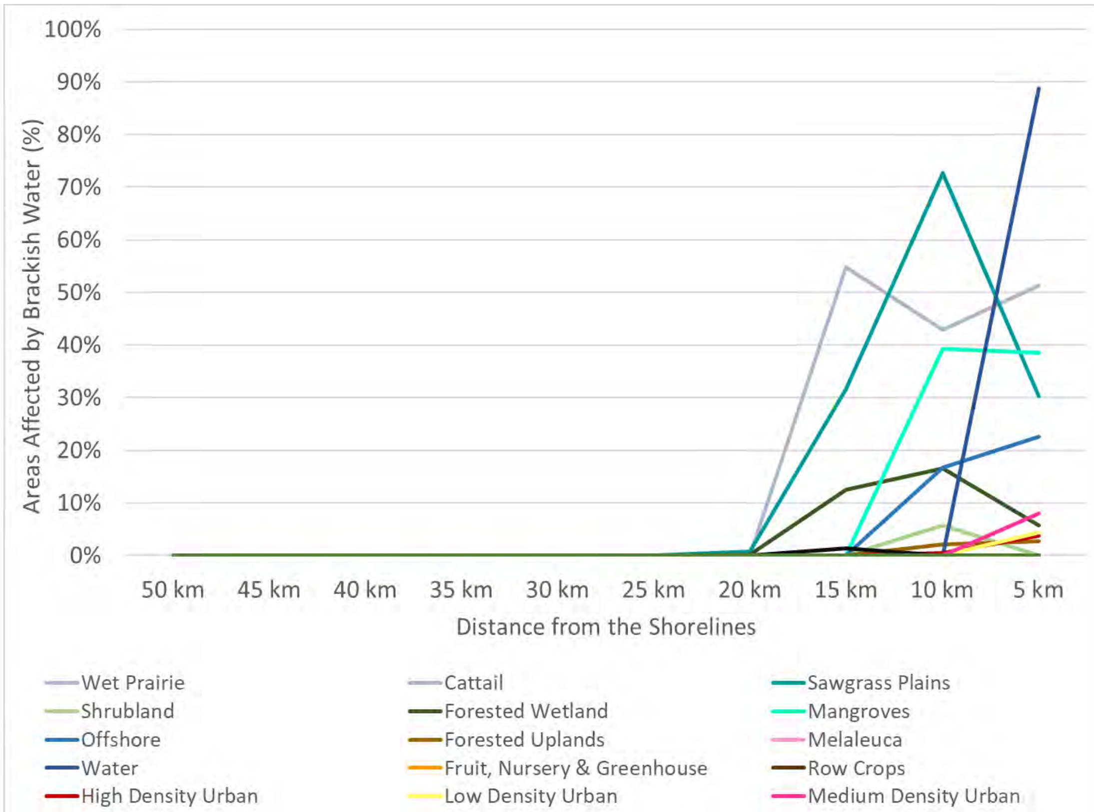


Figure 3.33. Projected overall sizes of areas affected by brackish water in 2026 to 2050 by land use/cover and distance from the shorelines under the NOAA Intermediate High sea level scenario.



Spatial Extent of Projected Changes

The UMD modeling results were summarized to provide an overall understanding of the projected changes in groundwater elevations and areas to be affected by saltwater intrusion in the previous sections. The projected changes may vary by location due to the spatial variations of geological features, the proximity to the shoreline (or seawater), land uses and covers, canal networks, and water management practices. For example, changes (or increases) in the groundwater elevations were projected to increase closer to the shoreline, as Figure 3.12 demonstrated. However, the magnitude of the projected changes is not solely determined by the distance from the shoreline (Figure 3.34). The comparisons of the groundwater elevations projected for the baseline period from 1996 to 2020 and a future period from 2041 to 2050 showed that the differences between them are relatively large (in a pale blue color in Figure 3.34) in the downstream areas of the C–1, C–7, C–8, C–102, and C–103 canals or at the vicinity of their outlets (S21 of C–1, S27 of C–7, S28 of C–8, S21A and S20G of C-102, and S20F of C–103). Thus, coastal agricultural areas located in the downstream areas, especially ones distributed along the C–102 and C–103 canals on the east side of Florida's Turnpike, are subject to being affected by the projected increase in groundwater elevation. The saltwater intrusion also may vary spatially. As seen in Figures 3.20, 3.21, and 3.35, land uses and covers mainly distributed in the southeast part of Miami-Dade County might be more susceptible to being intruded by saltwater. The UMD modeling results also showed that saltwater has already intruded into areas close to S21A, S20G, and S20F located at the end of the C-102 and C-103 canal networks (Figure 3.35 a)), and these areas were projected to continue to be affected by saltwater intrusion in the future (Figure 3.35 b)). In addition, the UMD modeling projected the interface (or brackish water areas) between the fresh groundwater and seawater to be narrowed in the future, which means that the gradient of salinity changes from the seawater (e.g., 35 grams of salt per liter of water) to the groundwater (e.g., 0.5 grams of salt per liter of water) might be steeper in the future as the sea level rises (Figures 3.18 and 3.19). This result can be confirmed in Figures 3.35 a) and b). For example, a buffer (e.g., areas in yellow) between areas in green and red was projected to become narrower in the future period from 2041 to 2050 compared to the baseline period, implying the areas to be affected by brackish water may decrease while the areas to be affected by seawater may increase. This can be possible as both seawater and brackish water may intrude into the aquifer of the inland areas, but the seawater may move faster toward inland than the brackish water and encroach into the brackish areas. The comparisons made for the two different periods (the baseline and a future period from 2041 to 2050) provided snapshots of the projected changes, which agree with the overall findings provided in the previous sections.

Figure 3.34. The spatial extent of projected changes in the groundwater elevations between the baseline period from 1996 to 2020 and the future period from 2041 to 2050. On the map, the elevation differences represent the projected changes in the groundwater elevations between the two periods.

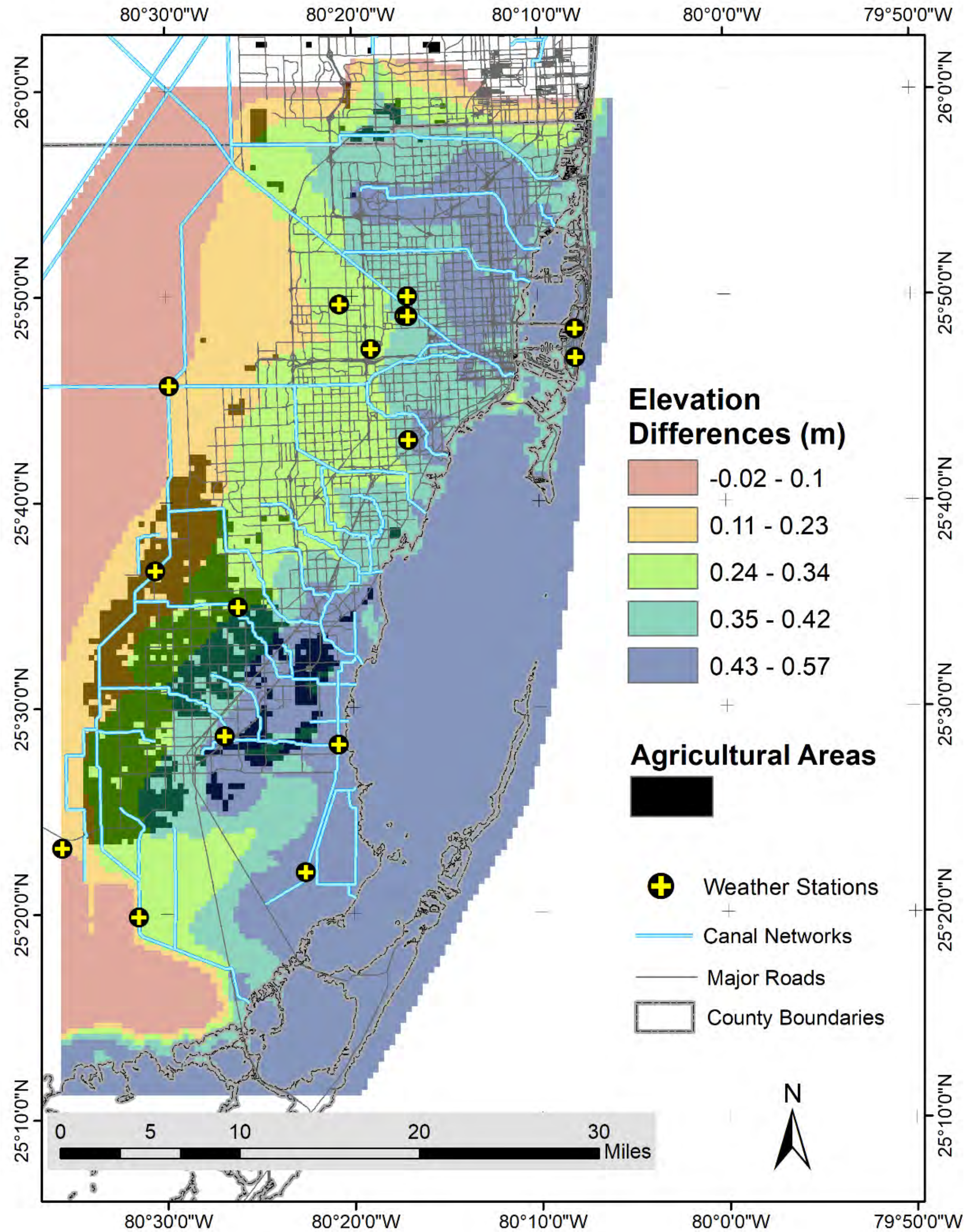
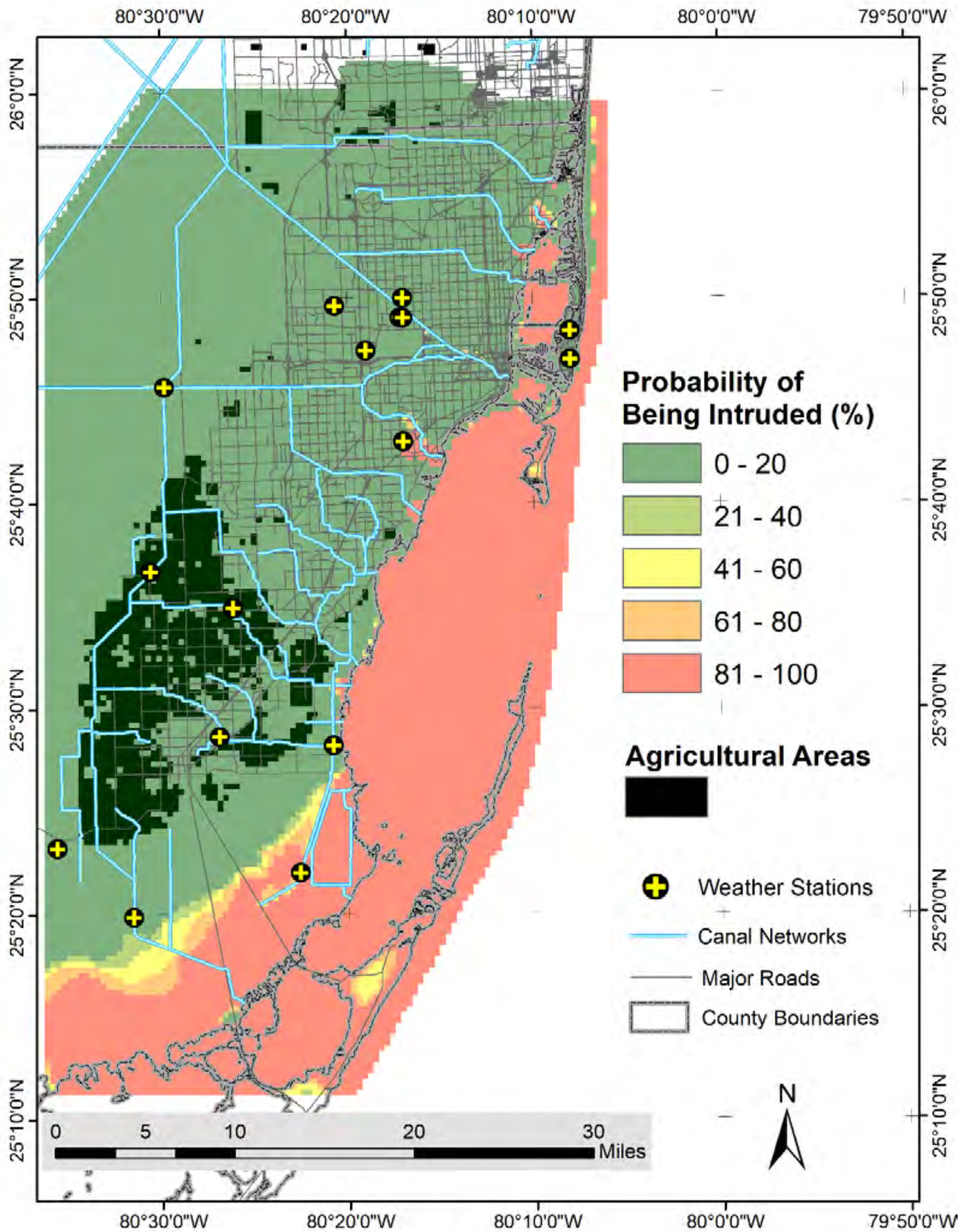
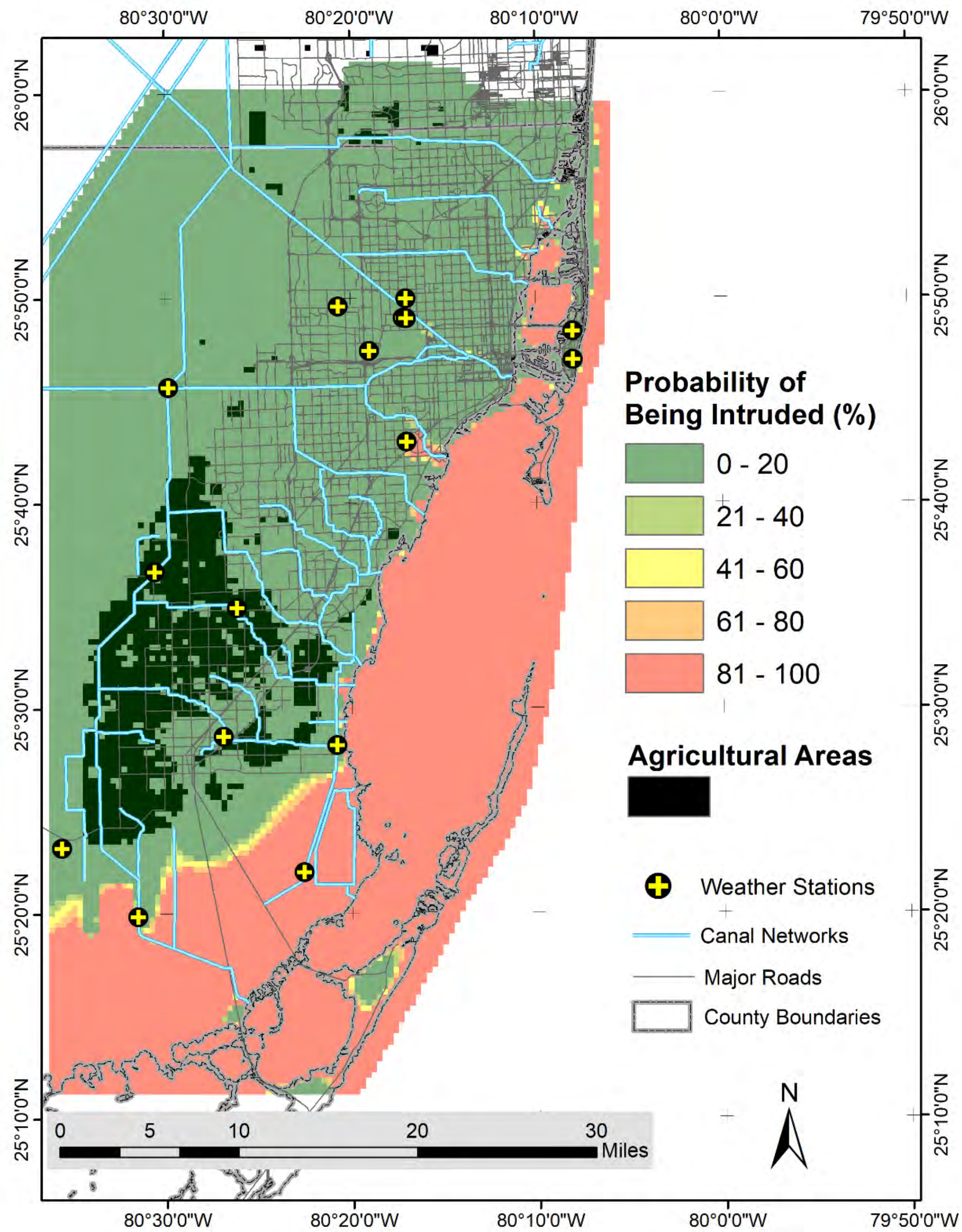


Figure 3.35. The spatial extent of projected seawater and brackish water intrusion into the aquifer for the baseline period from 1996 to 2020 and a future period from 2041 to 2050.

a) The probability of being intruded by saltwater (both seawater and brackish water) from 1996 to 2020 under the NOAA Intermediate High sea level scenario.



b) The probability of being intruded by saltwater (both seawater and brackish water) from 2041 to 2050 under the NOAA Intermediate High sea level scenario.



Sensitivity of Groundwater Projections to Climate and Sea Level Scenarios

The groundwater projections are sensitive to the sea level and climate scenarios selected. This report focuses on the NOAA Intermediate High sea level scenario, recommended as "the upper boundary for short-term use until 2070" and the SSP2-4.5 climate scenario representing "Middle of the road: Medium challenges to mitigation and adaptation" (Table 2.2). Among three different sea level scenarios, the IPCC Median and NOAA High sea level scenarios represent the lowest and highest boundaries of the sea level projections, while the NOAA Intermediate High scenario is the midrange or most likely scenario. Thus, the groundwater projections made under these three sea level scenarios can give us a picture of the range of the future groundwater elevations and saltwater intrusion processes.

The projected future groundwater elevations were relatively more sensitive to the sea level projections than the climate scenarios (Figure 3.34 and Table 3.3). For example, the difference between the overall average groundwater elevations projected for the far future period (2091 to 2100) under the SSP2-4.5 and SSP5-8.5 climate scenarios was 0.02 m regardless of the sea level scenario (Table 3.3). The difference between the projections for the same future period under the IPCC Median and NOAA High sea level scenarios reaches 1.05 m regardless of the climate scenarios (Table 3.3). The differences were projected to increase in the future (Figure 3.34).

Figure 3.34. Comparison of the groundwater elevations projected under the combinations of the climate change and sea level rise scenarios: IM, NI, and NH represent IPCC Median, NOAA Intermediate High, and NOAA High, respectively.

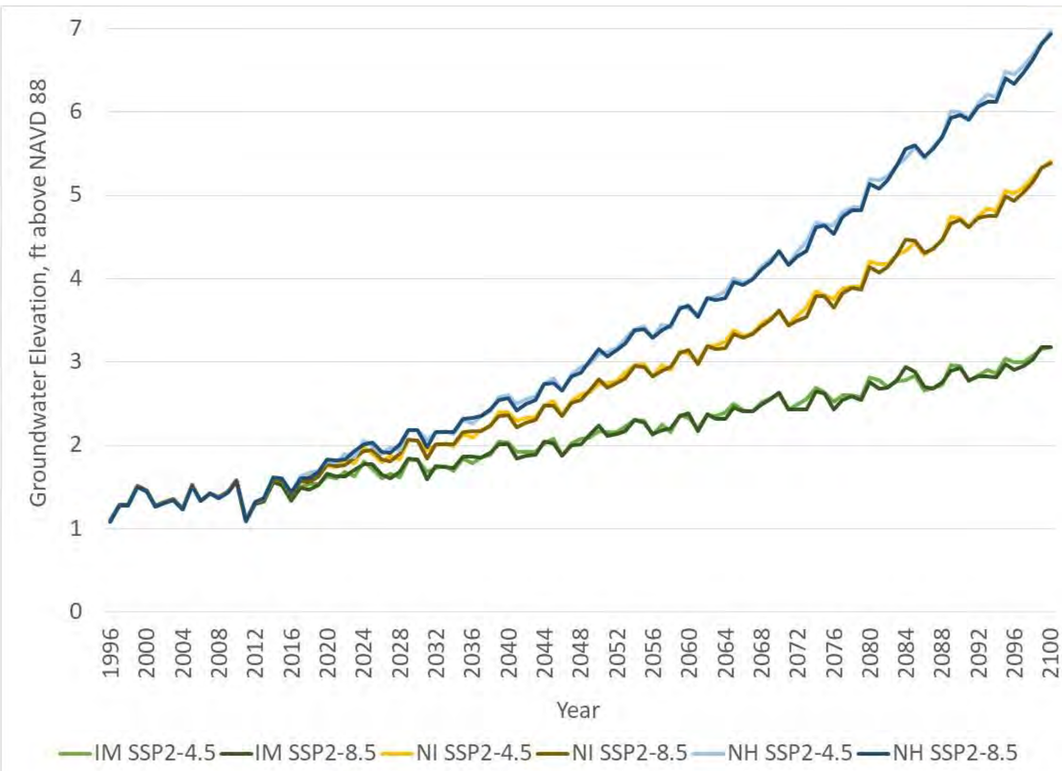


Table 3.3. Comparison of the groundwater elevation rises projected for the milestone periods under the combinations of the climate change and sea level rise scenarios.

Period	IPCC Median		NOAA Intermediate High		NOAA High	
	SSP2-4.5	SSP2-8.5	SSP2-4.5	SSP2-8.5	SSP2-4.5	SSP2-8.5
	meters (feet)					
2026 to 2035	0.10 (0.33)	0.10 (0.33)	0.17 (0.56)	0.17 (0.56)	0.21 (0.69)	0.21 (0.69)
2036 to 2045	0.17 (0.56)	0.16 (0.52)	0.28 (0.92)	0.27 (0.89)	0.34 (1.12)	0.33 (1.08)
2046 to 2055	0.23 (0.75)	0.22 (0.72)	0.40 (1.31)	0.39 (1.28)	0.51 (1.67)	0.50 (1.64)
2056 to 2065	0.28 (0.92)	0.27 (0.89)	0.51 (1.67)	0.51 (1.67)	0.68 (2.23)	0.67 (2.20)
2066 to 2075	0.35 (1.15)	0.34 (1.12)	0.65 (2.13)	0.64 (2.10)	0.87 (2.85)	0.86 (2.82)
2091 to 2100	0.49 (1.61)	0.47 (1.54)	1.10 (3.61)	1.08 (3.54)	1.53 (5.02)	1.51 (4.95)

The projected areas affected by brackish water and seawater were also relatively more sensitive to the sea level projections than climate scenarios (Figures 3.35, 3.36, Tables 3.4, and 3.5). For example, the difference between the seawater areas projected for 2091 to 2100 under the SSP2-4.5 and SSP5-8.5 climate scenarios was 0.72% when the NOAA High sea level scenario was employed, but the difference between projections under the IPCC Median and NOAA High sea level scenarios with the SSP5-8.5 climate scenario reaches 5.82% (Table 3.4). The sensitivity of projected brackish water and seawater areas to the climate scenarios was higher than to projected groundwater elevations (Tables 3.3 to 3.5). Such a finding indicates that saltwater intrusion processes may be relatively more responsive to the projected climate changes than the projected sea level rise. At the same time, it also implies that groundwater elevation changes may be more sensitive to the projected sea level rise than the projected climate change. However, the sensitivity should be dependent on the geological features of aquifers of interest and the proximity of to the shoreline. The sensitivity or the differences were also projected to increase in the future (Figure 3.34).

Figure 3.35. Comparison of areas affected by seawater projected under climate change and sea level rise scenarios.

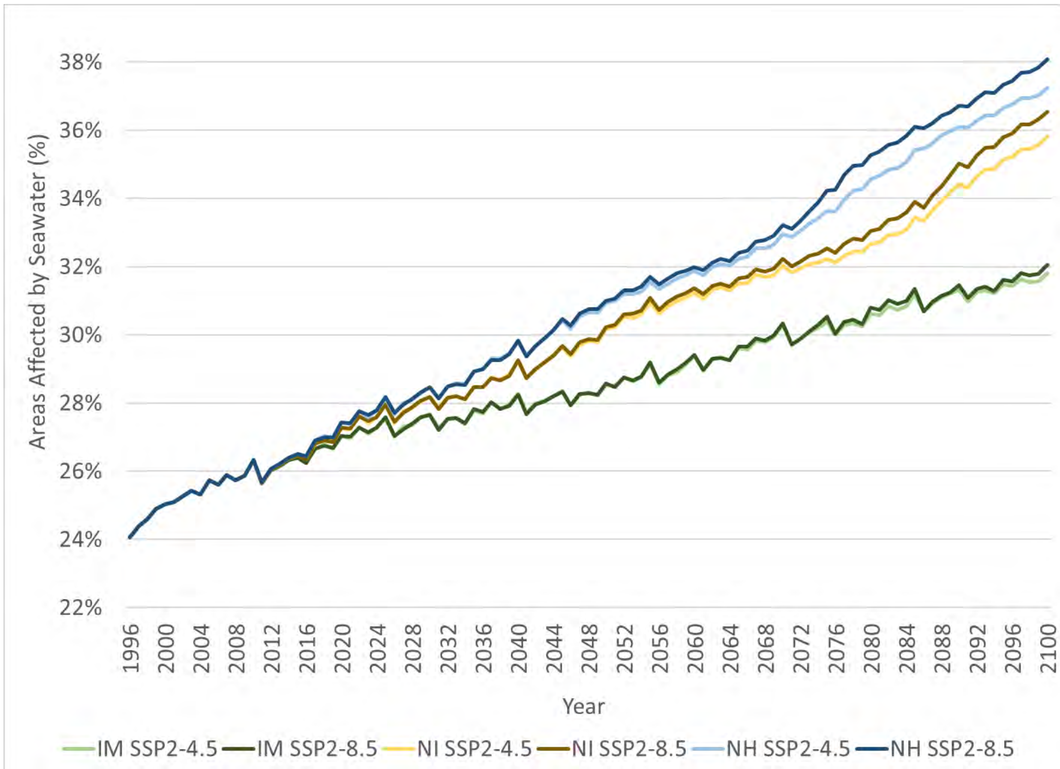


Table 3.4. Comparison of changes in the areas affected by seawater projected for milestone periods under climate change and sea level rise scenarios.

Periods	IPCC Median		NOAA Intermediate High		NOAA High	
	SSP2-4.5	SSP2-8.5	SSP2-4.5	SSP2-8.5	SSP2-4.5	SSP2-8.5
	Percent change (%)					
2026 to 2035	1.72	1.72	2.24	2.23	2.53	2.53
2036 to 2045	2.28	2.26	3.23	3.22	3.84	3.84
2046 to 2055	2.78	2.79	4.40	4.48	5.12	5.22
2056 to 2065	3.39	3.43	5.37	5.49	6.02	6.17
2066 to 2075	4.24	4.30	6.13	6.34	7.13	7.43
2091 to 2100	5.69	5.84	9.37	10.04	10.88	11.60

Figure 3.36. Comparison of the area affected by brackish water under the combinations of climate change and sea level rise scenarios.

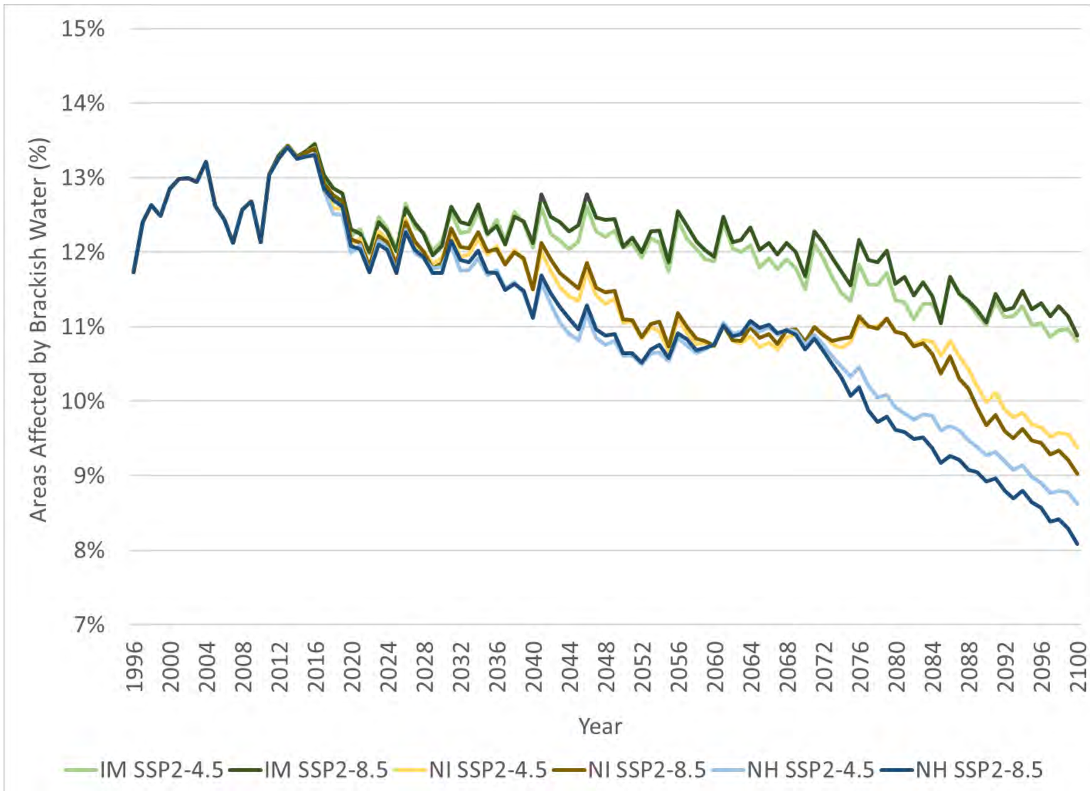


Table 3.5. Comparison of changes in the areas affected by brackish water projected for milestone periods under climate change and sea level rise scenarios.

Period	IPCC Median		NOAA Intermediate High		NOAA High	
	SSP2-4.5	SSP2-8.5	SSP2-4.5	SSP2-8.5	SSP2-4.5	SSP2-8.5
	Percent change (%)					
2026 to 2035	-0.44	-0.43	-0.68	-0.67	-0.83	-0.81
2036 to 2045	-0.49	-0.41	-1.01	-0.94	-1.42	-1.36
2046 to 2055	-0.62	-0.50	-1.61	-1.54	-2.01	-1.96
2056 to 2065	-0.69	-0.57	-1.89	-1.86	-1.87	-1.87
2066 to 2075	-1.03	-0.83	-1.93	-1.89	-1.97	-2.05
2091 to 2100	-1.72	-1.55	-3.05	-3.33	-3.77	-4.18

Summary

This report describes the future climate and groundwater projections made using climate models and groundwater models under various scenarios. The NOAA Intermediate High sea level rise scenario is recommended as the upper boundary for projects within a short-term planning horizon (until 2070). The SSP2-4.5 climate scenario has been used to represent future trends that continue their historical patterns in many studies. The ensemble average of climate projections made using climate models showed that precipitation will slightly and slowly increase with large model-wise variations in the future. The climate models agreed on an increase in daily air temperatures in the future, projecting an average increase in maximum and minimum air temperatures of 1.5 and 1.8 degrees Celsius (2.7 and 3.2 degrees Fahrenheit), respectively, from 2026 to 2050. Groundwater elevation was expected to increase mainly due to projected sea level rise. Seawater and brackish water were projected to intrude into the fresh groundwater aquifer, however, limited to 15 to 20 km from the shoreline. The groundwater modeling results indicate that the groundwater level rises may be controlled mainly by the distance from the coastline rather than the land uses and covers and may be more sensitive to the projected sea level changes than the projected climate changes. Agricultural land uses might not be substantially affected by the saltwater intrusion processes. The groundwater modeling projected that seawater and brackish water would intrude into less than 1% of the agricultural land uses until 2100. The groundwater of agricultural areas was projected to increase by 0.24 m by 2050 and 0.75 m by 2100, compared to the baseline groundwater elevation. The groundwater elevation of agricultural areas was expected to increase faster than some other land uses and covers such as wetlands and upland natural, and it can be higher than those of the others in the far future. This modeling result implies that the agricultural land uses may experience root zone saturation more frequently due to the high groundwater table in the future, which may affect crop productivity and require adaptive agricultural management practices that can mitigate the impacts.

Overall, the UMD modeling showed that the projected groundwater elevation increases were projected to occur in wider areas than the projected saltwater intrusion, implying the projected groundwater elevation increase may more comprehensively affect agriculture than the projected saltwater intrusion. In addition, the modeling results showed that the groundwater elevation of areas 15 km from the coastline may be subject to be affected by the projected changes in sea level and climate. Given the projections and understanding, thus, agricultural activities may not be encouraged in the coastal areas in the future.

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Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida

Final Report

Appendix B: Emerging Agricultural Technologies

Contents

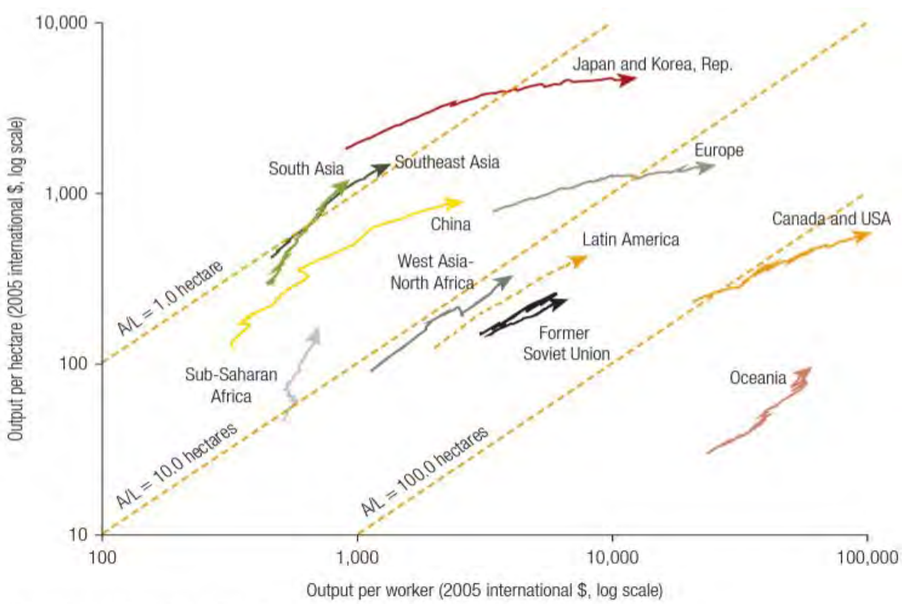
Introduction

This chapter aims to assess the emerging technological changes in agriculture that are expected to impact the agricultural sector in Miami-Dade County, Florida. We will summarize some of the information and data relevant to technology adoption before proceeding with the analysis of the significant trends in technology development, research-based emerging technological changes, and potential factors contributing to technology adoption.

Information retrieved from government reports and recent research publications has been compiled to assess emerging national or state changes or trends in technology development, research-based emerging technological changes, and potential factors contributing to the adoption of technology.

Agricultural technology is a broad term used here to describe equipment, genetic engineering, farming techniques (e.g., precision agriculture), and agricultural inputs that have been developed to improve the efficiency and productivity of agriculture. The World Bank Report *Harvesting Prosperity: Technology and Productivity in Agriculture* identifies the adoption of innovative technologies and practices by farmers as a “key driver” for increasing agricultural productivity and raising farmer income. The report explains that innovative technology would enable farmers to boost yields, manage inputs more efficiently, adopt new crops and production systems, and improve the quality of farm products while conserving natural resources and adapting to climate change and other challenges. In general, the output of crops and livestock per hectare of farmland and per worker has increased over a 50-year period, with the highest yields per hectare in the developed countries of northeast Asia (Japan and the Republic of Korea) and the highest output per agricultural worker in the United States and Canada, as shown in Figure 1.

Figure 1. Fifty-Year Trends in Agricultural Land and Labor Productivity.



Source: Derived from FAO (2018a) data.
Note: The diagonal lines represent constant land-labor (A/L) ratios.

Source: Word Bank, *Harvesting Prosperity: Technology and Productivity in Agriculture.*

The remainder of the report is organized as follows: Section 2 presents technology developments, Section 3 presents emerging technologies in specialty crop production and management, Section 4 discusses challenges and future developments, and Section 5 presents the conclusion of this study.

Technology Development

This section summarizes the history, status, and future development of technologies that have contributed to agriculture in the United States. These technologies encompass mechanization, information technology, automation/robotics, artificial intelligence, indoor production, biotechnology, and nanotechnology. Some advanced and interdisciplinary methodologies such as precision agriculture are also discussed.

Mechanization and Automation

Mechanization of an operation can provide mechanical power, speed, safety, and a greater potential for consistency and quality control of repetitive tasks. Automation includes these same attributes but with greater flexibility, and potentially, some automated decision making. Mechanization is normally defined as the replacement of a human task with a machine. On the other hand, true automation encompasses the entire process, including bringing material to and from the mechanized equipment, integrating multiple operations, and ensuring that different pieces of equipment communicate to ensure smooth operation. True automation often requires reevaluating and changing current processes rather than simply mechanizing them. The possible benefits associated with automation include reduced manual labor requirements, improved product quality and market value, elimination of hazardous working conditions, reduced production costs, and improved worker income and professional esteem.

In the United States, mechanization has contributed significantly to the agriculture sector. Currently, U.S. farmers are facing widespread labor shortages. The causes of these shortages are complex and multifaceted. Four key factors contributing to labor shortages are the aging agriculture workforce, decreased interest in hard manual labor, stricter immigration laws, and rising wages for farm workers. For specialty crop producers in Florida, production and harvest are labor intensive and depend on a significant number of seasonal and migrant farmworkers. Specialty crop producers are facing increasing challenges with respect to both the availability and cost of farm labor.

For several years, growers have become increasingly concerned about the availability and legality of their domestic workforce. There is a widespread belief among growers that native-born Americans are generally not willing to do farm work (Hoban, 2017). For those foreign workers, around 50 percent of the workers interviewed for the National Agricultural Worker Survey (NAWS) self-reported that they do not have legal documentation to work in the United States (Li and Reimer, 2020). A 2013 survey of strawberry growers (Guan et al., 2015) suggested that half of the growers in Florida believed undocumented workers account for 80 percent of the industry's workforce. The shortage of legal farmworkers increases the uncertainty of farming labor supply in Florida.

A worker's average hourly earnings must comply with minimum wage requirements. The minimum wage in Florida has increased over the past two decades, but these increases have not kept pace with inflation, as measured by the Consumer Price Index and GDP Implicit Price Deflator. The economic challenge of rising minimum wages is that worker productivity is ultimately limited by individual physical capacity. Consequently, an employer's primary recourse to comply with a higher minimum wage is to raise piece rates, which translates directly into higher unit costs of production. Higher piece rates needed to comply with higher minimum wage rates put pressure on the competitive position of Florida's specialty crop growers.

Automation of production and harvesting jobs could ultimately resolve many farm-owner labor concerns. Over the past decade, a trend of advancement in mechanization and automation has occurred. In the United States, the labor shortage and the average wage have increased significantly. This motivates the advancement of automation. The development of artificial intelligence (AI), sensing technologies, microelectronics, and Geographic Information Systems (GIS) has enabled technology advancement at a lower cost.

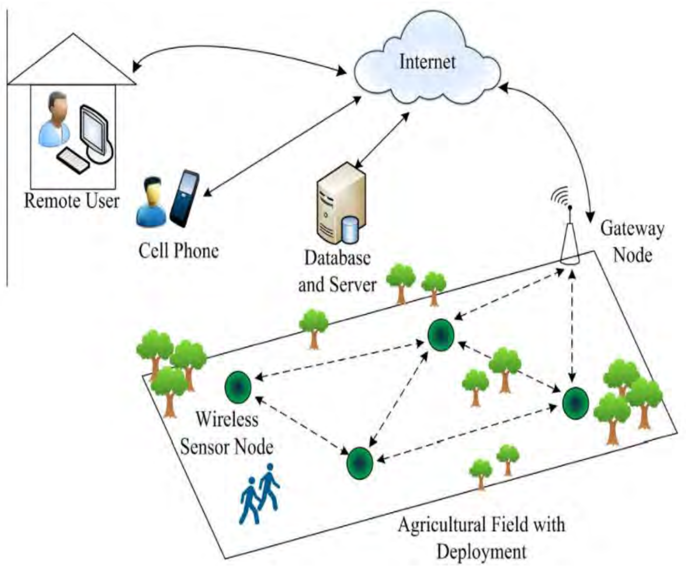
In Miami-Dade County, specialty crops such as fruits, vegetables, and nurseries are the primary crops in both acreage and value. Traditionally, these crops are very labor-intensive. Automation can mitigate labor shortage issues, reduce production costs, and increase competitiveness.

Internet of Things

The Internet of Things (IoT) provides solutions for continuous monitoring and control of agriculture activities. Typically, IoT uses a wireless sensor network (WSN) to monitor elements such as soil, wind, atmosphere, water, disease, location, environmental conditions, pests, and fertilization to facilitate better decision making (Farooq et al., 2020; Hamami and Nassereddine, 2020; Ojha et al., 2015; Aqeel-ur-Rehman et al., 2014). For example, WSNs for monitoring soil nutrients are applied for predicting crop health and production quality over time. As another example, irrigation scheduling can be controlled with WSNs to monitor soil moisture and weather conditions.

Figure 2 shows a typical wireless sensor network deployed for field agricultural applications. The network consists of sensor nodes that are powered with application-specific onboard sensors. The nodes in the on-field sensor network communicate among themselves using radiofrequency (RF) links of industrial, scientific, and medical (ISM) radio bands (such as 902–928 MHz and 2.4–2.5 GHz). Typically, a gateway node is also deployed along with the sensor nodes to enable a connection between the sensor network and the outer world. Thus, the gateway node is powered with both RF and Global System for Mobile Communications (GSM) or General Packet Radio Service (GPRS). A remote user can monitor the state of the field and control the on-field sensors and actuator devices. For example, a user can switch on/off a pump/valve when the water level applied to the field reaches some predefined threshold value. Apps are available for mobile phones to remotely monitor and control the on-field sensors. The mobile user is connected via GPRS or even through text messages known as Short Message Service (SMS). Periodic information updates from the sensors, and on demand system control can also be designed. WSN has been widely applied in irrigation to reduce water usage, reduce fertilizer usage, increase production yield, and reduce pollution.

Figure 2. Illustration of a wireless sensor network in agriculture.



Source: Ojha et al., 2015.

Artificial Intelligence

Artificial intelligence (AI) is a promising area in computer science, automation, robotics, and recently, in agriculture. Artificial intelligence describes the capability of a machine to imitate intelligent human behavior and mimic “cognitive” functions such as learning and problem solving.

Machine learning (ML). Machine learning (ML) is an application of AI based on the idea that a machine such as a computer or a microcontroller can learn from data and identify data patterns. A machine can “learn” without being programmed and adjust to new inputs to accomplish specific tasks (e.g., self-driving cars, phase/voice detection, and object classification). This process can eliminate human intervention and errors. In general, the simulation of human intelligence by machines can be described as machine learning. Machine learning creates models based on sample data, referred to as "training data," to make predictions or judgments without being explicitly programmed. ML typically involves three main steps: learning, testing, and self-adjusting. ML models try to mimic the step-by-step reasoning that humans employ when solving problems or making logical inferences. For example, artificial neural networks, an ML methodology, are inspired by our understanding of the biology of our brains, mimicking the vast number of interconnected neurons.

In specialty crop production, recent advances in AI and ML, together with the latest technological developments in remote sensing, automation, and robotics, can improve production management, optimize agrochemical applications, increase profit, and reduce negative environmental impacts.

Indoor Production

Indoor production is crucial for the future of the agricultural sector amidst the rapid changes in climatological conditions, the depletion of resources, and the constantly growing human population. The methods of monitoring and controlling environmental conditions in indoor production systems are critical to this end. These methods can be grouped under the term *Controlled Environment Agriculture* (CEA), referring to a type of farming that facilitates growing in spaces whose conditions can be manipulated to match the needs of specific plants. These techniques allow different plants to grow within a single indoor farm, in different areas with customized environmental conditions for humidity, temperature, light, and nutrients applied according to the individual needs of the species cultivated.

Modern vertical farming constitutes the state-of-the-art in CEA. Vertical farming refers to artificial indoor environments where crops grow on top of each other, in vertically stacked layers, in contrast to the traditional, horizontal rows. Growing vertically can support achieving sustainability. Vertical farming applies a variety of techniques, namely aquaponics, hydroponics, and aeroponics, minimizing the use of soil. Consequently, vertical farming allows conservation of space, resulting in higher crop yields per square foot of land used, while drastically reducing water consumption by capturing and reusing drainage. Vertical farms can also increase productivity per acre by accommodating many more crops, while occupying the same amount of land, reducing overall land requirements and pressure for deforestation and conversion of natural lands to agriculture. Furthermore, vertical farms can be integrated within urban areas, bringing production closer to consumers for local distribution, reducing transportation distances by truck or plane and leading to lower CO_2 emissions (USDA, 2021).

In addition to conservation of land and water, as well as increased productivity, vertical farming enhances food safety. These highly controlled enclosed environments protect crops from being exposed to extreme weather events, pests, and diseases. Thus, cultivation requires only nutrient elements in the irrigation system during the growing period, reducing the use of pesticides to zero levels (Avgoustaki and Xydis, 2020).

Genetic Engineering

Genetic engineering, or recombinant DNA technology, refers to techniques applied in the laboratory to manipulate genetic material. Genetic engineering is applied primarily to deoxyribonucleic acid or DNA from different biological species, usually by introducing genes from one into another. These procedures may involve changing a single base pair of amino acids (A-T or C-G), deleting a region of DNA or adding a new segment of DNA, aiming to alter, repair or enhance the form or function of the genetic material. Genetic engineering enables unprecedented levels of modifications to be achieved in biological systems from microorganisms to higher plants and animals (Rosenberg, 2017; Batt, 2014; Robert and Baylis, 2008).

Altering the genomes of plants and animals has a long-lasting tradition in human civilization. People were using traditional breeding techniques for centuries prior to the 1990s, when Genetically Modified Organisms (GMOs) started to become widespread. Some segments of the scientific community have expressed ethical concerns in genetic engineering as a revolutionary technology development with a crucial impact on the agricultural and food sector. In 2017, genetically modified (GM) crops occupied 13.5 percent of arable land globally (Schulman, 2020), providing manifold benefits for farmers and the environment.

Genetic engineering technologies can be applied to numerous areas. Most of the research on GM crops aims at helping farmers prevent crop loss. Some of the most essential benefits of GM crops include their resistance to insect damage and plant viruses, as well as tolerance to herbicides. Higher resistance to pests and diseases results in reduced use of spray pesticides. GM technology adoptions have reduced the use of chemical pesticides by 37 percent, and overall environmental impact by 18 percent (Klümper and Qaim, 2014). Tolerance to herbicides allows farmers to control weeds without tilling the soil—as is traditionally done—resulting in healthier soils and lower fuel use.

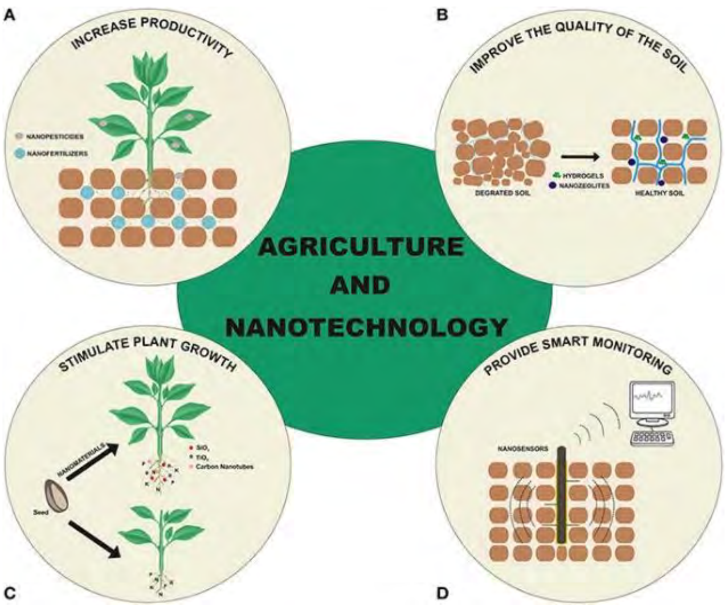
Use of genetic engineering technologies in agriculture has led to an increase of crop yields by 22 percent globally, and farmers' profits by 68 percent (Klümper and Qaim, 2014). In the period from 1996 to 2013, use of GM crops generated $117.6 billion in global farm income benefit (Raman, 2017), while from 2010 to 2012, global yearly net income increased by 34.3 percent (Chen and Lin, 2013). Taken all together, genetic engineering could have a positive impact on both economic and environmental dimensions of agriculture. However, the introduction of modified genes in plants has raised biosafety issues (Khan and Hakeem, 2015). Other potential concerns include risks to the environment (e.g., aggravate weed problems, competition with native plant species, etc.) (Bauer-Panskus et al., 2020).

Nanotechnology

Nanoscience or Nanotechnology refers to the manipulation and manufacture of materials on a near-atomic scale to produce new structures, devices, and systems. Nanomaterials have a size between 1 and 100 nanometers. At this scale, materials begin to exhibit unique properties that affect their physical, chemical, and biological behavior. In agriculture, nanotechnology (such as nanoscale biosensors and nanoparticles) can provide information on and manipulate processes such as the spread of pathogens (USDA, 2022).

Research reported by Fraceto et al. (2016) indicated that nanotechnology has a potential positive impact in agriculture (Figure 3). Nanotechnology has the potential to minimize problems of agricultural practices on environmental and human health, improve food security and productivity, and promote social and economic equity. Innovations in nanotechnology can be an asset in safeguarding food security and protecting the public from pathogens in food, water, and the environment (Ghidan and Antary, 2019; Prasad et al., 2017). Research developments in the field of nanotechnology include nanoscale sensors that detect pathogens, pesticides, heavy metals, and other contaminants in food, water, and soil. Many of these tools are smartphone-based, easier to use, faster, more sensitive, and more affordable compared to other methods that were applied previously. Other dimensions in which nanotechnology is used in agriculture include using nanoparticles in vaccines and disease treatments, and eco-friendly silver nanoparticles that act as antimicrobials in films and packaging (Ghidan and Antary, 2019; Prasad et al., 2017, Fraceto et al., 2016).

Figure 3. Potential Applications of Nanotechnology in Agriculture.



Source: Fraceto et al. 2016.

Emerging Technologies in Specialty Crop Production

Almost all agricultural inputs (e.g., water, pesticides, fertilizers) are applied uniformly with conventional equipment despite field variability (e.g., non-uniformity in soil composition, variability in tree size and age within a field, etc.) and the variable distribution of spatial pathogens. Uniform applications result in overusing agrochemicals (e.g., applications where no disease or pests occur; over-application of fertilizers and water), which leads to increased costs, risk of crop damage, environmental pollution, and contamination of the edible products.

Artificial Intelligence and automation can be used to develop smart agricultural technologies for the precision and timely management of inputs (e.g., agrochemicals, water, and energy). This section presents emerging technologies that can bring a significant change to the management of specialty crop production and can be used to improve best management practices. Several cutting-edge technologies that have not been largely commercialized but have great potential in reshaping agriculture are discussed here.

Unmanned Aerial Vehicles (UAVs) for Field Scouting

Assessment of crop growth and timely strategic responses to crop production variations are fundamental challenges in precision agriculture (Panda et al., 2010). In tree crops, for example, measurements of individual tree parameters such as tree canopy characteristics are essential to monitor tree growth and optimize orchard management (Maillard and Gomes, 2016). Detecting, counting, and assessing individual trees in orchards allow the selection of appropriate horticultural practices such as the timely application of chemicals and precision irrigation scheduling; hence, the development of low-cost high-throughput assessment tools for tree crops is critical for precision agriculture applications. Traditional evaluation of field phenotypes relies on manual sampling and are often very labor-intensive and time-consuming when covering large areas (Mahlein et al., 2016; Shakoor et al., 2017; Zhang et al., 2019). Additionally, field surveys for pest and disease detection, plant inventory, and plant health assessments are expensive, labor-intensive, and time-consuming (Cruz et al., 2019; Partel et al., 2019a; Luvisi et al., 2016).

Small unmanned aerial vehicles (UAVs) equipped with red, green, blue (RGB), and multispectral sensors have recently become flexible and cost-effective solutions for rapid, precise, and non-destructive high-throughput phenotyping (Ampatzidis et al., 2017; Pajares, 2015; Singh et al., 2016). UAVs allow growers to constantly monitor crop health status, estimate plant water needs, detect diseases and pests, and quantify pruning strategies and impacts (Abdulridha et al., 2019a, b; Harihara et al., 2019; Jiménez-Brenes et al., 2017). They represent a low-cost method for image acquisition in high spatial and temporal resolution and have been increasingly studied for agricultural applications.

Since UAVs can collect a huge and complex amount of data from a variety of sensors, big data analytics tools and cloud computing can be utilized to increase data processing efficiency, provide data security and scalability, and reduce cost. Cloud-based applications are a solution with low upfront investments, efficient computational resource utilization, and usage-based costs (Jinesh, 2011). While standard software must be installed and configured by the user and requires maintenance and some knowledge of the process, cloud computing eliminates nearly all these concerns. Outsourcing computation to an internet service also provides advantages in terms of mobility and accessibility (Hayes, 2008). This model allows companies to deploy applications that could scale their computing resources on demand (Villamizar et al., 2016).

Example of a cloud and AI-enhanced crop management information system. A novel cloud-based technology, named *Agroview* (http://agroview.farm), was recently developed at UF to process, analyze, and visualize data collected from UAVs and other platforms such as satellites (Ampatzidis et al., 2020). This application can: (i) detect, count, and geo-locate plants and plant gaps; (ii) estimate plant height and canopy size (plant inventory); (iii) estimate individual plant stress/health; and (iv) determine plant nutrients concentration and create fertility maps (Costa et al., 2022). This high-throughput phenotyping technology was utilized to evaluate several citrus rootstock varieties in large-scale commercial experiments (Ampatzidis and Patel, 2019; Ampatzidis et al., 2019).

The *Agroview* technology converts UAV and ground-based collected data into practical and useful information. For example, a large citrus production area with specific information for a selected area (outlined in red) displayed in the window on the left is shown in Figure 4. This information includes the total number of trees and gaps (spaces with no trees), the UAV flight date, the total size of the area, average tree size and density, and average plant nutrient concentrations, as well as other information. An individual field is shown in Figure 5, with information provided for every tree (e.g., tree height and canopy area, leaf density, etc.). The blue dots represent places with no trees, where growers had to remove dead or non-productive trees because of a citrus disease, known as citrus greening or HLB. A video demo of this technology can be found at: https://twitter.com/i/status/1202671242647490560. This novel platform can serve as a digital twin of an agricultural field.

Figure 4. View of a citrus grove with *Agroview*, a cloud-based application developed to convert UAV and ground-based collected data into practical information for growers.

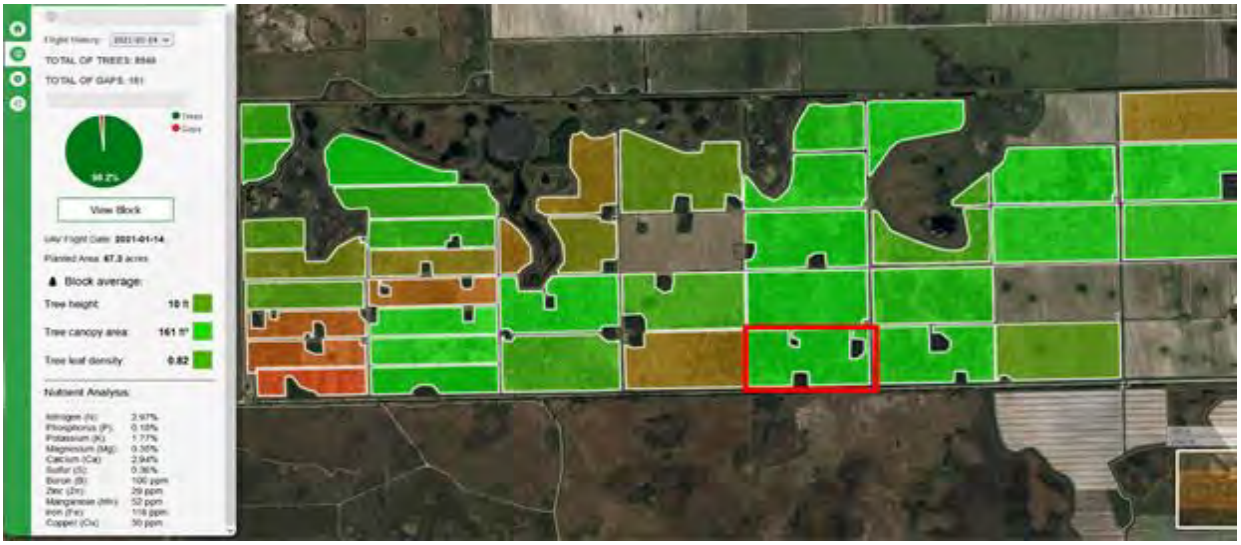
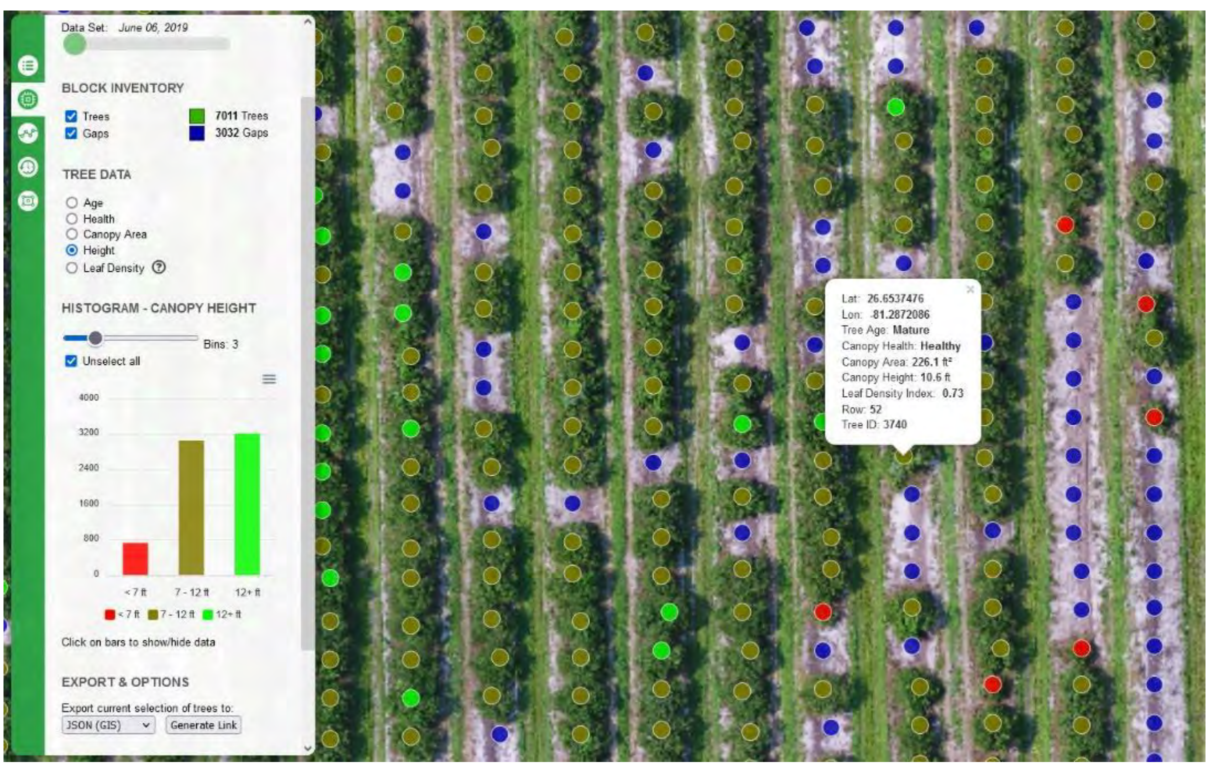


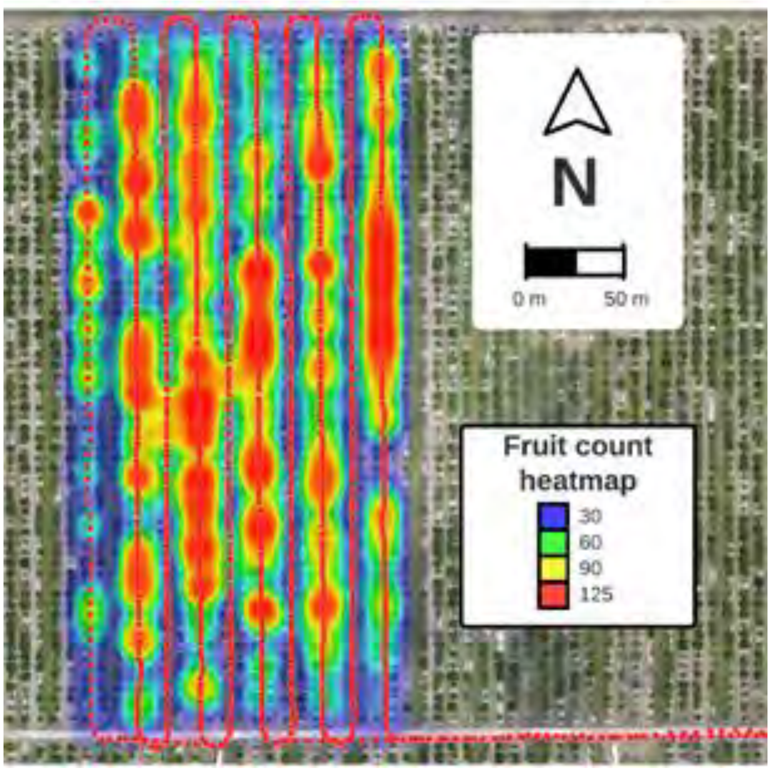
Figure 5. *Agroview* user interface to visualize data for an individual field, providing information for every citrus tree height or canopy size.



Yield prediction and harvest management using remote sensing and AI. Harvest costs are generally the single greatest expense for fruit and vegetable producers. Predicting harvest date and yield in advance can improve efficiency and optimize harvest timing, reducing costs and maintaining product quality and yield. Currently, growers use time-consuming, expensive, and destructive sampling methods to predict yield and collect other information such as fruit quality.

A real-time sensing technology, named *AgroSense*, which was also developed at UF, converts any farm vehicle or implement to a smart data collection machine (Partel et al., 2021). *AgroSense* can be used for fruit detection and counting of individual trees. The collected data from *AgroSense* can be used on *Agroview* to develop fruit distribution maps. Figure 6 shows a heatmap representing areas with high (red) and low (blue) fruit counts per tree. *AgroSense* only counts fruits visible from outside the tree's canopy and does not represent the actual number of fruits per tree. Although this is not a perfect measure of the plant's yield, it could be used as an indication for further yield prediction models by using spectral information from UAVs, tree canopy volume, and the tree health index (e.g., Vijayakumar et al., 2023). In Figure 6, significant color differences show missing trees (gaps) and trees with fewer fruits. Ground-based fruit counting technology presents a novel opportunity for yield prediction models. This data can be used on data fusion systems, combining ground (e.g., *AgroSense*) and aerial (UAVs, satellite) data for higher reliability and precision in estimating yield (Vijayakumar et al., 2023) and providing other crop insights on crop health/stress status. These results can be combined with weather and soil data to increase yield prediction accuracy.

Figure 6. Example of a heatmap of fruits detected and counted by *AgroSense* and visualized by *Agroview*.



Impact on the industry. The *Agroview* and *AgroSense* technologies can be used to save U.S. growers millions of dollars annually by reducing data collection time and cost. For example, USDA requires growers to create and submit accurate tree inventories for perennial tree insurance policies to document significant increase/decrease in coverage resulting from natural disaster events. Traditional field data collection tools are very labor intensive and time consuming. The *Agroview* platform can be used to create tree inventories and save the U.S. tree crop industry at least 70 percent of the data collection cost, and 90 percent of the data collection time. For crop phenotyping (e.g., variety trials evaluation) and yield prediction, *Agroview* and *Agrosense* can reduce collection time and cost by 90 percent (Ampatzidis et al., 2019; Vijayakumar et al., 2023). *Agroview* and *Agrosense* provide a consistent, more direct, cost-effective, and rapid method for field surveys, plant phenotyping, yield prediction, and precision nutrient applications. For example, manual tree count procedures can cost around $14 per acre, and 2-4 weeks to cover 1,000 acres, so if 50 percent of the Florida tree crop growers (approximately 570,000 acres) utilize *Agroview* or other similar technologies, it could save the industry at least $2 million per year and reduce the data collection time by 90 percent. *Agroview* and *Agrosense* could also be used to rapidly assess damage after an extreme weather event (e.g., hurricanes).

Precision Nutrient Management

Nutrient management is important for specialty crop production. Regular nutrient assessments should be conducted to optimize nutrient balance and prevent deficiencies or overfertilization. Optimizing nutrition is important for plant health and productivity and can improve plants' tolerance to stresses and diseases. Good nutrient management requires regular field monitoring to identify problems and examine crop responses. For most specialty crops, a time consuming and costly procedure is to collect leaves and send them to a specialized laboratory for a detailed analysis of macro- and micronutrients. For example for citrus, it is recommended to conduct nutrient analyses in July and August after the spring flush (see https://edis.ifas.ufl.edu/pdf/SS/SS53100.pdf), but more frequent analyses of leaf nutrients may be necessary to determine deficiencies associated with Huanglongbing disease (citrus greening) or other biotic and abiotic factors. Additional analyses may also be necessary where responses to novel management practices need to be monitored. However, it is not economically feasible to frequently collect and analyze leaves for plant nutrient status (Ampatzidis and Albrecht, 2021).

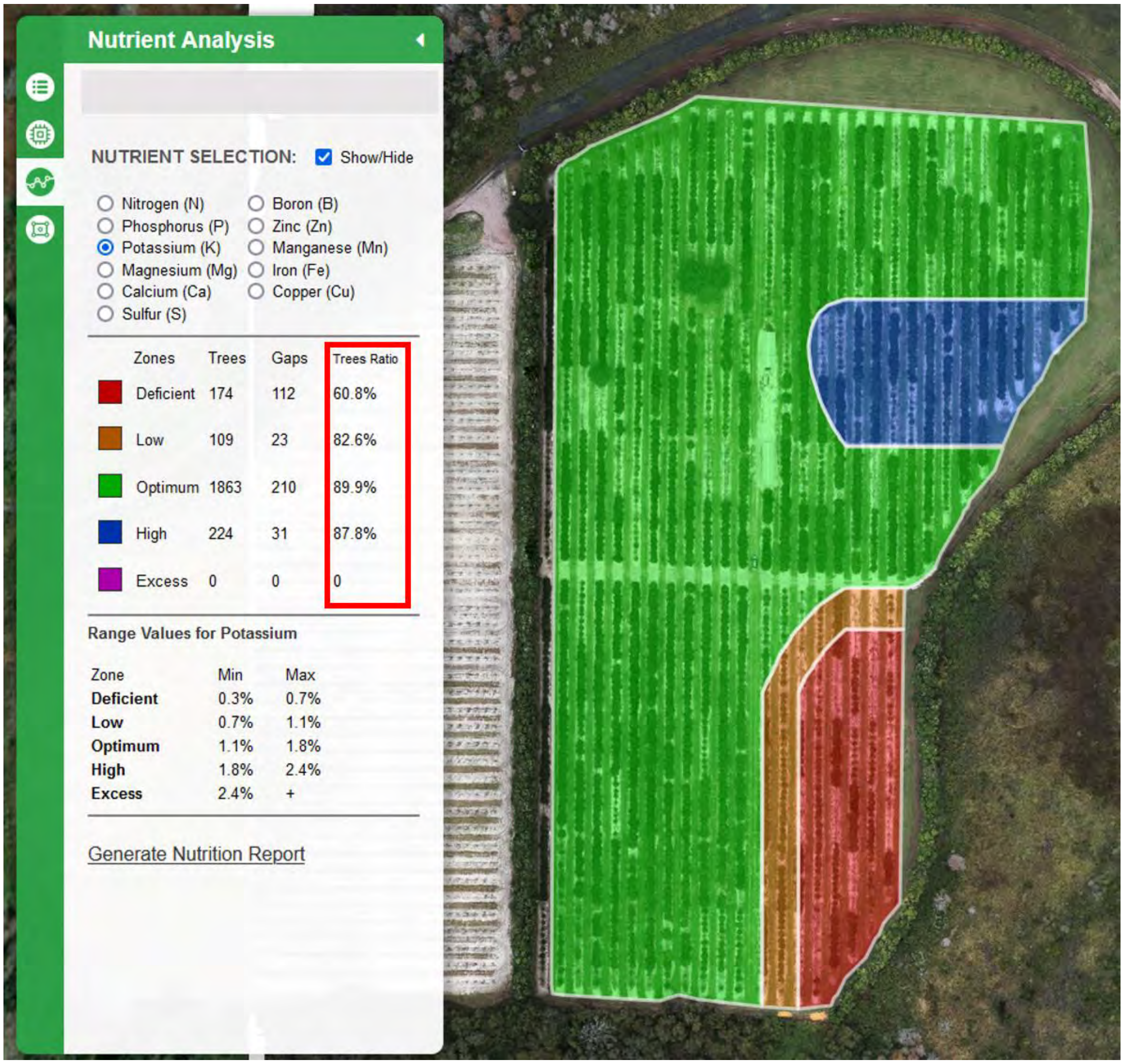
In addition to being time consuming and costly, leaf nutrient analysis is prone to human error because of inconsistencies and bias during leaf sampling and analysis, which can compromise the interpretation and relevance of the data. Faster and cheaper alternatives to conventional nutrient analysis methods are rapidly being developed. New technologies like UAVs and AI can be utilized to develop a more efficient methodology to determine leaf nutrient concentrations and improve the speed of data collection and consistency.

For example, a non-destructive method that can be used to quickly and efficiently determine citrus leaf nutrients and create nutrient or fertility maps that are compatible with variable rate technologies for fertilizer applicators was developed at UF/IFAS Southwest Florida Research and Education Center (SWFREC). This novel method can help overcome or complement some of the limitations of traditional leaf nutrient analysis methods (Costa et al., 2022). The spectral reflectance (i.e., the energy a surface reflects at a specific wavelength) of citrus canopies in five bands of light (red, green, blue, red edge, and near-infrared) was used to create an AI-based model to determine plant nutrient concentrations. The data were collected with a quadcopter UAV equipped with a multispectral camera (Figure 7). A large dataset with good variability was developed by analyzing four large-acreage commercial field trials in two different citrus production areas (central Ridge and southeast Florida) with two different scions (Hamlin and Valencia orange) and a large diversity of rootstocks. Differences in location, grove management, and scion−rootstock combination affect nutrient uptake and distribution in the tree canopy, which made the dataset sufficiently robust to develop a precise predictive model.

Figure 7. UAV (drone) equipped with a multispectral camera.

The AI model developed provides nutrient concentrations for individual trees. The novel cloud-based application, *Agroview* (previously described), was used to create fertility maps with discrete management zones to help visualize the data on plant nutrient concentrations. An example of a fertility map for potassium can be seen in Figure 8. Five zones (Deficient, Low, Optimum, High, and Excess) were determined based on UF/IFAS guidelines; the figure shows the range values for each zone. The 'Tree Ratio' for each zone is the number of trees divided by the number of tree spaces (trees + gaps). If the tree ratio is 100 percent, it means that the entire area (zone) has zero gaps. As can be seen in Figure 8, the tree ratio for the 'Deficient' and 'Low' zones are lower (60.8 percent and 82.6 percent respectively) than the 'Optimum' and 'High' zones (89.9 percent and 87.8 percent respectively) in this grove. Similar patterns can be observed for the nitrogen and phosphorus in this area. This indicates that this area of the grove might be "problematic" and require different management.

Figure 8. Potassium map of a citrus grove showing 'Deficient' (red), 'Low' (brown), 'Optimum' (green), and 'High' (blue) zones, developed by *Agroview*.



The main advantage of this AI-based methodology is that large populations of citrus trees can be assessed quickly and at a low cost while reducing inaccuracies that result from sampling a small subset of plants. The AI model had an error of less than 15 percent for most of the nutrients analyzed (Costa et al., 2021) but is expected to improve accuracy with more experiments and data. This new technology can be used to generate prescription maps for variable-rate applications of fertilizers (e.g., compatible with variable-rate applicators) based on UAV imagery. Although this model was tested in commercial citrus production systems, it can be easily adapted to other tree crops and production systems.

Smart and Variable-Rate Spray Technologies

Technological advances in machine vision, mechatronics, and AI can be used to help develop smart spraying technologies for specialty crops. For example, a smart tree crop sprayer that utilizes a low-cost and novel *AgroSense* sensor with a combination of a light detection and ranging (Lidar) and two RGB cameras and AI-based data fusion to optimize agrochemical (e.g., pesticide, foliar fertilizers) applications (Figure 9) was developed by UF/IFAS at the SWFREC. This sensor and variable rate spraying technology detects tree canopy, estimates tree height and leaf density, and based on this information, controls liquid flow and nozzle zones (or individual nozzles). The Lidar estimates tree height and canopy size and the cameras and AI verify if the detected "object" is a citrus tree. It will not spray if another object, human, other structures, other trees, etc., are detected. Together, the Lidar and cameras are also used to estimate tree leaf density with an AI-based data fusion algorithm and vary the amount of agrochemicals applied based on tree height and canopy leaf density. This technology can detect "at-risk" trees and does not spray on dead trees or gaps with no trees. While spraying, it detects and counts fruits and estimates their size (see demonstration video: https://www.youtube.com/watch?v=qRd4g44b2lk&feature=youtu.be). It can also "read" fertility maps developed by *Agroview* as described above and vary the amount of the foliar fertilizer based on the management zones. At the end of each application, it develops spraying and fruit heat-maps that can be visualized by *Agroview* (Figures 10 and 11).

Use of this novel sensing system reduced spraying volume by 30 percent compared to conventional spraying (Partel et al., 2021). This technology shows great potential to optimize spraying applications, minimize waste of agrochemicals, and collect critical data to support precision decision-making and predict yields.

Figure 9. Top view of the *AgroSense* technology utilizing sensor fusion with two color cameras and Lidar and artificial intelligence to optimize spraying applications.

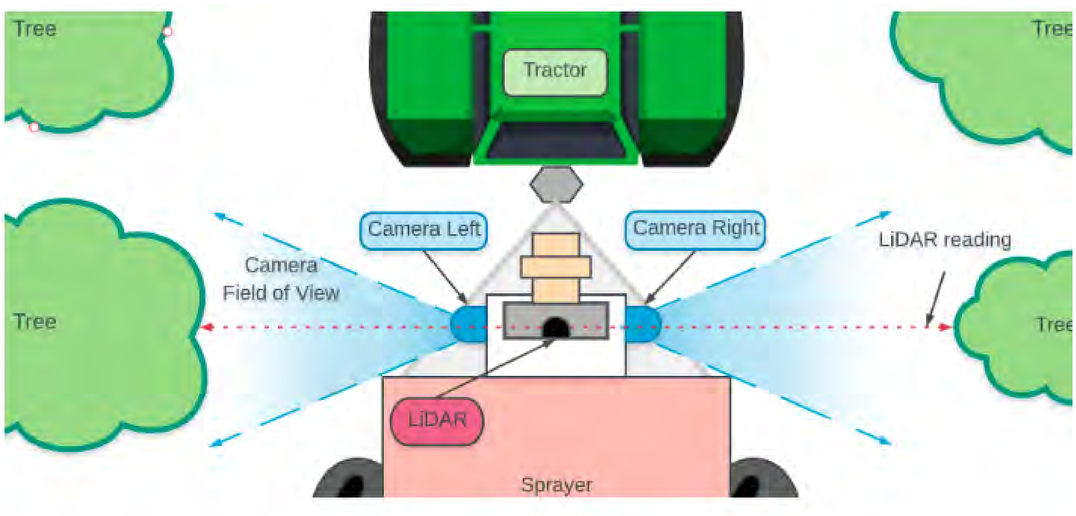


Figure 10. Example of a spraying heatmap for a 5.44-hectare citrus orchard.

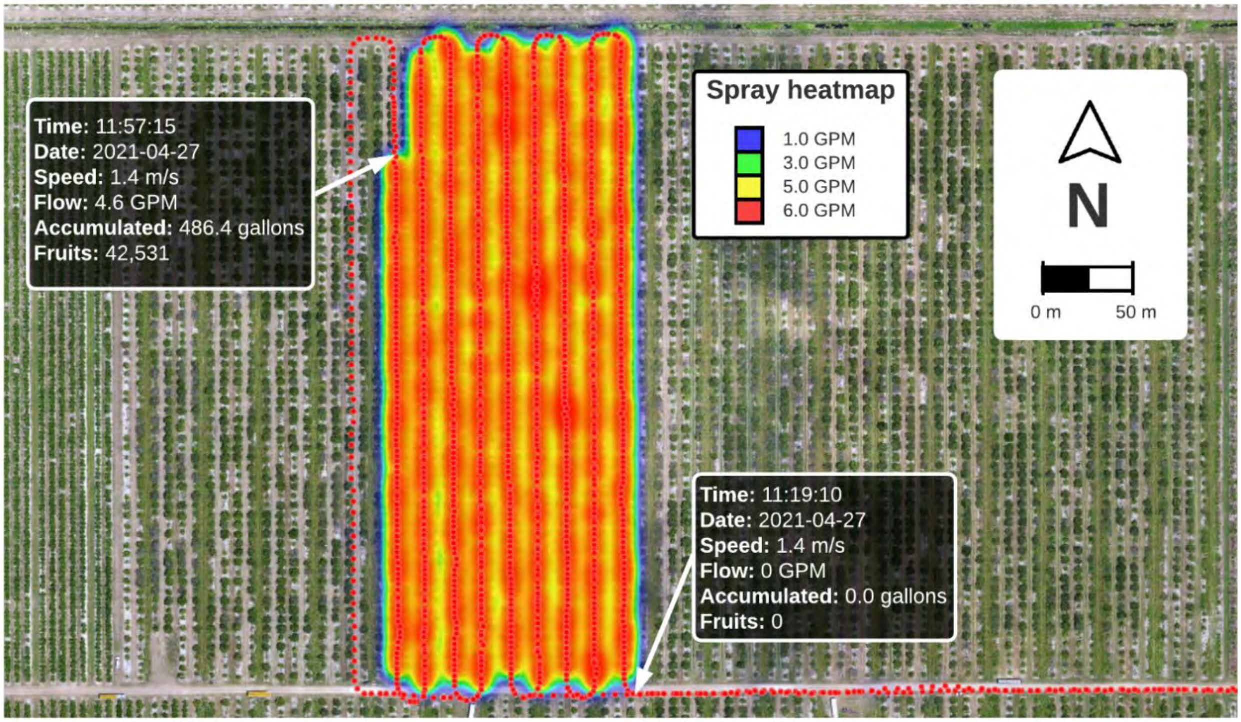
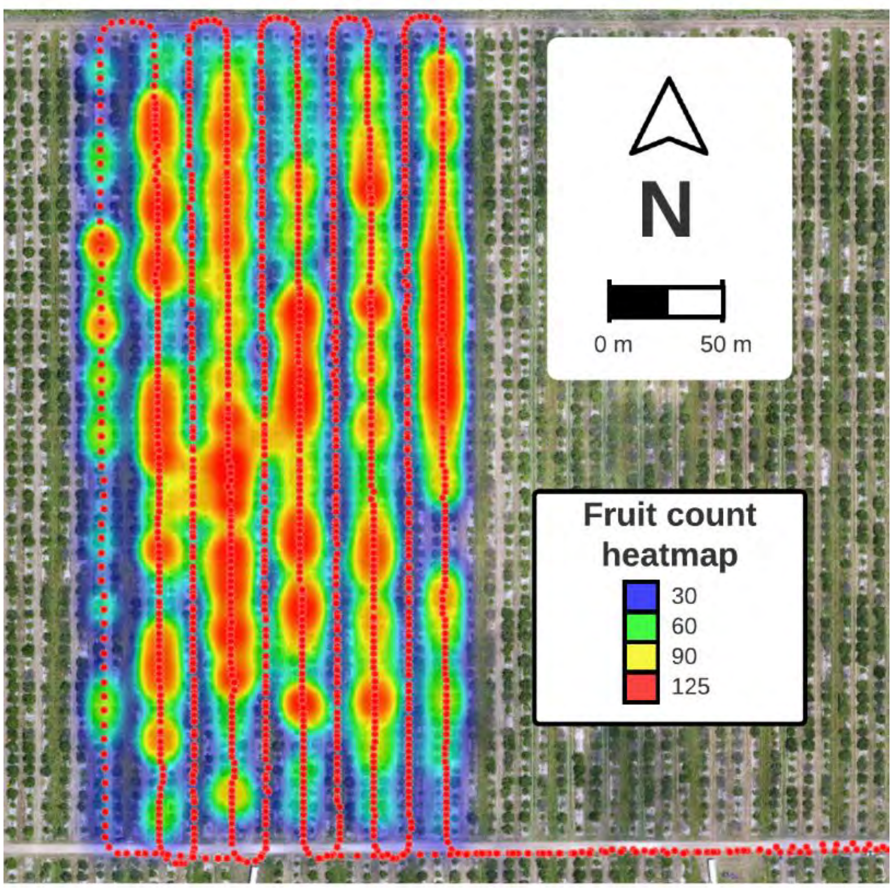


Figure 11. Example of a heatmap of citrus fruits detected and counted by the smart sensing system.



Precision Weed Management

Weed control is vital for profitable specialty crop production since weeds compete for nutrients and water, can harbor diseases and pests, and get in the way of equipment and workers. Without proper management, weeds lead to reduced crop yield and economic losses. Chemical weed control using herbicides is the most common control measure due to its low cost, high efficacy, and relative ease of use, although applying herbicides with traditional sprayers comes with challenges. For one, weeds in the fields are not evenly distributed and often grow in patches. In these cases, the wide spray path of a boom sprayer (the most common apparatus for applying herbicides, with multiple spray nozzles spaced along wide arms [booms] close to the ground) applying post-emergence herbicide would thoroughly cover the entire area, including where no weeds are growing, thus wasting chemical, and adding unnecessary expense. Additional and unneeded herbicide increases the risk that the herbicide or its active ingredients end up in non-target areas via soil run-off and drainage discharge, causing environmental risk. Innovations in spray technologies are being explored to increase the efficiency of herbicides, reduce chemical footprints, and minimize or eliminate negative environmental impacts.

More than 90 percent of the acreage of crops in the United States are being sprayed by herbicides (Gianessi and Reigner, 2007). The use of herbicides has eliminated the need for manual labor to pull weeds out of fields and has resulted in reduction of production costs and increase of crop yields. United States farmers dedicate around 65 percent of their total expenditure towards herbicides for weed control, and it is estimated that around $26 billion is spent on herbicides each year in the United States (Gianessi and Reigner, 2007). Pests reduce global potential crop yield by up to 40 percent, and that figure could be twice as large if no agrochemicals were used (Deutsch et al., 2018; Oerke, 2006). Global pesticide use was assessed to be 3.5 billion kg/year, with an estimated cost of $45 billion in 2015 (Pretty and Bharucha, 2015).

Apart from the advantages of using agrochemicals for pest and weed control, there are also disadvantages mainly due to the limitations of conventional spraying technologies. Most conventional sprayers apply agrochemicals uniformly, even though the distribution of weeds is typically patchy, resulting in waste of valuable compounds, increased costs, crop damage risk, environmental pollution, and contamination of products and land. Additionally, plants' resistance to herbicides is posing a significant threat to crop production in many countries; there are currently 263 species of herbicide-resistant weeds globally (Jeanmart et al., 2016; Owen and Zelaya, 2005).

Hence, there is an urgent need to redesign conventional sprayers and optimize agrochemical applications without affecting agricultural yield. For example, herbicides are mainly applied using hydraulic and hydro-pneumatic sprayers that have high inefficiencies, and significant amounts of the active ingredient end up elsewhere in the environment contaminating natural resources. Contamination can be caused by run-off from the field, discharge from drainage, and spray drift (off target deposition of spray). The spray drift usually occurs when small droplets of the spray liquid are carried away by the wind onto the neighboring crops/fields, which results in herbicide residues on plant products. This may cause damage to the crops and can also be carried over to the end consumer where it may have a significant effect on their health. Therefore, the use of herbicides should be as minimal and as efficient as possible to eliminate the negative environmental impacts—a step closer to agricultural sustainability.

Variable rate application of herbicides. Traditionally, in large-area cropping systems such as specialty crop production, herbicides are applied uniformly without considering variations of weed density and growth. On farms where a great variation in weed distribution is found, spraying herbicides at a fixed rate leads to economic losses, as unnecessary product is applied together with the associated person hours. As previously mentioned, this increases the chance of environmental implications associated with herbicides leaching or ending up in non-target areas. Further, weeds could develop herbicide resistance, providing yet another reason to use only the minimal amount of herbicide to effectively control weeds. New advancements in sprayer technology greatly minimize these issues by changing the way products are applied. By utilizing precision application tools, herbicides can be sprayed only where needed through variable rate application (VRA). This can be accomplished in various ways such as selectively opening spray nozzles (valves can be opened and closed using compressed air or solenoids), switching between nozzles of different types, or adjusting in other ways to adapt to field conditions. VRA spray applications in specialty crop production can be categorized as either map-based spraying or real-time sensor-based spraying.

Map-based spraying. In this system, herbicide application is based on a prescription map or guidance map prepared based on data related to weed species, location, distribution, and density. This information is collected through manual sampling or by remote sensing (e.g., using UAVs). A decision algorithm (computer process to make decisions based on variables) then calculates the precise herbicide VRA and creates the prescription map. This type of map-based variable rate spray has been tested successfully for weed management in row crops; however, it is not without limitations. This method is only as good as its map. Usually, a global positioning system (GPS) is used to collect the preliminary weed data and to guide herbicide application. While widely available and relatively inexpensive, GPS has low positioning accuracy, generally within a few meters, so real-time kinematic (RTK) GPS with much higher accuracy is generally recommended. Additionally, generating the prescription map requires extensive data analysis, so if too much time has elapsed from initial sampling until spraying, field conditions could have changed to such an extent that the VRA may not be maximally effective.

Real-time sensor-based spraying. This method of VRA uses real-time sensors so weed detection and spraying happen simultaneously. No prior mapping or data collection is required. Sensors act like the “eyes” of the sprayer, sending and receiving signals to detect the target and its physical characteristics. This can be especially advantageous in an orchard, where trees often vary in size. For example, a tractor equipped with real-time sensors can be configured to adjust its spray rate depending on whether the tractor is passing mature trees with a large canopy or young or reset trees where a lower rate of herbicide is desired. Measurements are made on-the-go and processed immediately to control and vary the herbicide application. Several types of sensors can be used for this purpose including photoelectric (e.g., used on the WeedSeeker® spot spray system), ultrasonic, and laser (e.g., LiDAR).

Machine vision and AI. A smart spraying system aims to apply chemicals only where they are needed, combining sensors and detectors to identify weeds and activate smart spray nozzles to deliver targeted chemical at an optimized amount. Such a system may incorporate a variety of sensors and techniques for weed detection such as thermal imagery, spectral analysis (determining characteristics from properties of light wavelengths), and machine vision. Machine vision is technology-based automation that uses imaging (input) to determine an action (output). In the context of herbicide use in agriculture, this is often limited to little more than distinguishing weeds from the soil background, and has difficulty distinguishing between crop plants and weeds. However, when combined with AI, machine vision becomes an excellent tool for precision herbicide spraying. AI is capable of processing large amounts of data and speeds up the decision-making process. This type of system takes advantage of cutting-edge AI technologies based on a deep learning neural network (an AI approach where many interconnected processes called nodes or neurons are grouped functionally in multiple deep "layers" to teach computers how to process data in a complex way that is continuously improving). In this way, AI is used for image analysis and object recognition to train a computerized smart spray system so that differences in crop, soil, weed identity, and weed growth are factored into whether herbicide will be sprayed and in what way, either spot spraying or determining the rate of VRA. This type of machine vision AI smart spray system is currently being studied for weed management in Florida specialty crop production. Recent work from the University of Florida/IFAS has shown promising results using a prototype for an AI-enhanced smart sprayer to accurately distinguish common weeds such as purslane and sedges from pepper and tomato plants and perform targeted sprays.

Examples of AI-enhanced smart spraying technologies for precision weed management. Machine vision and AI have been used to develop "smart" sprayers that can optimize agrochemical applications. A smart sprayer system needs to be able to locate weed spots in real time and spray the desired chemical only on the proper location. Machine vision has been used for many years to distinguish vegetation from the soil background through image segmentation processes due to the color difference between them. But now, AI can help to distinguish crops from weeds, and even classify weeds based on their species (e.g., grass, broadleaf). A smart sprayer now can target individual weeds instead of spraying the entire field and hence reduce costs and risk of crop damage and excess pesticide residue, as well as potentially reducing environmental impact. Several research and commercial smart spraying technologies are presented here.

WEED-IT precision spraying system, developed at the Wageningen University in the Netherlands, can be built onto any type of sprayer, and by utilizing blue LED-lighting can identify weeds for spot spraying. This system targets all living green material; hence, it cannot distinguish weeds from crops. It is also able to vary the rate of individual nozzles continuously by a pulse width modulation. The company claims that this system can save up to 90 percent on chemical costs.

See & Spray™, a novel sprayer developed by Blue River Technology in the United States, was acquired by John Deere in 2017, utilizes computer vision and deep learning (AI methodology) to identify a variety of weeds and crops, and directs micro-doses of herbicides to the target weeds. See & Spray™ was first used for lettuce thinning in California (Figure 12), and now is used for weed control in cotton and soybeans (Figure 13).

Figure 12. *See and Spray* technology for lettuce thinning by Blue River Technology.

Figure 13. *See & Spray* technology for weed control by Blue River Technology.

Bilberry, a French company, introduced an “intelligent spot spraying system”—compatible with most sprayers—that can reduce herbicide usage by more than 80 percent (company’s claim). This camera-based system utilizes deep learning to recognize weeds within crops, and only spray on the weeds. It can also create weed maps automatically. A similar camera- and AI-based technology has been developed by Agrifac, a Dutch manufacturer. This product, AiCPlus (“I see Plus”), can detect weeds (e.g., Rumex in grass fields) and apply herbicides only on the weeds. Robocrop is another similar technology for an in-row spot sprayer, designed by Garford in England to treat rogue potatoes growing among carrots, parsnips, and onions.

Ecorobotix, a company from Switzerland, is developing a solar-powered autonomous weeding robot, AVO (Figure 14), for row crops (e.g., sugar beets and green beans; and soon spinach, onions, and salads), meadows, and intercropping cultures that can treat up to 10 ha/day and use up to 95 percent less herbicides (based on Ecorobotix’s estimations). It integrates RTK-GPS and machine vision for precision navigation within a field. It can distinguish weeds from crops by using machine vision and AI.

Figure 14. AVO from *Ecorobotix*.

Farming Revolution, a German company, developed autonomous robots for mechanical (non-chemical) weed control in sugar beet, lettuce, and brassicas fields. The robots, (Figure 15) utilize machine vision and deep learning to distinguish crops from weeds, and a mechanical chopper to remove weeds (without the use of chemicals). This technology can be used also in organic farming. Similarly, Zasso, a Japanese tech company, developed several technologies for non-chemical weed control (e.g., utilizing electric weeding solutions).

Figure 15. Autonomous robots for mechanical (non-chemical) weed control by *Farming Revolution*.

AI-Enhanced Disease Detection and Management

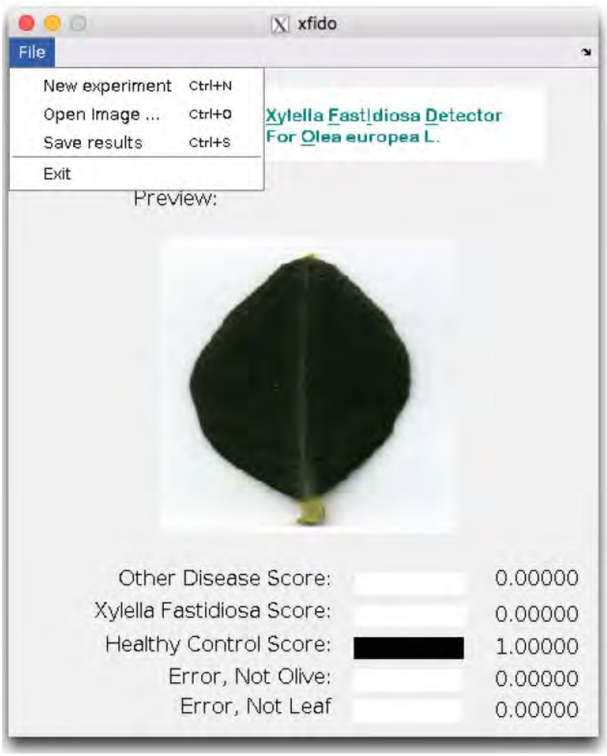
Disease identification in the field can be a very complicated procedure because it requires experienced personnel and frequent monitoring. Currently, growers use mainly visual observations to identify diseases in specialty crop fields, targeting early disease detection in order to apply the right treatment(s) and control disease spread. Artificial Intelligence can be used to develop cost-effective scouting systems that optimize pest and disease identification and management.

AI-enhanced symptom-based disease identification. Recently, several image-based pattern recognition systems have been developed for pest and disease detection. Some of these systems utilize ML models to detect, from images, a pest or visual symptoms of a disease. By evaluating a vast amount of training data, an ML-based image recognition technology can learn to identify and characterize objects (e.g., symptoms of a specific disease) in pictures. These systems enable users to take photos of a possibly infected plant with their mobile device, upload the image from the mobile device or computer, have the image processed remotely through the cloud by an ML model, and receive a prompt diagnosis of the specimen. There are several software (mobile or web) applications commercially available for image- and symptom-based disease detection. However, identification of diseases by pictures alone relies upon the quality of the photos and typical diagnostic symptoms or signs of the pathogen.

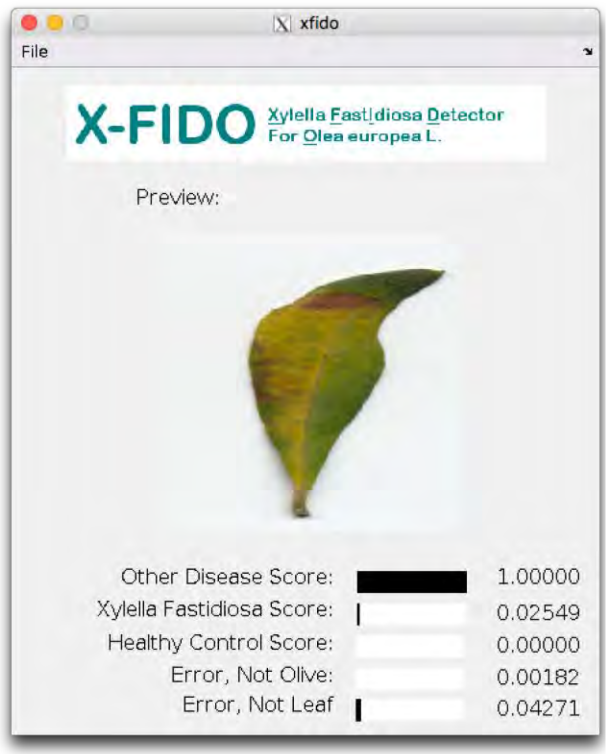
Vision-based pattern recognition and the utilization of deep learning (AI approach) systems to identify plants and detect diseases is not a new concept. Computer vision techniques to identify plant diseases have been described as early as the 2000s. Nowadays, machine vision and AI can be used to distinguish among a variety of diseases with similar symptoms and reduce diagnosis time and cost (Abdulridha et al., 2018). Cruz et al. (2017) developed a vision-based X-FIDO program (Figure 16) to detect symptoms of Olive Quick Decline Syndrome

(OQDS) on leaves of *Olea europaea L.* infected by *Xylella fastidiosa* with a true positive rate of 98.60±1.47 percent. This system utilizes a deep learning convolutional neural network (DP-CNN) and a novel abstraction-level data fusion algorithm to improve detection accuracy.

Figure 16. Screen shots of the X-FIDO program. The program is simple to operate and consists of three commands: new experiment; open image, which prompts the user to open an image, automatically processes the image and logs the confidence scores; and save results, which saves all logged confidence scores to a comma-separated value (CSV) file. In sub-figure (a) the program correctly classified a healthy control. Sub-figure (b) presents an OQDS-infected leaf (*Xylella Fastidiosa*) (Cruz et al., 2017).



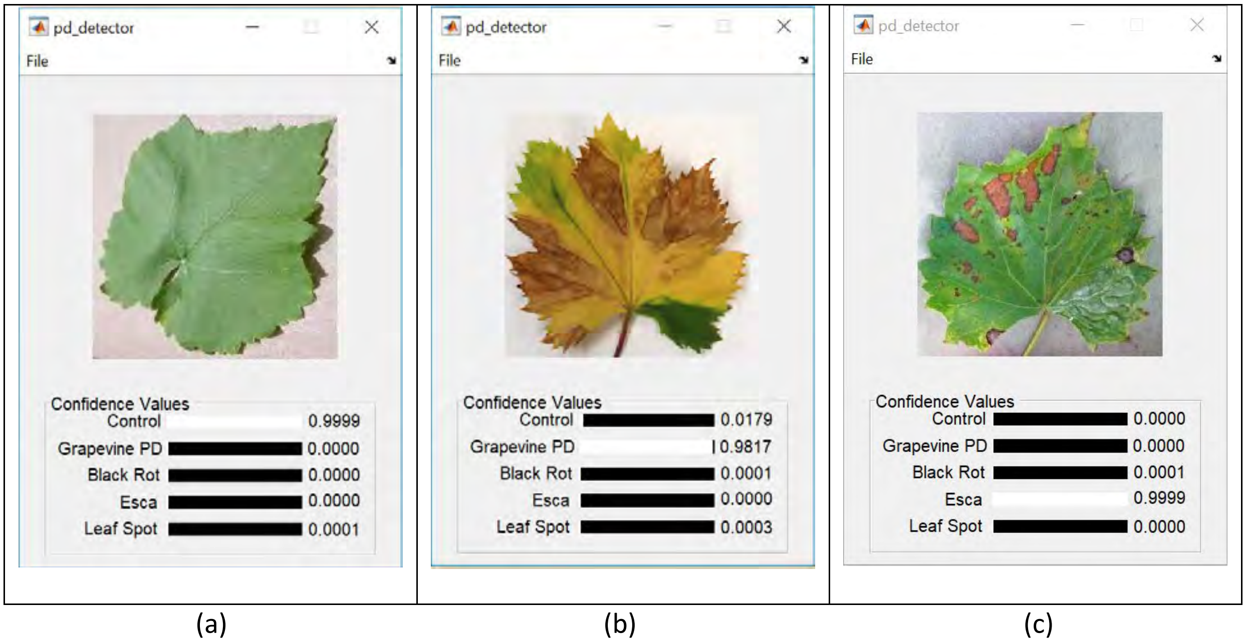
(a)



(b)

Ampatzidis et al. (2018a) and Ampatzidis and Cruz (2018) developed vision-based artificial intelligence disease detection systems (Figure 17) to identify Grapevine Pierce's disease (PD) and Grapevine Yellows (GY) and distinguish them from other diseases (e.g., black rot, esca, leaf spot). PD and GY symptoms are easily confused with other diseases and conditions that can cause vine stress. This technology has the potential to automate the detection of plant disease symptoms.

Figure 17. Example of the program that allows the user to submit images to the deep learning (AI) algorithm for analysis. (a) Control image. (b) Grapevine PD verified by lab analysis. (c) Esca disease. To the right of each pathogen/disease label is a horizontal bar plot of the confidence values. The confidence values are given to the far right of each bar.



Source: Cruz et al., 2018.

Smartphone apps for citrus. Dr. Arnold Schumann, a soil and water scientist and professor at the Citrus Research and Education Center (University of Florida), developed an AI-based app for smartphones to identify unique leaf symptom expressions (e.g., nutrient deficiencies, HLB symptoms). This diagnostic tool can help citrus growers and gardeners rapidly identify common citrus pests and diseases from foliage symptoms (download the app here: http://www.makecitrusgreatagain.com/SmartphoneApp.htm).

Intelligent early plant disease identification utilizing remote sensing and machine learning. Accurate and rapid disease identification at the beginning of an outbreak is essential for implementing effective management tactics. Diagnosis based on visual symptoms is often compromised by the inability to differentiate among similar symptoms caused by plant pathogens and abiotic disorders. Recent technological advances in sensors, machine vision, mechatronics, big data analytics, and Artificial Intelligence (AI) have enabled the development and implementation of remote sensing technologies for rapid disease identification and management. Early disease detection technologies can determine the spatial distribution of a disease outbreak for targeting precise management tactics. These technologies can be used to distinguish among a variety of disease symptoms in the field and/or transplant house, thus reducing both time and cost for diagnosis and management. This section presents examples of recent advances and latest technical developments in ML for intelligent plant protection.

Early identification of a specific disease in a crop would help growers to make the right decisions in selecting appropriate management practices. An infected plant may exhibit similar visual symptoms despite being caused by different pathogens, especially in early disease development stages, therefore, visual observation to identify and differentiate between the diseases is difficult. For example, early lesions of target spot (TS) caused by the fungus *Corynespora cassicola* and bacterial spot (BS) caused by *Xanthomonas perforans* may be similar in tomato plants. Any delay or incorrect diagnosis can lead to incorrect management decisions that could increase the spread of disease within the field, reduce crop health and yield, and increase the economic loss. Many diseases only need a few days to spread rapidly in the field.

For early plant disease and stress identification, multi- and hyperspectral sensing and ML have been utilized with promising results. These sensors measure the energy a surface (e.g., leaf or plant canopy) reflects at a specific wavelength. Any change that might occur and disturb the plant canopy or the leaf surface (e.g., caused by a disease) would affect the light reflectance and diffuse the light direction. Detecting these changes enables identification of abnormalities in plants and has the potential to detect and distinguish a specific disease in an asymptomatic stage (before symptoms become obvious to direct visual observations). For example, a study at the University of Florida's Southwest Florida Research and Education Center by Drs. Ampatzidis and Roberts' groups utilized a hyperspectral sensing system (380-1020 nm) and novel ML techniques to early detect and classify three critical tomato diseases (BS, TS, and Tomato yellow leaf curl) in the laboratory and field with high accuracies (more than 90 percent). In the laboratory, a benchtop hyperspectral imaging system was used, and in the field an UAV equipped with the same hyperspectral sensor (Figure 18) was utilized, and ML models were developed to classify diseases in early (asymptomatic) and late (symptomatic) disease development stages.

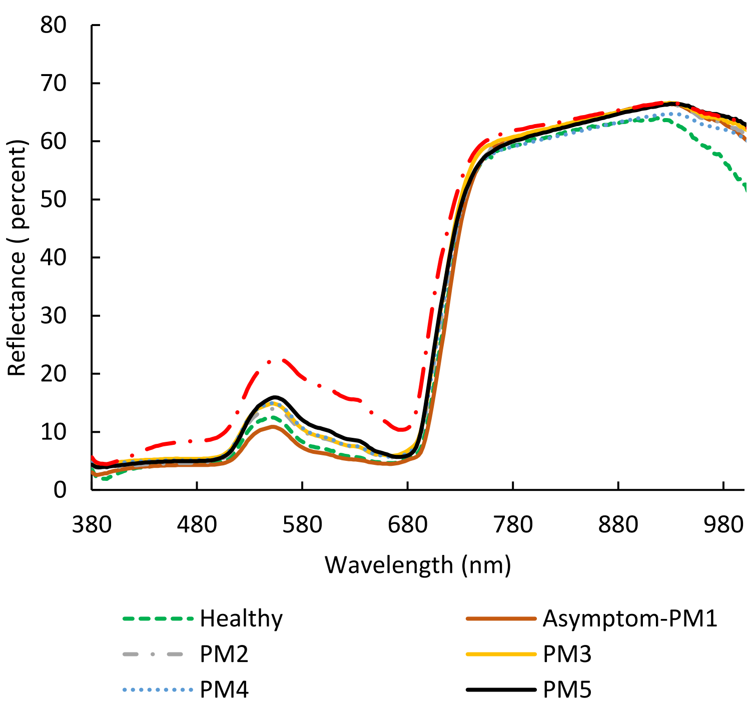
In another study from the same group (Abdulridha et al., 2020), hyperspectral imaging (same as above) and ML were utilized to develop a technique for detecting different disease development stages (asymptomatic, early, intermediate, and late) of powdery mildew (PM) in squash, in the laboratory and in the field. Powdery mildew is a common disease on squash in the United States. Powdery mildew can decrease yield potential and reduce fruit quality if it is not controlled early. First, the spectral signatures of healthy and PM-infected plants were created (e.g., Figure 19), and then, ML models were utilized to classify the disease development stages. As expected, the higher classification accuracy was achieved in the late disease development stages (~97 percent) but was lower (~84 percent) in the early disease development stages.

Both studies identified the most significant wavelengths for disease detection and classification in order to develop low-cost (multispectral) sensing systems for rapid disease detection in the field or transplant house. Additional studies are planned to evaluate the detection accuracy of the proposed techniques in commercial fields.

Figure 18. Unmanned aerial vehicle equipped with a hyperspectral imaging sensor.

Source: Abdulridha et al., 2020.

Figure 19. Spectral reflectance signatures of healthy squash plants and powdery mildew (PM) infected plants in different disease development stages [asymptomatic (PM1), early (PM2), and late (PM5) stages obtained under laboratory conditions.



Source: Abdulridha et al., 2020.

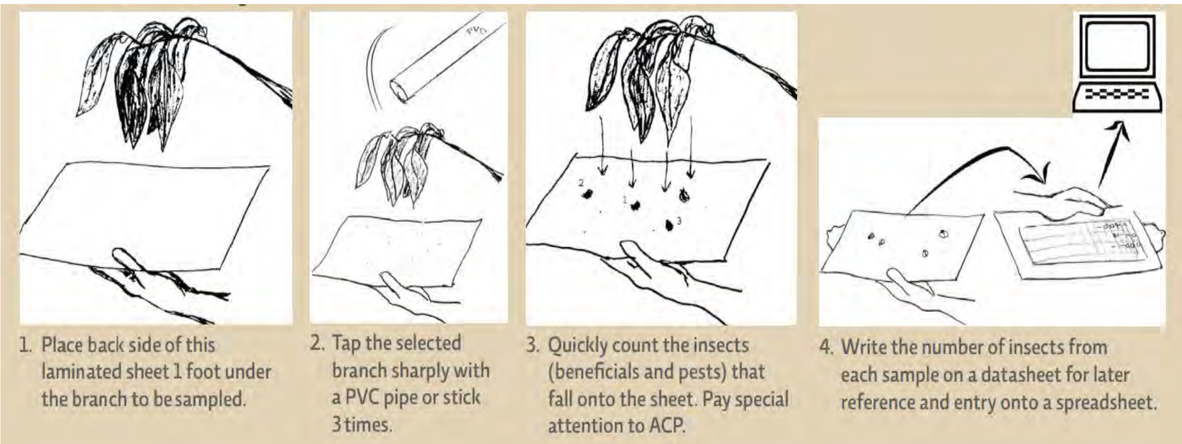
Integrated Pest Management

Agricultural pest management strategies have long been used for better pest control. Most research has focused on the development of new and effective products rather than on application strategies to replace toxic and non-effective old products. Pest control can be more sustainable when farming practices become more compatible with ecological systems.

Integrated Pest Management (IPM) can make a difference in this effort, as it emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural mechanisms for pest management (Lamichhane et al., 2016; Miedaner and Juroszek, 2021). IPM is a systems approach that combines different crop protection practices to manage the development of populations of harmful organisms and keeps the use of plant protection products to levels that are economically and ecologically justified to reduce risks to human health and the environment (Flint and van den Bosch, 1981). The aim is not to eradicate pest populations but rather to manage them below levels that cause economic damage (Naranjo et al., 2015). The first step of an IPM is to monitor insect populations in order to determine the need to spray. For example, there are several methods for monitoring insects in orchards (Stansly et al., 2010; Hall et al., 2007) including: (i) yellow sticky trap, which uses an adhesive board to collect insects for later visualization; however, sticky traps sampling is slow, labor intensive, costly, and assesses insects in flight, which may not always correlate well with numbers in trees; (ii) sweep nets, where a net is swept manually into the canopy of trees to collect insects; (iii) the tap sample method, which uses a short length of PVC pipe to strike the tree's branches, forcing the insects to fall over a whiteboard positioned below to visualize the insects (Figure 20). Other recent technologies, such as the Spensa Tech ® Z-trap® (Spensa Tech, 2018) use computational machine vision to monitor insects collected on the device fixed in orchards.

The tap sample method was developed to monitor the populations of Asian citrus psyllid (ACP) (Qureshi and Stansly 2007; Qureshi et al. 2009). It is the most common sampling method used in Florida (Stansly et al., 2010), being a fast and low-cost method compared to others. Tap sampling requires striking randomly selected branches with a stick or length of PVC pipe and counting ACP adults falling onto a laminated sheet held below (Figure 20). The tap sample has proved to be a fast and reliable tool for assessing ACP numbers in the tree canopy and the method was adopted in 2011 by the Animal Plant Health Inspection Service - Plant Protection & Quarantine (APHIS-PPQ) and the Florida Department of Agriculture & Consumer Services - Division of Plant Industry (FDACS-DPI) as an integral part of the citrus health response program (CHRP). CHRP employs some 80 workers to monitor over 5,000 blocks of citrus every 3 weeks in Florida using the tap sample (Monzo et al., 2015). Results are rapidly made available to clientele by email and on the website www.flchma.com.

Figure 20. Traditional manual ACP monitoring tap sample method.

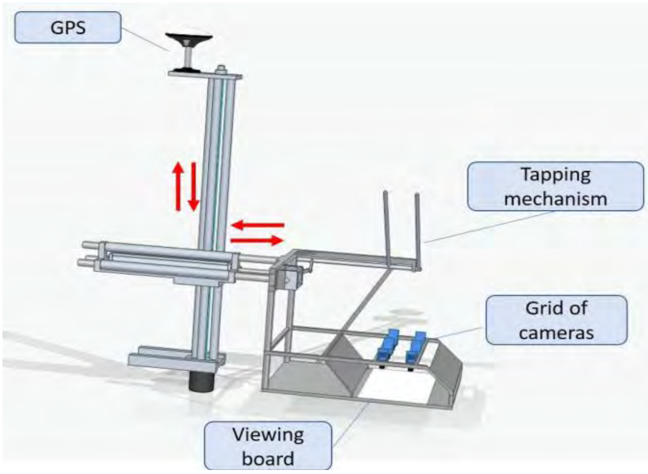


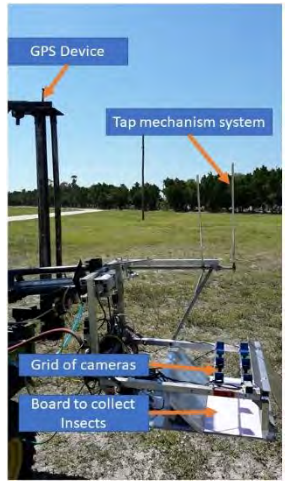
Source: Arevalo et al., 2012.

Most successful growers supplement this government service with their own ACP monitoring system to provide block-by-block information needed to fine-tune insect (e.g., ACP) control (Monzo and Stansly, 2017). Real-time georeferenced insect incidence data could be used to mitigate spray delivery for development of a precision, target-based sprayer. Automated and georeferenced insect monitoring is a first logical step toward precision insect management.

Example of an AI-enhanced pest detection system. The ACP is a key pest of citrus in Florida due to its role as a vector of citrus huanglongbing (HLB) (Monzo and Stansly, 2017). These pests and diseases can cause serious yield loss and reduce the ability of Florida growers to export or transport fresh fruit nationally and internationally. Growers/inspectors detect most of the pests in the field through visual inspection. However, visual detection is labor-intensive, expensive, and limited by the number of inspectors. The industry needs an automated method for the detection of ACP to assist growers in making timely management decisions and limit disease spread. Dr. Ampatzidis of the University of Florida led a team to automate the “tap sample method” (described previously) and develop a vision-based automated system to detect, geo-locate, and count ACP in the field (Partel et al., 2019b; Figure 21).

Figure 21. Automated and mobile system for monitoring and mapping pests (e.g., ACP) in orchards (including all moving components): a) first design; and b) actual system in field trials attached on an ATV.

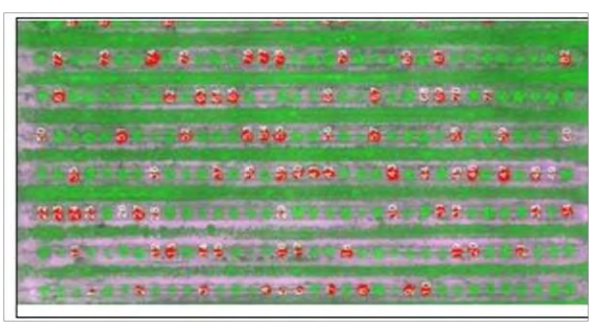




a) b)

This novel technology includes a tapping mechanism that strikes a tree's branches so insects fall onto a board with a grid of cameras used for image acquisition and processing (video demo: [https://twitter.com/i/status/1110151596770500608; patent #16/505,927)](https://twitter.com/i/status/1110151596770500608). It can distinguish and count adult ACPs and visualize the number of ACPs per sample tree on maps (Figure 22) compatible with precision equipment for variable rate applications. This helps determine where to apply the right amount of pesticide, decrease chemical use and expenses, and reduce environmental impact.

Figure 22. Example of a map of detected insects in an orchard in randomly selected trees (red color).

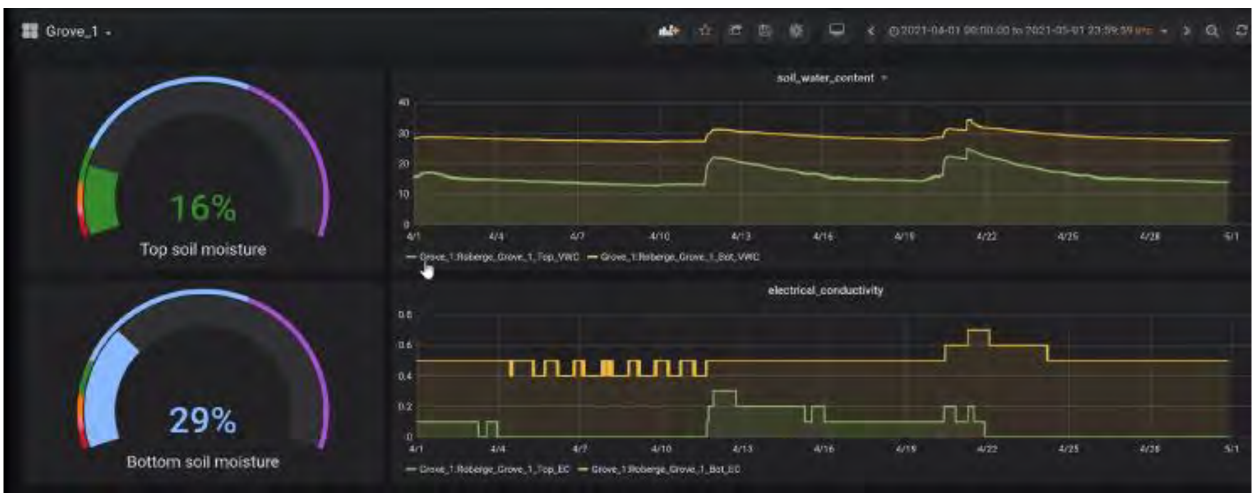


Precision Irrigation

Irrigation is defined as the artificial application of water on agricultural land, and is considered one of the most important constituents of agriculture. The scarcity of water in several areas motivates the need for proper use of water to use only in those places where water is needed and in the required quantity. Different methods of irrigation are in use, such as drip irrigation and sprinkler irrigation, to cope with the water wastage problem found in traditional methods such as flood irrigation and furrow irrigation. Precision irrigation is a sustainable approach that utilizes sensing technologies and decision support tools to optimize the application of water to the plants at the right time, amount, and place.

One example of the tools available for citrus water management is the IrrigMonitor (Figure 23). This decision support system, developed at the UF Indian River Research and Education Center (IRREC), combines data from different types and brands of in-field sensors, including soil moisture and weather sensors for the assessment of the water status of the orchard. IrrigMonitor provides real-time information on the tree water needs and the display can be personalized based on the specific soil conditions of each orchard (Ampatzidis and Guzmán).

Figure 23. One of the IrrigMonitor irrigation decision support system displays. Right panel: soil moisture and soil salinity real-time data from sensors in the field. Left panel: soil moisture content based on the field soil water holding capacity conditions.



The color-based displays allow the rapid assessment of irrigation needs at the soil layers where the roots are commonly located. By making decisions with the top layer, one can introduce high-frequency low volume irrigation schedules automatically. This high-frequency, low-volume irrigation is especially recommended to reduce stress in trees with the citrus greening disease. In addition, the bottom layer color-based display allows visualization of excess water applied, nutrients being lost, or water table rise. For example, in Figure 23, the bottom layer has a higher moisture percentage than the top layer and electrical conductivity increased at the same time in the bottom layer. This means that for a fertigation event, some of the nutrients were lost to the deeper layers of the soil. Graphs are available for more detailed assessments of weather and real-time sensor information.

Mechanical Harvest Technologies

Specialty crop growers face several serious challenges with respect to farm labor. The number of domestic farmworkers has decreased substantially and in some cases growers are unable to fully harvest their marketable fruit. A high percentage of the remaining domestic workers are not legally authorized to work in the United States (Guan et al., 2015; Li and Reimer, 2020). The costs to recruit temporary foreign agricultural guest workers through the H-2A program are quite high. Furthermore, United States specialty crop growers face stiff competition from other countries. Mechanical harvesting systems for specialty crops could simultaneously lessen the dependence on manual labor, reduce harvesting costs, and improve the overall competitiveness of United States growers.

Mechanical harvesters for specialty crops should meet several challenging requirements, including accuracy, speed, low cost, high throughput, etc. Four main problems need to be solved in developing successful harvesting using robots: (1) accurate navigation throughout the field; (2) location and characterization of the fruit in the plant; (3) grasping and detachment of each fruit; and (4) reduce damage to the plants and flowers (and not only the harvested fruit). Damage to a plant (or flower) will affect the development of new berries and hence, decrease the overall yield of the plant throughout the season.

Recent technological advances in sensors, machine vision, mechatronics, GPUs (graphical processing units), and AI have enabled the development and implementation of robotic technologies for mechanical fruit harvesting (Ampatzidis, 2022).

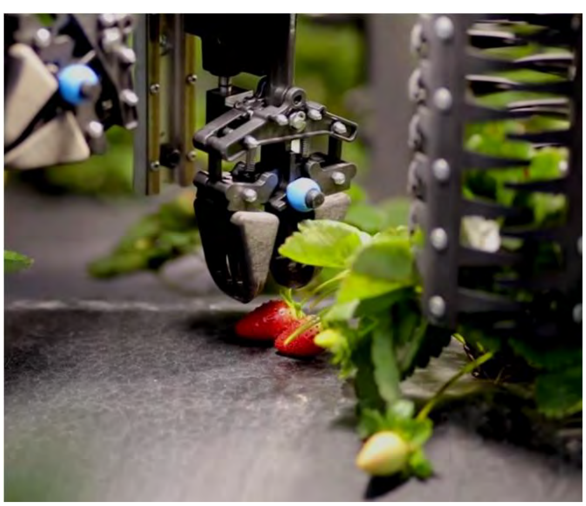
Example of mechanical strawberry harvesters. In this section, examples of autonomous strawberry harvesters are discussed. Strawberries in the U.S. are harvested every 3-4 days. Workers cut the berries by the stem (they do not just pull the berry) and pick only red (plump and firm; ripe) berries. Harvest can last up to 6-8 weeks. Picking conditions change daily, and the berry quality is affected by the local weather (among other factors, e.g., pests and diseases). Strawberries will not continue to ripen once they are picked. Hence, it is challenging to develop effective strawberry harvesters for continuous and selective picking of mature (ripe) berries without damaging the fruit and plants (during detachment).

Harvest CROO Robotics (HCR; https://www.harvestcroorobotics.com) is a Floridia company funded by the strawberry industry to develop an electric-powered robotic harvester. Formed in 2014, more than 70 percent of the U.S. strawberry production industry has invested in HCR. Since then, HCR has been developing the components necessary to automate the process of robotically picking strawberries. HCR has developed autonomous subsystems that can work together to accomplish the overall goals of mechanized picking, shorting, and packing of current strawberry varieties with high efficiency and significantly reduced cost while maintaining high-quality fruit. This technology does not require growers to radically change the way they currently grow strawberries, and it can solve the urgent labor shortage problem.

The HCR autonomous harvest platform (Figure 24) was designed to be a modular and scalable system. The current version of the harvester includes 16 independently working picking robots; four robots per row (double plants rows). It utilizes sensor fusion (e.g., LIDAR, multiple cameras, etc.) and AI for fully autonomous navigation, to avoid obstacles (e.g., colliding with growing rows or human workers), and for picking and packing berries. A novel mechanism for moving leaf foliage (Figure 25) was designed and utilized to pick healthy and ripe berries. HCR harvesters pick, inspect, clean (via hydro-cooling), short (e.g., berries for fresh market or juice, rejects), and pack berries in the field. They are holistic pick-to-pack solutions (a combination of a harvester and packing house in the field). These harvesters can work day and night, seven days per week, and replace a crew of around 24 human workers. For a video demonstration of this technology see: https://youtu.be/AO1mZrB5XK8. Furthermore, this harvester collects data from individual plants to help growers make informed production management and business decisions.

Figure 24. *Harvest CROO Robotics* strawberry harvester.

Figure 25. HCR mechanism for moving leaf foliage (right) and an end effector of a picking robot (left).



Agrobot (https://www.agrobot.com) is a company from Spain that has developed an electric-powered and adjustable harvest robot (E-Series model). This robot utilizes machine vision and AI for navigation and picking. The adaptable platform of this robot (Figure 26) can fit into multiple farming configurations and, based on the company, can be used for outdoor and indoor production systems (see video at: https://www.agrobot.com/e-series). The autonomous platform can contain up to 24 independent robotic arms for picking ripe strawberries. A machine vision and AI-based system detects and locates the ripe berries and then controls the movement of the robotic arm and the cutting system. The robotic arm grips and cuts the strawberry from the stem with two razor-sharp blades, and then places the strawberries into a container for later packing in clamshells. This technology requires a specific configuration of the growing rows (raised beds covered with plastic), including farming in single rows (not suitable with double plant rows commonly used in Florida) and potentially raising the bed's height, so the strawberries are hanging at the side of the bed (Figure 27). The harvester cannot see and pick berries covered by foliage.

Figure 26. *Agrobot* strawberry harvester.

Figure 27. *Agrobot* harvester picks berries hanging from raised beds.

There are other prototypes under development from a few startup companies, including the TX robotic strawberry harvester developed by Advanced Farm Technologies, a company based in Davis, California. Advanced Farm Technologies (https://www.advanced.farm), founded in 2017, recently raised $25M in a series B investment round for developing a multi-fruit robotic harvester. The TX harvester utilizes soft robotic grippers, machine vision, and AI for picking ripe strawberries (see video at: https://www.advanced.farm). The company's plan is to adapt the existing TX robotic prototype for apple harvesting too.

Challenges and Future Developments

Potential Benefits of Technology

The powerful and innovative technologies presented in this report have potential for improving agricultural practices in many ways. For example, using a smart spray system to apply herbicides at varying rates has significant economic and environmental benefits. By using only as much chemical as needed, the system reduces spray drift, ground losses, and off-target environmental impacts, especially to beneficial organisms and workers, thereby improving sustainability. The biggest savings come from purchasing and applying significantly less product (in some cases, a more than 70 percent savings). Using less herbicide also means fewer trips to refill the spray tank, saving time and labor hours as well as reducing fuel and labor costs. Overall, this makes a much more efficient system while maintaining weed control comparable to traditional methods.

Nevertheless, these systems have limitations. Sensor-based spray technology in a production system like orchards and vegetable fields is challenging because of limited detection range and varying environmental conditions. Depending on the type of sensor used, the accuracy and precision of the spraying application can be affected by factors such as ambient light, background noise, weather conditions (such as changing temperature, presence of dust or fog), vehicle shadows, or vehicle speed and acceleration. Much of testing and development of sensors is under ideal conditions, so the need for continued optimization for uncontrolled environmental variables and overcoming other technical difficulties and limitations of sensors and software cannot be overlooked.

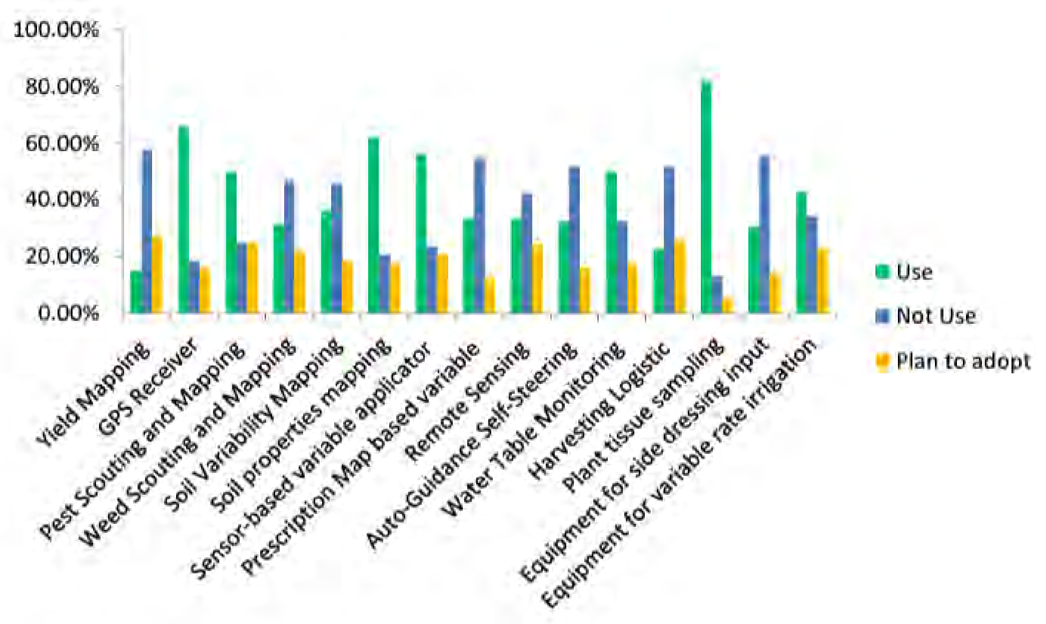
Developing accurate vision-based AI technologies involves a learning (training) process that requires collection and photographing many samples in a natural and dynamic environment to accurately represent the conditions in which devices will operate. A deep learner's (AI technology) performance typically improves as the volume of high-quality data increases, enabling the system to overcome a variety of imaging conditions (such as lighting conditions, poor alignment, and improper cropping of the object). Another major challenge with AI machine vision is the lengthy data processing time, especially when a hyperspectral (wide spectrum of light) camera is used. Despite many advances, some variable-rate spray technologies that use sensors still struggle with identifying weeds, pests, and diseases based on morphology, texture, or color for a particular species. AI can tremendously aid the improvement of sensor-based precision spraying systems. Ongoing innovations of deep learning-based AI are expected to develop robust systems in the future for precision spraying by addressing these issues. Such advancements will continue to increase efficiency, improve crop yield, lower the cost of these technologies, and make such systems more readily available.

AI-enhanced technologies can also be used for the development of mechanical harvesting (or pruning, thinning, etc.) technologies, for fruit and vegetables, to pick only “ready-to-harvest” (ripe) fruit with high accuracy and low cost. Still, a significant amount of research and development is needed to develop low-cost and efficient AI-based systems for precision agricultural applications that can be affordable and adaptable to small and medium size farms.

Technology Adoption

Emerging technologies and precision agriculture (PA) can help growers to optimize the use of agricultural inputs such as pesticides and fertilizers, which may lead to production cost reduction and environmental impact minimization. Despite numerous benefits, the adoption rate of PA technologies in the state of Florida is slow. A survey study published in 2020 (Ghatrehsamani et al., 2020) revealed that growers’ (N = 65) attitudes towards PA technology adoption have remained the same since 2005, when another survey was conducted. The percentage of use of the various PA technologies in 2017-2018 is shown in Figure 28. Respondents indicated that the most used PA technologies were ‘Plant tissue sampling’ (81.6 percent), ‘GPS Receiver’ (65.8 percent), and ‘Soil Properties Mapping’ (61.8 percent). The least used PA technology was ‘Yield Mapping’, with only 15.2 percent of participants reporting use of this technology. However, the fact that ‘Yield Mapping’ simultaneously presented the highest “plan to adopt" rate indicates the potential for future adoption and could be used as a roadmap for future research and development.

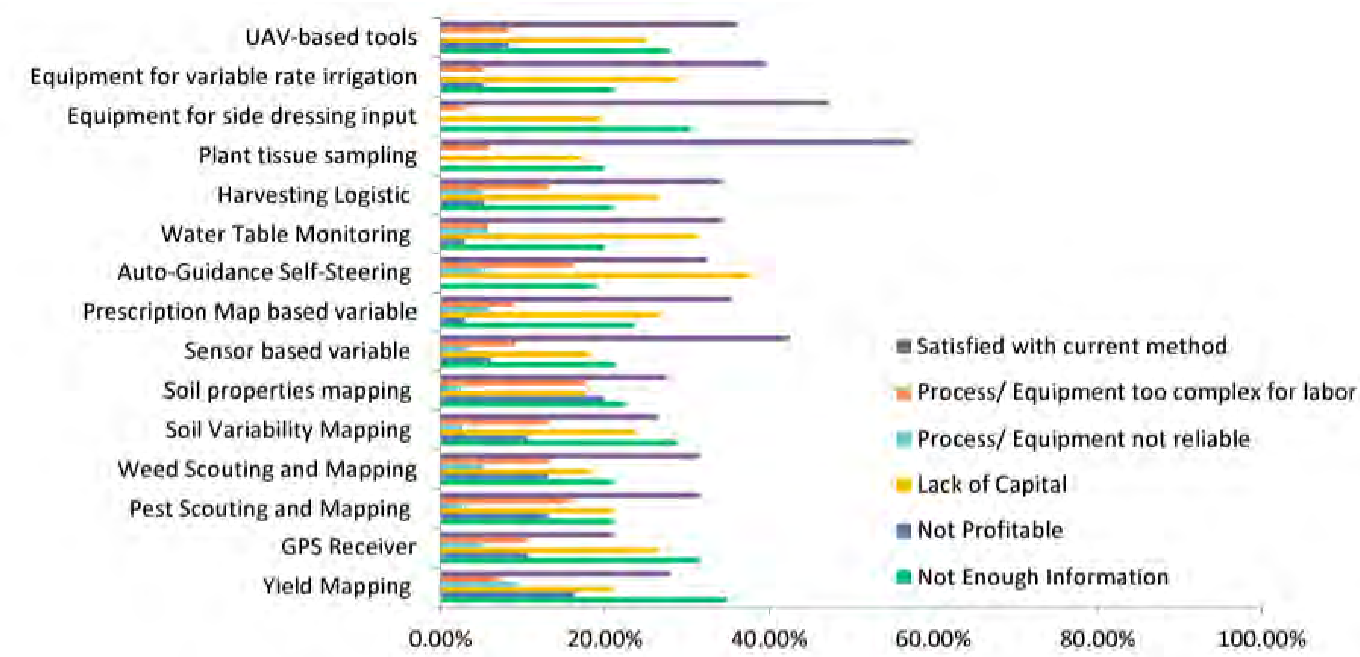
Figure 28. The use of PA technology in 2017-18.



Source: Ghatrehsamani et al., 2020.

Ghatrehsamani et al. (2020) also investigated the reasons why the various PA technologies were not used, to identify possible barriers to adoption. As shown in Figure 29, the most common answer was related to high satisfaction levels with the methods they currently used when the study took place. Other reasons indicated were a lack of capital for investment and insufficient information about the respective technologies.

Figure 29. Growers' reasons for not using PA technologies.

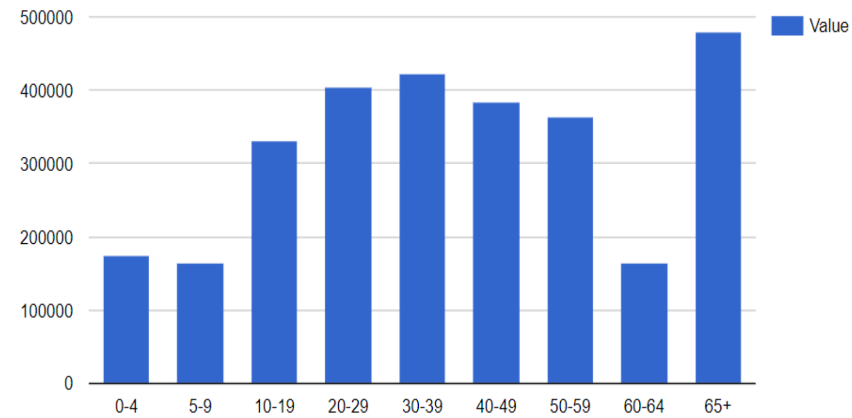


Source: Ghatrehsamani et al., 2020.

Factors contributing to the adoption of technological changes. This section discusses the factors contributing to the adoption of technological changes. These factors include farmer age and education, climate change, household size, land size, access to credit, land tenure, access to extension services, and organization membership (Ruzzante et al., 2021).

Aging farmers and education. As the third most populous state in the nation, Florida continues to attract more people. Miami-Dade County is home to 26 percent of foreign immigrants who relocated to Florida between 2010 through 2014. Tampa and Miami rank first in the state for attracting millennials. Statewide, Florida's population increased by 211,000 between July 2020 and July 2021, according to the census report—ranking second in the nation. With 2.7 million residents, Miami-Dade County's population is larger than 16 U.S. states. It is estimated that Miami-Dade will continue growing, likely reaching 3 million in 2025. The projected age distribution in Miami-Dade County in 2024 is shown in Figure 30.

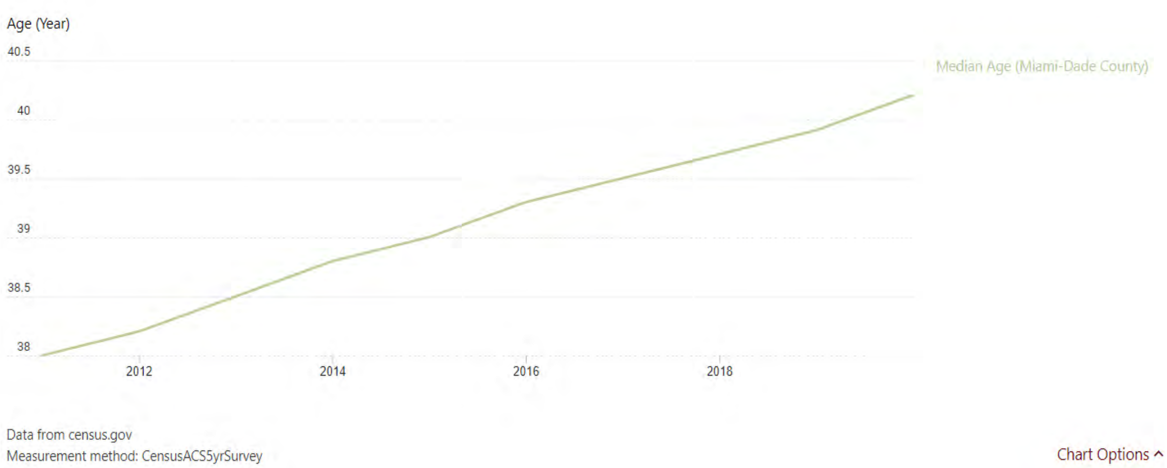
Figure 30. Projected age distribution in Miami-Dade County, 2024.



Source: Miami-Dade Beacon Council, https://www.beaconcouncil.com/data/demographic-overview/forecast-population/.

Despite the positive data and projections about population growth, the median age of Miami-Dade has been increasing since 2012, posing a potential threat to the labor market, as shown in Figure 31. The Census of Agriculture shows the age distribution of farm owners is decidedly older, with 59 percent aged 55 or older, while only 7 percent were under age 35. The data on age distribution is consistent with the rest of the United States. Aging farmers tend not to adopt new technologies and make significant changes to their production systems (Michels et al., 2020).

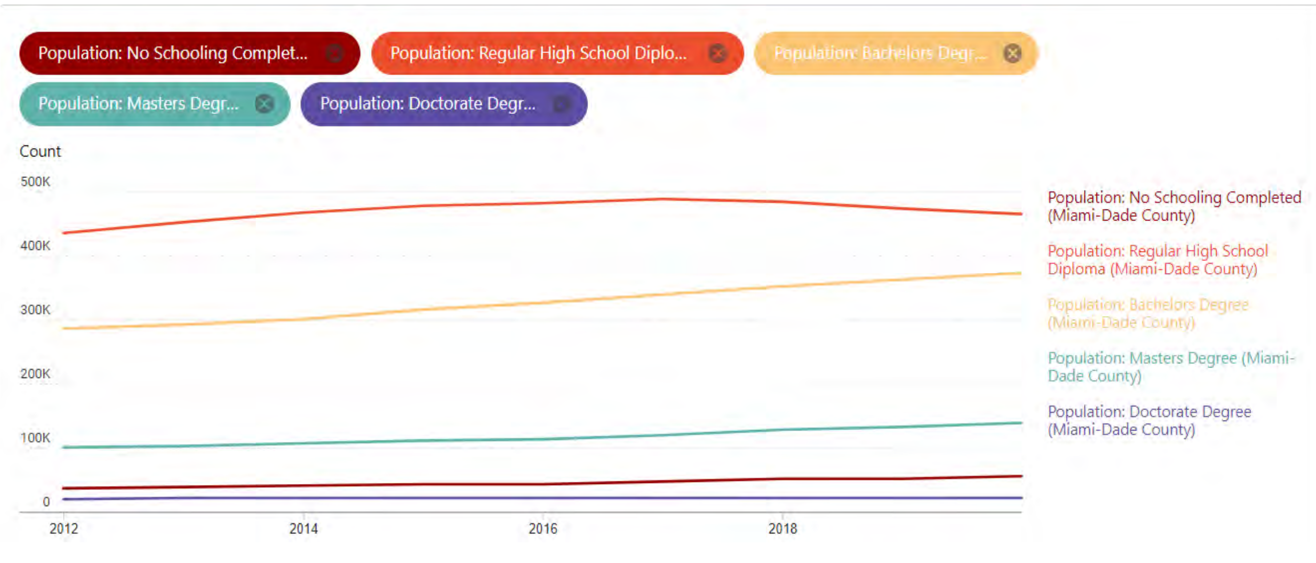
Figure 31. Median age in Miami-Dade County.



Source: U.S. Census Bureau, https://datacommons.org/place/geoId/12086?utm_medium=explore&mprop=age&popt=Person&hl=en

A research study published in 2021 (Ruzzante et al., 2021) examined 204 adoption studies and identified farmer education as one factor that positively correlates with the adoption of many agricultural technologies. According to the United States Census Bureau, in 2016-2020, 88.5 percent of Florida residents aged 25 years and older have a high school diploma, and 30.5 percent have a bachelor's or higher degree. Since 2012, there has been a significant increase in the population who attained bachelor's degrees. However, there has also been an increase in the number of residents with no schooling completed. Since 2017, there has been a decrease in the population who attained a regular high school diploma (Figure 32). Thus, it is estimated that this tendency may create obstacles in the adoptions of new technologies that constantly change.

Figure 32. Education attainment in Miami-Dade County for population aged 25 and over.

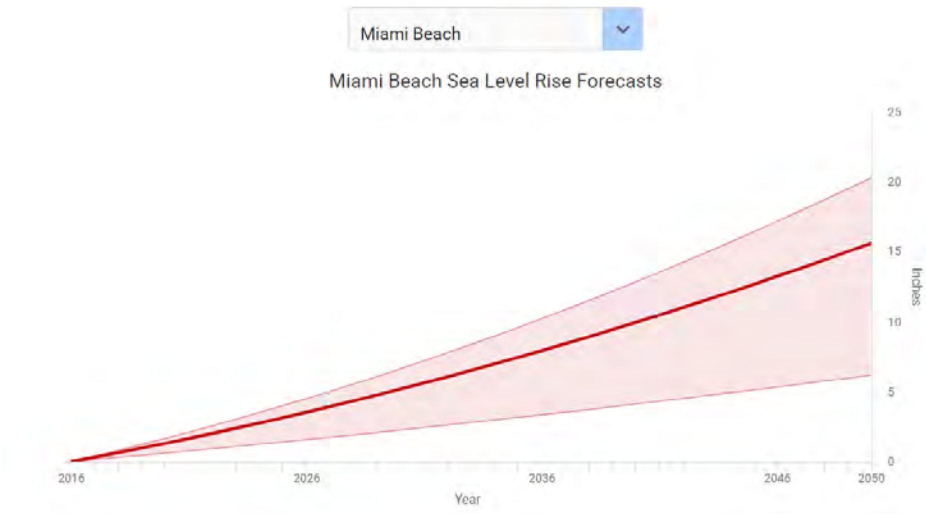


Source: U.S. Census Bureau, https://datacommons.org/place/geoId/12086?utm_medium=explore&mprop=age&popt=Person&hl=en

Climate Change

Climate change refers to any significant change in the measures of climate lasting for an extended period. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. Climate change, coupled with a deteriorating natural resource base, will greatly impact agriculture. According to the U.S. Geological Survey (USGS), in North America, regional impacts of global climate change include decreasing snowpack in the western mountains; 5-20 percent increase in yields of rain-fed agriculture in some regions; and increased frequency, intensity, and duration of heat waves in cities (https://www.usgs.gov/faqs/what-are-long-term-effects-climate-change). According to NOAA tidal station data at Key West, sea levels have risen by eight inches compared to 1950 levels. With more residents in the state and rising sea levels (Figure 33), vast development such as building seawalls and raising roads are expected, potentially resulting in a change in water resources in the environment. Water levels at the aquifer are depleting and there is a high risk of widespread Florida water shortage in the next 30 years.

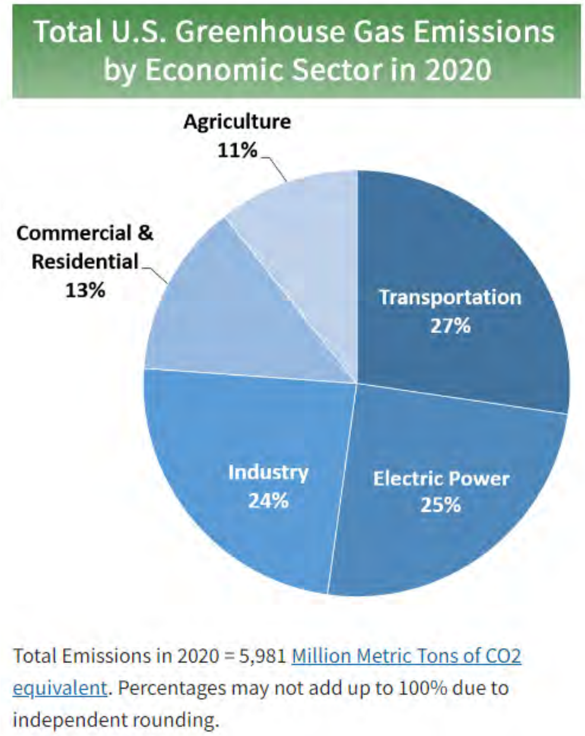
Figure 33. Miami Beach sea level rise forecasts.



Source: https://sealevelrise.org/states/florida/.

The U.S. Environmental Protection Agency has estimated that the agriculture sector accounts for 11 percent of greenhouse gas emissions across the country (Figure 34). Greenhouse gas emissions from agriculture occur from livestock such as cows, agricultural soils, and crop production. Miami- Dade County's goal is to reduce greenhouse gas emissions and mitigating climate change effects through further adoption of a range of green and environmentally friendly strategies. The agricultural sector can play a major role in that end if climate-smart practices and technologies are adopted on a large scale. Some examples are cover crops utilized to enhance carbon storage in the soil, and vertical farming technology allowing farms to be located closer to consumers and thus minimizing transportation, which results in reduced CO2 emission. Additionally, farms located closer to the urban areas can help reduce the Urban Heat Island effect (referring to an urbanized location in which the temperature rises higher than in a nonurban outlying reference location ((US EPA, 2014; Taha, 2004)), by expanding the plant canopy, which will increase transpiration, creating a net cooling effect.

Figure 34. U.S. greenhouse gas emissions in 2018.



Source: U.S. Environmental Protection Agency.

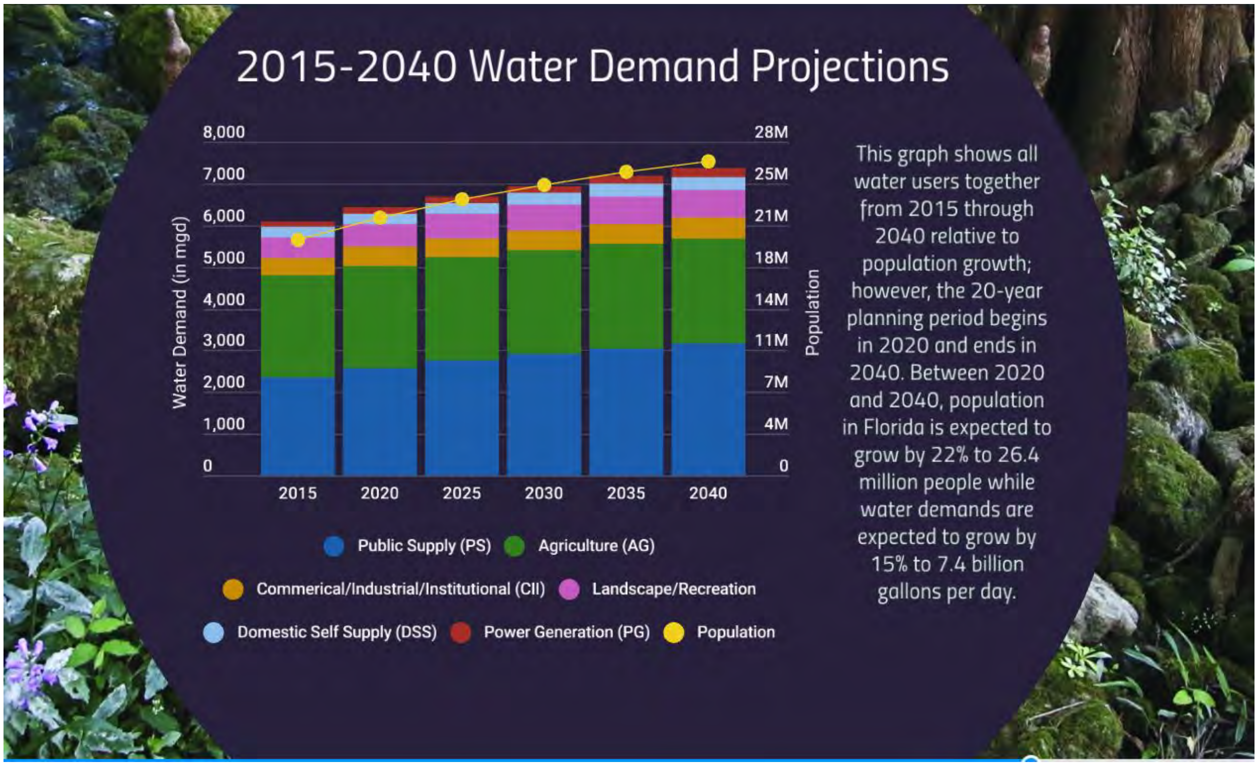
Mixed with an increasing population and need for land, climate change may push growers to adopt climate-smart strategies to maintain crop productivity. Climate-smart agriculture involves farming practices that improve farm productivity and profitability, help farmers adapt to the negative effects of climate change, and mitigate climate change effects. Climate-smart practices aim to conserve soil moisture, retain crop residues for soil fertility, disturb the soil as minimally as possible, and diversify through rotation or intercropping. Research shows that climate-smart agricultural practices and technologies, such as mulching, cover crops, crop rotation, and no tillage (among other practices) can boost production and resilience [source: International Maize and Wheat Improvement Center]. One emerging paradigm of sustainable agriculture resilient to climatic changes is conservation agriculture—defined by minimal soil disturbance, crop residue retention and diversification through crop rotation, potential to conserve soils, improve yields, and limit environmental impacts. Other climate-smart technologies and management methods include early warning systems, risk insurance, and other innovations that promote resilience and combat climate change.

According to the report *Action Plan for Climate Adaptation and Resilience*, USDA will continue to support and coordinate the efforts of its research agencies to develop innovations in climate-smart agriculture and forestry. USDA identifies evaluating the efficacy of adaptive practices and technologies on working lands, including productivity synergies and tradeoffs and mitigation co-benefits on soil carbon storage as a research priority.

Increasing Water Demand

Florida's demand for fresh water is estimated to increase by about 22 percent between 2020 and 2040. Figure 35 illustrates the water demand projections from 2015 to 2040 for Florida. Agriculture will be the second largest user, with an increase in demand of 3 percent between 2020 and 2040.

Figure 35. 2015-2040 water demand projections for Florida.



Source: Regional Water Supply Planning 2020 Annual Report, Florida Department of Environmental Protection [https://fdep.maps.arcgis.com/apps/MapSeries/index.html?appid=432a39dd369e4c87936fd89bfec40d28].

Unsustainable public and agricultural practices such as excessive lawn watering and inefficient farm irrigation pose another challenge, as does pollution from fertilizer and sewage runoff, which are harming the health of springs and contaminating the main source of usable water. Florida water management districts have developed plans to handle this new demand and more. In 2017, the Florida Department of Environment proposed 747 projects to conserve water around the state. The following year, the 2018 America's Water Infrastructure Act provided investment in water infrastructure improvements across the country including Florida. Miami-Dade County has long been working to increase water efficiency; agricultural practices could potentially adopt technologies to meet the call.

Conclusions

The emerging technologies presented in this report (e.g., artificial intelligence, automation, robotics, etc.) can provide Miami-Dade County growers with low-cost and smart-climate tools to continually monitor individual crop health/stress status, determine plant needs, and optimize water, nutrient, pest, and disease management.

These technologies have real potential to deliver more productive and sustainable agriculture through a precise and cost-efficient approach, especially in the face of farming labor shortages and climate change.

Potential issues that emerging technologies can address for the future of Miami-Dade County can be summarized as:

- Labor shortages
- Climate change
- Water availability and quality
- Land availability; competition with urban development
- Cost (or lack) of agricultural inputs (e.g., water, labor, energy, agrochemicals) – optimization of inputs usage, optimization of logistics
- Competition with other countries in a global market
- Competition with solar panel parks/developments

Continued progress in the fields of AI, mechanization, automation, and genetic engineering (among other areas) can provide solutions to these potential issues to support the future of the industry in Miami-Dade County.

There are still challenges for adopting new technology that need to be considered:

- Technology cost; limited budgets for new technologies
- Lack of awareness, technology exposure, education, and extension activities
- Unclear short-term benefits and profit
- Aging of growers' population; resistance to change because of a specific organizational structure
- Talent and skilled worker shortages
- High training costs and need for employees with special (e.g., AI) skills
- Social influence
- Need for technology modifications. Research and development to adjust technologies to specific production systems in Miami-Dade County, which includes primarily nurseries, tree crops and other horticultural crops

Some of these emerging technologies will be adopted and bring changes soon (in less than 10 years), and others in the future (between 10-30 years). For example, AI-enhanced tools for field scouting utilizing aerial (e.g., UAVs or satellites) and ground (e.g., smart sprayer or ground inspection robots) imaging are already commercially available for a few specialty crops (e.g., citrus). In the next 5-10 years, it is expected that these tools will be more reliable and robust and will include other tree crops and vegetables. In the next 10-30 years, technology also will be able to detect pests and diseases in early disease development stages accurately and reliably. Variable rate spraying technologies (including fertilizer spreaders) are commercially available for citrus and a few other tree crops. There is an effort to further improve these technologies with the use of sensor fusion and AI. We can expect to see these technological changes in the next 5-10 years. A few fully autonomous (robotic) spraying systems (e.g., the Guss sprayer; https://gussag.com) are available for tree crops (e.g., citrus) in the United States These technologies are currently expensive, not affordable by small- and medium- size growers, and they require a significant effort to be adapted to the production systems in Florida. More fully autonomous systems are expected to be commercially available in specialty crop production in 10-20 years. Regarding the smart (spot) sprayers for precision weed management in specialty crops, there is no system commercially available currently in Florida. In the next 5-10 years, a few of these technologies will be developed and commercialized, and it is expected that in more than 10-20 years, fully autonomous (robotic) systems will be introduced in Florida. As discussed in this report, a robotic strawberry harvester already has been developed and evaluated in commercial fields in Florida by HCR (https://www.harvestcroorobotics.com). This technology can transform agriculture. The development of mechanical harvesters for specialty crops is a very challenging task. We believe that fully autonomous and reliable (successful) harvesters for other specialty crops will be commercially available in Florida in more than 15 or 20 years. The development of these technologies relies on funding, urgent need, industry support, and political influence.

With these technologies, there is a need to build the workforce of the future that can help not only develop and operate these emerging technologies but modify and further improve technologies used in other countries, crops, and production systems. AI is transforming Florida's economy into one that is tech-driven and high-wage, and the agriculture sector should be part of that transformation. The University of Florida (UF) is a global leader in this effort and partnered with FAMU, Miami-Dade College, and Palm Beach State College to train their faculty so they can provide more AI courses for their students. UF faculty are also working with the Florida Department of Education to develop the nation's first AI curriculum for public schools.

Despite the positive impacts of emerging technology on agriculture, the economy, and the environment, new technologies have often had negative impacts on other groups through various externalities and unintended consequences (Vinuesa et al., 2020). Most studies focus on assessing new technologies based on their economic and environmental impacts. However, a few studies on new technology adoption have identified changes in farm structure and culture, farmers' self-identity, labor requirements, and work routines (Carolan, 2017; Miles 2019; Eastwood et al., 2012). For example, concerns have been raised on the potential for AI technology to shift the farm from traditional "hands-on" management and implementation to becoming "data-laborers," beholden to information technology providers (Rotz et al., 2019). This could have a negative effect on sustainability of the agro-ecology, considered ideally managed intensively on a small-scale by human involvement and interaction with the environment that digital farming cannot replace (Plumecocq et al., 2018; Van Hulst et al., 2020).

Another important social concern is displaced labor. The shift towards automation of manual farm tasks requires new levels of human capital that will disadvantage the digitally illiterate, including migrants and other less-skilled workers (Rotz et al., 2019; Smith, 2018). This could reduce rural employment and shift farm capital expenditures away from locally sourced products and services to large-scale AI and IT corporate entities. This could lead to concerns over monopoly and monopsony market power because of the concentration of critical technology in large-scale information providers.

Access to training, equipment, and infrastructure among small farming communities, women, and minorities should hence be considered vital to reducing the digital divide and social biases (Mehrabi et al., 2021). The social implications of emerging technology adoption and potential displaced labor should also be evaluated (Barnes et al., 2019). Potential inequalities could also result among groups receiving access to AI enabled technologies, services, and cutting-edge education and those without access.

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Evaluation of Agricultural Land Use Trends and Outlook in Miami-Dade County, Florida

Final Report

Appendix C: Agricultural Commodity Budget Profitability Analysis

Contents

Introduction

Production costs and returns for the major commodity crops with a significant production area or sales of at least $5 million were evaluated. The four major commodity groups under analysis included fruits (avocado, mango, and carambola), vegetables (snap beans, tomatoes, squash, and sweet corn), floriculture (tropical foliage and flowering plants) and nursery (shrubs and ground cover).

Enterprise crop budgets are standard documents used to evaluate the economic/financial situation of an existing agricultural enterprise because they show all costs and returns associated with a particular commodity. Enterprise crop budgets include information about established or running enterprises; they do not include information about establishment costs, capital expenditures and financing (amortization), which would be required for conducting a feasibility study.

One of the main advantages of enterprise budgets is their relative simplicity; however, results from the enterprise budget are limited as it does not provide any indication of the likelihood of a particular result being achieved (Morgan et al. 2021). Therefore, a more realistic approach is to use stochastic budgeting to account for some of the main uncertainties in the model such as changes in prices and yields, which provide useful insights into the likelihood of realizing a specific level of return (net profit).

Methodology

Enterprise budgets are based on the expected (average) costs, prices and marketable yields. Primary and secondary data sources were used to collect the data needed to construct the budgets. Primary data was obtained by interviewing growers using the convenience sampling technique. Growers were contacted to see if they were interested in being part of the study, and only those willing to participate were interviewed. During the interviews, growers were asked about their cultural costs, harvesting and marketing costs, and fixed costs. Additionally, growers were asked about the lowest, average, and highest yields and prices obtained during the last 10 years. Secondary data included publicly available information and published reports to confirm the information gathered from the interviews and to construct the budgets when it was not possible to get price, yield, and production data directly from the growers.

Enterprise budgets for each of the commodities considered were constructed based on the information available. The average prices, yields, and costs reported capture the difference in production practices and managerial styles of the different growers interviewed. Results from the enterprise budget also included a sensitivity analysis to compare revenue changes in a baseline (expected) scenario based on potential changes in prices and/or yields. The results presented in the enterprise budget are considered deterministic as they are based on average or expected yields and prices. While average prices and yield provide an estimate of the expected profitability of growing a crop, associated risk factors are not accounted for. Therefore, incorporating risk may supply a more realistic overview of the profitability of an agricultural enterprise.

The stochastic budgets were based on the approach outlined by Richardson (2006) who is a pioneer int the area of simulation and risk analysis in agriculture. First, probability distributions were assigned to the variables affected by the risk factors. Second, the stochastic values sampled from the probability distributions were used in accounting equations to calculate production, receipts, and net returns. Third, the stochastic budget was simulated 500 times using random values for the risky (price and yield) variables. The results of the 500 samples provide the information needed to estimate the empirical probability distribution for the unobserved net return. This information can be further analyzed using a cumulative distribution function (CDF) of the net return. The model was programmed in Excel (Microsoft Corp., Redmond, WA) and simulated using the Excel Add-In, Simulation & Econometrics to Analyze Risk (Simetar, College Station, TX).

Because of the limited price and yield information available, the Gray, Richardson, Klose and Schumann (GRKS) distribution was used to conduct the simulation. The GRKS is a continuous probability distribution for sampling from a minimum data population. The population can be defined using the minimum, middle and maximum values. Therefore, the input values needed to generate a GRKS distribution for a particular variable are (min, mid, max) (Richardson et al., 2006). The GRKS distribution was used to generate the prices and yields data used for the simulation. The simulation analysis is useful to report the results of the variable net return per-acre as a cumulative distribution function (CDF), which shows the likelihood (probability) that the net return would be less than or equal to any given value.

This report provides an estimate of the costs and returns associated with the four major commodity groups grown in Miami-Dade County (MDC), including a brief analysis of the profitability of each of the crops considered. Typically, an enterprise budget consists of four main sections: income, operating costs, harvest and marketing costs and fixed costs. The income section shows the average (expected) yield, and the average (expected) price per unit of product prevailing in the area. Revenue is the product of quantity times the price received. Operating costs include inputs such as agrochemicals, fertilizers, labor, and capital. Fixed costs include land rental, taxes, insurance, and overhead costs. Harvest costs include pick up, transport, washing and grading, and packing materials. Gross returns provide a short-term view of the viability of a farm operation, while net returns including fixed costs give a more accurate measure of the long-term viability of a farm operation.

Cost and Returns Analysis for Fruits

The first commodity group considered in the present study is fruits; more specifically avocados, mangoes, and carambolas.

Avocados

A summarized version of the avocado enterprise budget is shown in Table 1; the extended/detailed version of the avocado enterprise budget can be found in Appendix 1. Avocado season in Miami-Dade County runs from late June to March; however, the bulk of the crop is harvested from June to September. Under a marketable yield of 14,025 lbs. per-acre (255 bushels/acre), and an average grower's price of $0.36/lb. ($19.80/bushel), total revenue is $5,049 per-acre. Subtracting operating and harvesting costs ($2,725 and $897.60, respectively) from revenue ($5,049) results in a gross return of $1,426.40 per-acre, or about $0.10 per lb. Subtracting the total cost of production ($4,817.60) from the total revenue ($5,049) results in a net return of $231.40 per-acre, or about $0.02 per lb. Avocado production costs have increased in recent years because an invasive pest; the Red Ambrosia Beetle, and its nutritional symbiont the *Raffaelea Lauricola* fungus, which is the causal agent of the Laurel Wilt (LW) disease. LW is a very aggressive disease that can kill a tree in just a few weeks. To stay in production, preventive disease treatment consists of fungicide injections, which last for about 18 months. Research is underway to find a solution, however, it is important to note that the industry is resilient, other disease management strategies adopted by the industry includes partial and complete tree replanting.

Table 1. Deterministic Enterprise Budget for an Avocado Grove in Miami Dade County.

Item	Quantity (lbs./acre)	Value ($/lb.)	Value ($/acre)	Value ($/lb.)
Revenue				
Marketable Yield (lbs./acre)	14,025			
Producer Price		0.36		
Total revenue			5,049.00	
Operating cost			2,725.00	0.19
Fixed cost			1,195.00	0.09
Harvest and marketing cost			897.60	0.06
Total production cost			4,817.60	0.34
Gross return			1,426.40	0.10
Net return			231.40	0.02

Sensitivity Analysis. Table 2 illustrates a sensitivity analysis of the average net return to an avocado grower in MDC on a per-acre basis under different price and yield scenarios. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $231.40 (baseline scenario) to $1,263.64. Under the worst-case scenario where both yield and price decline by 10 percent, net return would fall from $231.40 to -$688.64 per-acre. Different combinations of changes in prices and yield, and their impact on the profitability of an avocado farm are illustrated in Table 2 as well.

Table 2. Sensitivity Analysis of Net Returns for an Avocado Grove in Miami Dade County.

Yield (lbs./acre)		Producer price ($/lb.)				
		0.32 (-10%)	0.34 (-5%)	0.36 (Base)	0.38 (+5%)	0.40 (+10%)
12,623	(-10%)	(688.64)	(436.19)	(183.74)	68.71	321.16
13,324	(-5%)	(509.12)	(242.64)	23.83	290.31	556.78
14,025	(Base)	(329.60)	(49.10)	231.40	511.90	792.40
14,726	(+5%)	(150.08)	144.45	438.97	733.50	1,028.02
15,428	(+10%)	29.44	337.99	646.54	955.09	1,263.64

Note that a 5 percent price increase has a higher impact on the profitability of an avocado operation as net return increases by $280.50 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $207.57 per-acre over the base scenario.

Stochastic budget analysis. Table 3 shows the results of the deterministic and the stochastic budget based on the expected (average) values for the variable net return per-acre. The details about the yield and price values used to conduct the simulation can be found in Appendix 2. Compared with the deterministic net return value of $231.40, the stochastic average net return is $815.13 with a standard deviation (S.D.) of $2,482.14 and a coefficient of variation (C.V.) of 304.51 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net returns per-acre are -$3,777.39 and $10,395.52, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive, but it also provides an insight into the distribution of the net return.

Table 3. Deterministic and Stochastic Budgets to Assess the Profitability of an Avocado Grove in Miami Dade County.

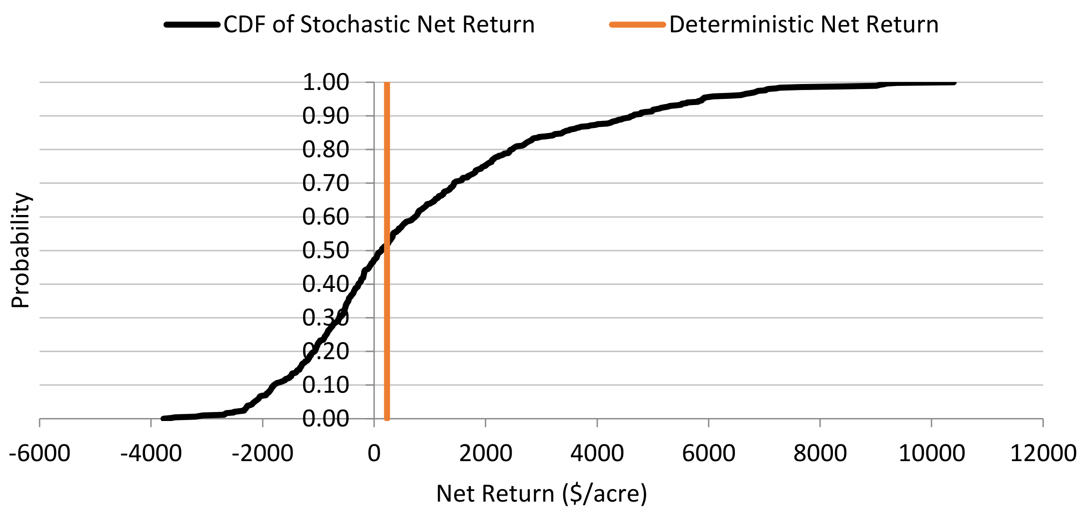
	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	231.40	815.13
S.D.	-	2,482.14
C.V.	-	304.51
Min	231.40	(3,777.39)
Max	231.40	10,395.52

Figure 1 shows the cumulative distribution function (CDF) for the net return of an avocado grove on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line).

The deterministic net return bisects the CDF of the stochastic net return at about 52 percent, indicating that there is a 52 percent chance of the stochastic net return being less than or equal to the deterministic net return ($231.40). The CDF of the net return indicates that there is a moderate chance of an avocado farm in MDC being profitable; it has a 53 percent chance of getting positive net returns.

The CDF allows us to determine the probability of getting a net return less than or equal to (or greater than) a particular value. For example, Figure 1 shows that there is a 75 percent probability of an avocado farm getting a net return less than or equal to $2,000 per-acre. Alternatively, it means that there is a 25 percent probability that an avocado farm would get a net return greater than $2,000 per-acre. Additionally, the CDF allows us to estimate the probability of a net return falling between two values; it can be found by subtracting the probabilities of each one of the values. As an example, the probability of the net return of an avocado farm being less than or equal to $5,000 but more than or equal to $2,000 is 0.16 (0.91-0.75) or 16 percent.

Figure 1. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for an Avocado Grove in Miami Dade County.



Mangos

A summarized version of the mango enterprise budget is shown in Table 2; the extended/detailed version of the mango enterprise budget can be found in Appendix 3. Mango season in MDC runs from May to September. Under a marketable yield of 18,700 lbs. per-acre, and an average grower's price of $0.35/lb., total revenue is $6,545 per-acre. Factoring in operating and harvest and marketing cost results in a gross return of $3,068.95 per-acre, or about $0.16 per lb. After considering total production cost, net return is $1,918.61 per-acre, or about $0.10 per lb.

Table 4. Deterministic Enterprise Budget for a Mango Grove in Miami Dade County.

Item	Quantity (lbs.)	Value ($/lb.)	Value ($/acre)	Value ($/lb.)
Revenue				
Marketable Yield (lbs./acre)	18,700			
Producer Price		0.35		
Total revenue			6,545.00	
Operating cost			2,050.66	0.11

Fixed cost	1,150.00	0.06
Harvest and marketing cost	1,425.39	0.08
Total production cost	4,626.39	0.25
Gross return	3,068.95	0.16
Net return	1,918.61	0.10

Sensitivity Analysis. Table 5 illustrates a sensitivity analysis of the average net return to a mango grower in MDC on a per-acre basis. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $1,918.61 (baseline scenario) to $3,253.37. Under the worst-case scenario where both yield and price decline by 10 percent, net return per-acre would fall from $1,918.61 to $901.75. Mangoes remain profitable even with a moderate negative price and yield shock. Different combinations of changes in prices and yield, and their impact on the profitability of a mango farm are illustrated in Table 5 as well.

Table 5. Sensitivity Analysis of Net Returns for a Mangoes Grove in Miami Dade County.

Yield (lbs./acre)		Producer price ($/lb.)				
		0.32 (-10%)	0.33 (-5%)	0.35 (Base)	0.37 (+5%)	0.39 (+10%)
16,830	(-10%)	901.75	1,070.05	1,406.65	1,743.25	2,079.85
17,765	(-5%)	1,129.68	1,307.33	1,662.63	2,017.93	2,373.23
18,700	(Base)	1,357.61	1,544.61	1,918.61	2,292.61	2,666.61
19,635	(+5%)	1,585.54	1,781.89	2,174.59	2,567.29	2,959.99
20,570	(+10%)	1,813.47	2,019.17	2,430.57	2,841.97	3,253.37

Price increase has a noticeable impact over profitability compared to a yield increase. A 5 percent price increase results in a net return increase of $374 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $255.98 per-acre over the base scenario.

Stochastic budget analysis. Table 6 shows the results of the deterministic and the stochastic budget based on the expected (average) values for the variable net return per-acre. The details about the yield and price values used to conduct the simulation can be found in Appendix 4.

Table 6. Deterministic and Stochastic Budgets to Assess the Profitability of a Mango Grove in Miami Dade County.

Item	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	1,918.61	1,487.45
S.D.	-	1,318.40
C.V.	-	88.64
Min	1,918.61	(3,066.01)
Max	1,918.61	4,461.92

Compared with the deterministic net return value of $1,918.61, the stochastic average net return is $1,487.45 with a standard deviation (S.D.) of $1,318.40 and a coefficient of variation (C.V.) of 88.64 percent. The range of net returns obtained from the stochastic budget varied widely as the minimum and maximum net returns per-acre are -$3,066.01 and $4,461.92, respectively. The cumulative distribution function (CDF) for the net return of a mango grove on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 2.

Figure 2. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Mango Grove in Miami Dade County.

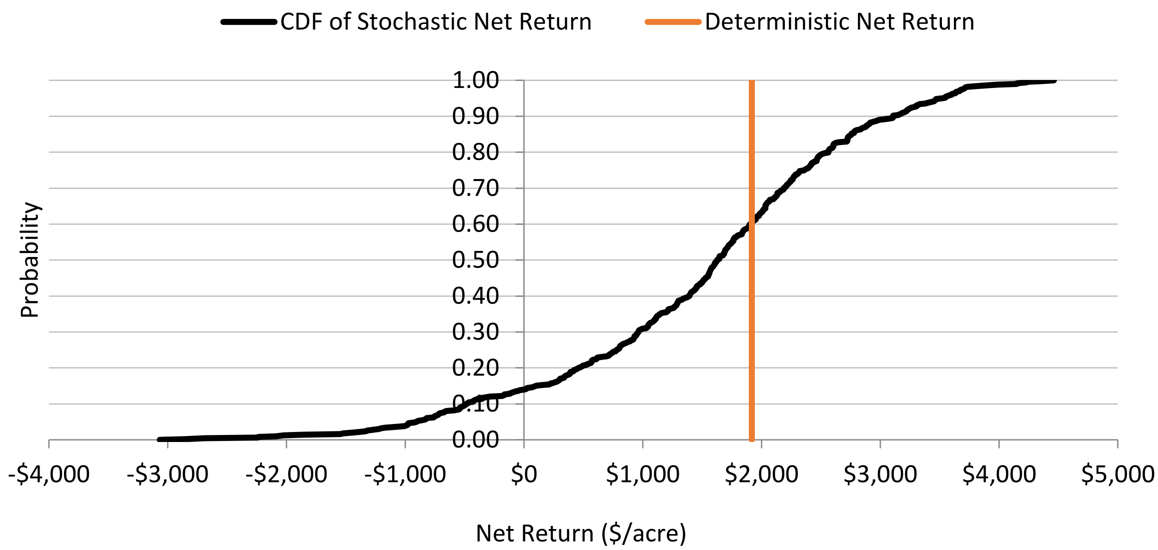


Figure 2 indicates that there is a 60 percent chance of the stochastic net return being less than or equal to the deterministic net return ($1,918.61). The CDF of the net return indicates that there is a significant chance of a mango farm in MDC being profitable; it has an 86 percent chance of getting positive net returns.

The CDF may help us determine the probability of getting a net return less than or equal to a particular value. For example, Figure 2 indicates that there is a 63 percent probability of a mango farm getting a net return less than or equal to $2,000 per-acre. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a mangoes farm being less than or equal to $4,000 but more than or equal to $2,000 is 0.35 (0.98-0.63) or 35 percent.

Carambola

A summarized version of the carambola enterprise budget is shown in table 7; the extended/detailed version of the carambola enterprise budget can be found in Appendix 5. Carambola in MDC has two harvest seasons: the first from June through September and the second from November to February. Under a marketable yield of 29,750 lbs. per-acre, and an average grower's price of $0.65/lb., total revenue is $19,338 per-acre. Factoring in operating and harvesting and marketing costs results in a gross return of $3,314 per-acre, or about $0.11 per lb. After considering total production cost, net return is $1,714 per-acre, or about $0.06 per lb.

Table 7. Deterministic Enterprise Budget for a Carambola Grove in Miami Dade County.

Item	Quantity (lbs.)	Value ($/lb.)	Value ($/acre)	Value ($/lb.)
Marketable Yield (lbs./acre)	29,750			
Producer Price		0.65		
Total revenue			19,338	
Operating cost			2,636	0.09
Fixed cost			1,600	0.05
Harvest and marketing cost			13,388	0.45
Total production cost			17,624	0.59
Gross return			3,314	0.11
Net return			1,714	0.06

Sensitivity Analysis. Table 8 illustrates a sensitivity analysis of the average net return to a carambola grower in MDC on a per-acre basis. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $1,714 (baseline scenario) to $4,599.75. Under the worst-case scenario where both yield and price decline by 10 percent, net return per-acre would fall from $1,714 (baseline scenario) to -$487.5. Different combinations of changes in prices and yield, and their impact on the profitability of a carambola farm are illustrated in Table 8 as well.

Table 8. Sensitivity Analysis of Net Returns for a Carambola Grove in Miami Dade County.

Yield (lbs./acre)		Producer price ($/lb.)				
		0.59 (-10%)	0.62 (-5%)	0.65 (Base)	0.68 (+5%)	0.72 (+10%)
26,775	(-10%)	(487.50)	315.75	1,119.00	1,922.25	2,993.25
28,263	(-5%)	(279.25)	568.63	1,416.50	2,264.38	3,394.88
29,750	(Base)	(71.00)	821.50	1,714.00	2,606.50	3,796.50
31,238	(+5%)	137.25	1,074.38	2,011.50	2,948.63	4,198.13
32,725	(+10%)	345.50	1,327.25	2,309.00	3,290.75	4,599.75

Price has a higher impact on the profitability of a carambola operation compared to a yield. A 5 percent price increase results in a net return increase of $896.50 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $297.50 per-acre over the base scenario.

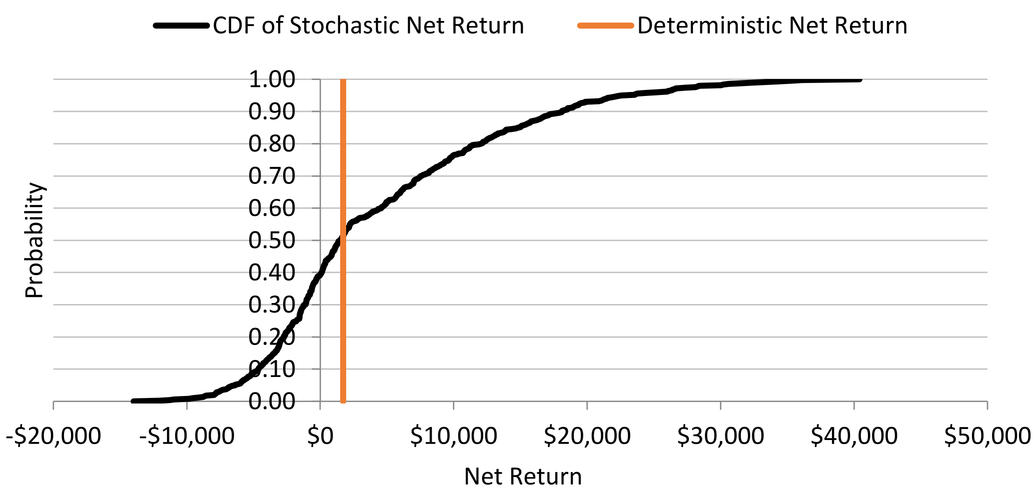
Stochastic budget analysis. Table 9 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in appendix 6. Compared with the deterministic net return value of $1,714.00, the stochastic average net return is $4,525.60 with a standard deviation (S.D.) of $9,281.3 and a coefficient of variation (C.V.) of 205.08 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return per-acre are -$13,988.07 and $40,401.16, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive.

Table 9. Deterministic and Stochastic Budgets to Assess the Profitability of a Carambola Grove in Miami Dade County.

	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	1,714.00	4,525.60
S.D.	-	9,281.30
C.V.	-	205.08
Min	1,714.00	(13,988.07)
Max	1,714.00	40,401.16

The cumulative distribution function (CDF) for the net return of a carambola grove on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 3. Figure 3 indicates that there is a 51 percent chance of the stochastic net return being less than or equal to the deterministic net return ($1,714.00). The CDF of the net return indicates that there is a moderate chance of a carambola farm in MDC being profitable; it has a 60 percent chance of getting positive net returns. The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 3 indicates that there is a 54 percent probability of a carambola farm getting a net return less than or equal to $2,000 per-acre.

Figure 3. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Carambola Grove in Miami Dade County.



Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a carambola farm being less than or equal to $5,000 but more than or equal to $2,000 is 0.08 (0.62-0.54) or 8 percent.

Cost and Returns Analysis for Vegetables

The second commodity group considered in the present study is vegetables, more specifically, snap beans, sweet corn, tomatoes, and squash.

Snap Bean

A summarized version of the snap bean enterprise budget is shown in Table 10; the extended/detailed version of the snap bean enterprise budget can be found in Appendix 7. Snap bean harvesting season runs from late November to mid-April. From planting to harvest it may take about 50 to 60 days. There is a possibility of having two to three productive cycles for the full season.

Table 10. Deterministic Enterprise Budget for a Snap bean Operation in Miami Dade County.

Item	Quantity (boxes)	Value ($/box)	Value ($/acre)	Cost ($/box)
Marketable Yield (boxes/acre)	220			
Producer Price		15.00		
Total revenue			3,300	
Operating cost			1,319	6.00
Fixed cost			690	3.14
Harvest and marketing cost			1,100	5.00
Total production cost			3,109	14.13
Gross return			881	4.00
Net return			191	0.87

Under a marketable yield of 220 boxes per-acre, and an average grower's price of $15/box, total revenue is $3,300 per-acre. Factoring in operating and harvesting and marketing costs results in a gross return of $881 per-acre, or about $4.00 per box. After considering total production costs, net return is $191 per acre, or about $0.87 per box.

Sensitivity Analysis. Table 11 illustrates a sensitivity analysis of the average net return to a snap bean grower in MDC on a per-acre basis. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $191 (baseline scenario) to $774. Under the worst-case scenario where both yield and price decline by 10 percent, net return per-acre would fall from $191 (baseline scenario) to -$326. Different combinations of changes in prices and yield, and their impact on the profitability of a snap bean operation are illustrated in Table 11 as well.

Table 11. Sensitivity Analysis of Net Returns for a Snap Bean Operation in Miami Dade County.

Yield (boxes/acre)		Producer price ($/box)				
		13.50 (-10%)	14.25 (-5%)	15.00 (Base)	15.75 (+5%)	16.50 (+10%)
198	(-10%)	(326.00)	(177.50)	(29.00)	119.50	268.00
209	(-5%)	(232.50)	(75.75)	81.00	237.75	394.50
220	(Base)	(139.00)	26.00	191.00	356.00	521.00
231	(+5%)	(45.50)	127.75	301.00	474.25	647.50
242	(+10%)	48.00	229.50	411.00	592.50	774.00

It is important to note that a 5 percent price increase has a higher impact on the profitability of a snap bean operation as net return increases by $165 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $110 per-acre over the base scenario.

Stochastic budget analysis. Table 12 shows the results of the deterministic and the stochastic budget based on the expected (average) values for the variable net return per-acre. The details about the yield and price values used to conduct the simulation can be found in Appendix 8. Compared with the deterministic net return value of $191, the stochastic average net return is $145.11 with a standard deviation (S.D.) of $660.10 and a coefficient of variation (C.V.) of 454.90 percent. The range of net returns obtained from the stochastic budget varied significantly as the minimum and maximum net return per-acre are -$1,346.69 and $2,412.23, respectively.

Table 12. Deterministic and Stochastic Budgets to Assess the Profitability of a Snap Bean Operation.

	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	191.00	145.11
S.D.	-	660.10
C.V.	-	454.90
Min	191.00	(1,346.69)
Max	191.00	2,412.23

Figure 4 shows the cumulative distribution function (CDF) for the net return of a snap bean farm on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line).

Figure 4. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Snap Beans Operation in Miami Dade County.

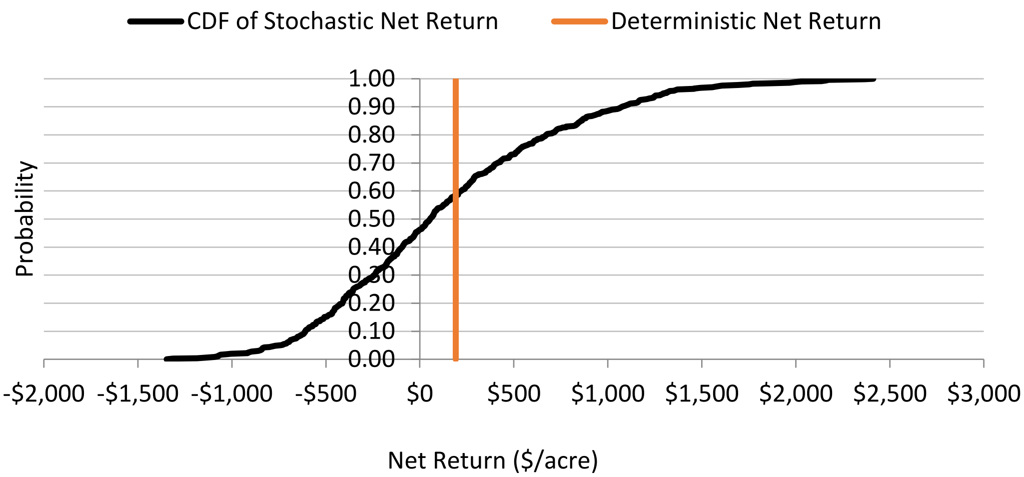


Figure 4 indicates that there is a 58 percent chance of the stochastic net return being less than or equal to the deterministic net return ($191). The CDF of the net return indicates that there is a moderate chance of a snap bean farm in MDC being profitable; it has a 54 percent chance of getting positive net returns.

The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 4 indicates that there is an 89 percent probability of a snap bean operation getting a net return less than or equal to $1,000 per-acre. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a snap bean farm being less than or equal to $2,000 but more than or equal to $1,000 is 0.10 (0.98-0.88) or 10 percent.

Sweet Corn

Table 13 shows a summarized version of the sweet corn enterprise budget; the extended/detailed version of the sweet corn enterprise budget can be found in Appendix 9. Sweet corn harvest season extends from January to April; there is a possibility of getting two crops, as harvest usually takes from 60 to 90 days after planting. Under a marketable yield of 300 boxes per-acre, and an average grower’s price of $15.50/box, total revenue is $4,650 per-acre. Factoring in operating and harvesting and marketing costs results in a gross return of $895 per-acre, or about $2.98 per box. After considering total production cost, net return is $137 per-acre, or about $0.46 per box.

Table 13. Deterministic Enterprise Budget for a Sweet Corn Operation in Miami Dade County.

Item	Quantity (boxes)	Value ($/box)	Value ($/acre)	Cost ($/box)
Marketable Yield (boxes/acre)	300			
Producer Price		15.50		
Total revenue			4,650	
Operating cost			2,192	7.31
Fixed cost			758	2.53
Harvest and marketing cost			1,563	5.21
Total production cost			4,513	15.04
Gross return			895	2.98
Net return			137	0.46

Sensitivity Analysis. Table 14 illustrates a sensitivity analysis of the average net return to a sweet corn grower in MDC on a per-acre basis.

Table 14. Sensitivity Analysis of Net Returns for a Sweet Corn Operation in Miami Dade County.

Yield (boxes/acre)		Producer price ($/box)				
		13.95 (-10%)	14.73 (-5%)	15.50 (Base)	16.28 (+5%)	17.05 (+10%)
270	(-10%)	(590.20)	(379.60)	(171.70)	38.90	246.80
285	(-5%)	(459.10)	(236.80)	(17.35)	204.95	424.40
300	(Base)	(328.00)	(94.00)	137.00	371.00	602.00
315	(+5%)	(196.90)	48.80	291.35	537.05	779.60
330	(+10%)	(65.80)	191.60	445.70	703.10	957.20

Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $137 (baseline scenario) to $957.20. Under the worst-case scenario where both yield and price decline by 10 percent, net return per-acre would fall from $137 (baseline scenario) to -$590.20. Different combinations of changes in prices and yield, and their impact on the profitability of a sweet corn operation are illustrated in Table 14 as well.

It is important to note that a 5 percent price increase has a higher impact on the profitability of a sweet corn operation as net return increases by $234 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $154.35 per-acre over the base scenario.

Stochastic budget analysis. Table 15 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 10.

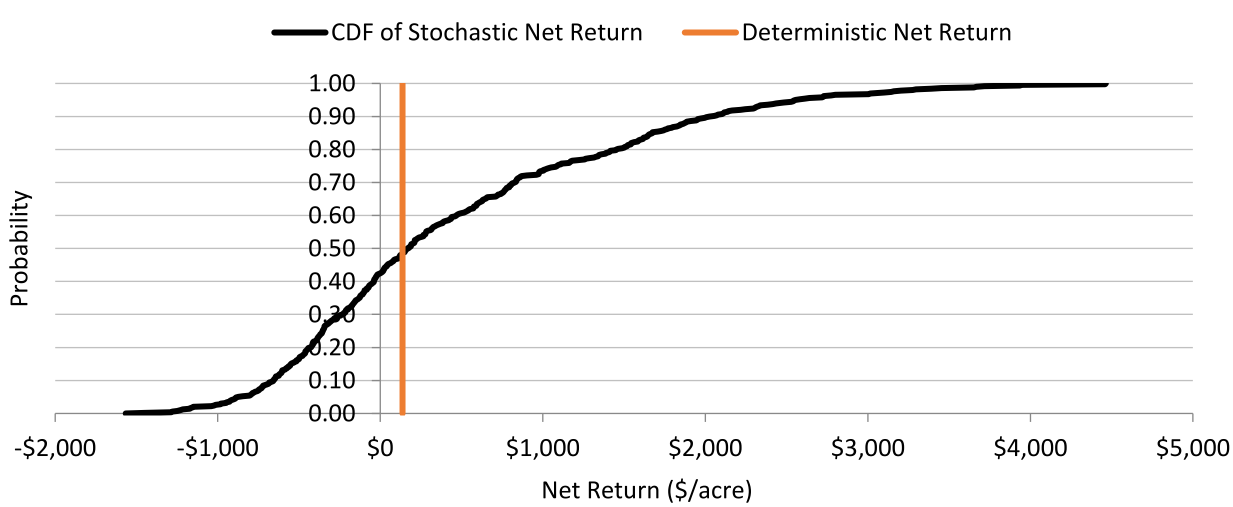
Table 15. Deterministic and Stochastic Budgets to Assess the Profitability of a Sweet Corn Operation in Miami Dade County.

Item	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	137.00	467.08
S.D.	-	1,098.61
C.V.	-	235.21
Min	137.00	-1,566.05
Max	137.00	4,464.40

Compared with the deterministic net return value of $137, the stochastic average net return is $467.08 with a standard deviation (S.D.) of $1,098.61 and a coefficient of variation (C.V.) of 235.21 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return per-acre are -$1,566.05 and $4,464.40, respectively.

The cumulative distribution function (CDF) for the net return of a sweet corn on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 5. Figure 5 indicates that there is a 48 percent chance of the stochastic net return being less than or equal to the deterministic net return ($137). The CDF of the net return indicates that there is a moderate chance of a sweet corn farm in MDC being profitable; it has a 57 percent chance of getting positive net returns. The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 5 indicates that there is an 89 percent probability of a sweet corn farm getting a net return less than or equal to $2,000 per-acre. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a sweet corn farm being less than or equal to $4,000 but more than or equal to $2,000 is 0.10 (0.99-0.89) or 10 percent.

Figure 5. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Sweet Corn Operation in MDC.



Tomato

A summarized version of the tomato enterprise budget is shown in Table 16; the extended/detailed version of the tomato enterprise budget can be found in Appendix 11. Harvest season in MDC extends from December to May. The crop is planted once; tomatoes are harvested several times during the growing cycle.

Table 16. Deterministic Enterprise Budget for a Tomato Operation in Miami Dade County.

Item	Quantity (boxes)	Value ($/box)	Value ($/acre)	Cost ($/box)
Marketable Yield (boxes/acre)	1,200			
Producer Price		12.00		
Total revenue			14,400	
Operating cost			7,460	6.22
Fixed cost			1,350	1.13
Harvest and marketing cost			4,680	3.90
Total production cost			13,490	11.24
Gross return			2,260	1.88
Net return			910	0.76

Under a marketable yield of 1,200 boxes per-acre, and an average grower's price of $12/box, total revenue is $14,400 per-acre. Factoring in operating and harvesting and marketing costs results in a gross return of $2,260 per-acre, or about $1.88 per box. After considering total production cost, net return is $910 per-acre, or about $0.76 per box.

Sensitivity Analysis. Table 17 illustrates a sensitivity analysis of the average net return to a tomato grower in MDC on a per-acre. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $910 (baseline scenario) to $3,466. Under the worst-case scenario where both yield and price decline by 10 percent, net return per-acre would fall from $910 (baseline scenario) to -$1,358. Different combinations of changes in prices and yield, and their impact on the profitability of a tomato operation are illustrated in Table 17 as well.

Table 17. Sensitivity Analysis of Net Returns for a Tomato Operation in Miami Dade County.

Yield (boxes/acre)		Producer price ($box)				
		10.80 (-10%)	11.40 (-5%)	12.00 (Base)	12.60 (+5%)	13.20 (+10%)
1,080	(-10%)	(1,358.00)	(710.00)	(62.00)	586.00	1,234.00
1,140	(-5%)	(944.00)	(260.00)	424.00	1,108.00	1,792.00
1,200	(Base)	(530.00)	190.00	910.00	1,630.00	2,350.00
1,260	(+5%)	(116.00)	640.00	1,396.00	2,152.00	2,908.00
1,320	(+10%)	298.00	1,090.00	1,882.00	2,674.00	3,466.00

Price increase has a noticeable impact over profitability compared to a yield increase. A 5 percent price increase results in a net return increase of $720 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $486 per-acre over the base scenario.

Stochastic budget analysis. Table 18 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 12.

Table 18. Deterministic and Stochastic Budgets to Assess the Profitability of a Tomato Operation in Miami Dade County.

	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	910.00	1,775.49
S.D.	-	4,721.76
C.V.	-	265.94
Min	910.00	-9,545.21
Max	910.00	16,867.16

Compared with the deterministic net return value of $910, the stochastic average net return is $1,775.49 with a standard deviation (S.D.) of $4,721.76 and a coefficient of variation (C.V.) of 265.94 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return per-acre are -$9,545.21 and $16,867.16, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive, but it also provides an insight into the distribution of the net returns.

The cumulative distribution function (CDF) for the net return of a tomato farm on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 6.

Figure 6. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Tomato Operation in Miami Dade County.

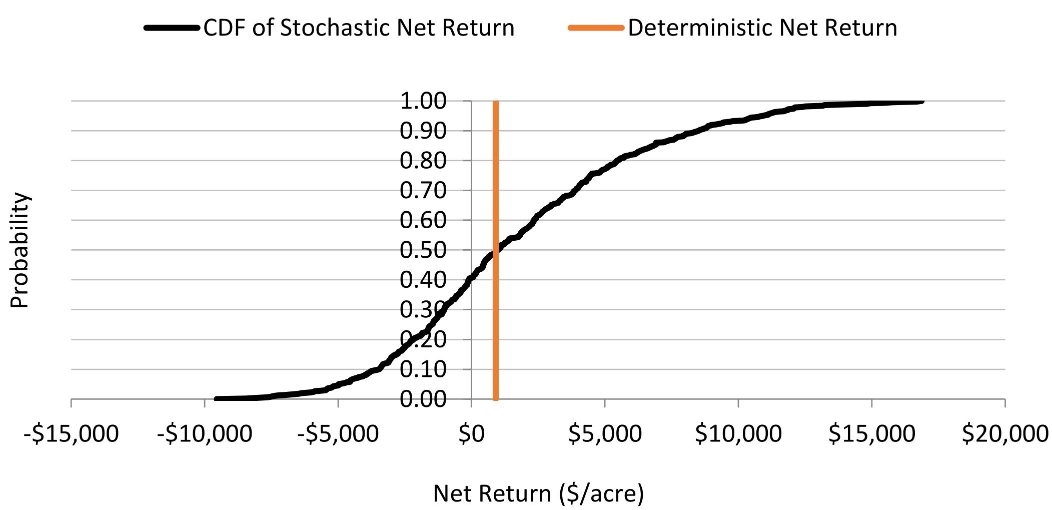


Figure 6 indicates that there is a 50 percent chance of the stochastic net return being less than or equal to the deterministic net return ($910). The CDF of the net return indicates that there is a moderate chance of a tomato farm in MDC being profitable; it has a 59 percent chance of getting positive net returns.

The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 6 indicates that there is a 57 percent probability of a tomato farm getting a net return less than or equal to $2,000 per-acre.

Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a tomato farm being less than or equal to $5,000 but more than or equal to $2,000 is 0.20 (0.77-0.57) or 20 percent.

Squash

A summarized version of the squash enterprise budget is shown in Table 19; the extended/detailed version of the squash enterprise budget can be found in Appendix 13. Squash winter harvest season runs from August to March. It takes from 85 to 120 days from planting to harvest. Under a marketable yield of 675 boxes per-acre, and an average grower's price of $13/box, total revenue is $8,775 per-acre. Factoring in operating and harvesting and marketing costs results in a gross return of $2,018.25 per-acre, or about $2.99 per box. After considering total production cost, net return is $1,188.25 per-acre, or about $1.76 per box.

Table 19. Deterministic Enterprise Budget for a Squash Operation in Miami Dade County.

Item	Quantity (boxes)	Value ($/box)	Value ($/acre)	Cost $/box
Marketable Yield (boxes/acre)	675			
Producer Price		13.00		
Total revenue			8,775.00	
Operating cost			3,564.00	5.28
Fixed cost			830.00	1.23
Harvest and marketing cost			3,192.75	4.73
Total production cost			7,586.75	11.24
Gross return			2,018.25	2.99
Net return			1,188.25	1.76

Sensitivity Analysis. Table 20 illustrates a sensitivity analysis of the average net return to a squash grower in MDC on a per-acre basis.

Table 20. Sensitivity Analysis of Net Returns for a Squash Operation in Miami Dade County.

Yield (boxes/acre)		Producer price ($/box)				
		11.70	12.35	13.00	13.65	14.30
		(-10%)	(-5%)	(Base)	(+5%)	(+10%)
608	(-10%)	(159.73)	235.15	630.03	1,024.90	1,419.78
641	(-5%)	75.51	492.33	909.14	1,325.95	1,742.76
675	(Base)	310.75	749.50	1,188.25	1,627.00	2,065.75
709	(+5%)	545.99	1,006.68	1,467.36	1,928.05	2,388.74
743	(+10%)	781.23	1,263.85	1,746.48	2,229.10	2,711.73

Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return per-acre would increase from $1,188.25 (baseline scenario) to $2,711.73. Under the worst-case scenario where both yield and price decline by 10 percent, net return per-acre would fall from $1,188.25 (baseline scenario) to -$159.73. Different combinations of changes in prices and yield, and their impact on the profitability of a squash operation are illustrated in Table 20 as well. It is important to note that a 5 percent price increase has a higher impact on the profitability of a squash operation as net return increases by $438.75 per-acre over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $279.11 per-acre over the base scenario.

Stochastic budget analysis. Table 21 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 14.

Table 21. Deterministic and Stochastic Budgets to Assess the Profitability of a Squash Operation in Miami Dade County.

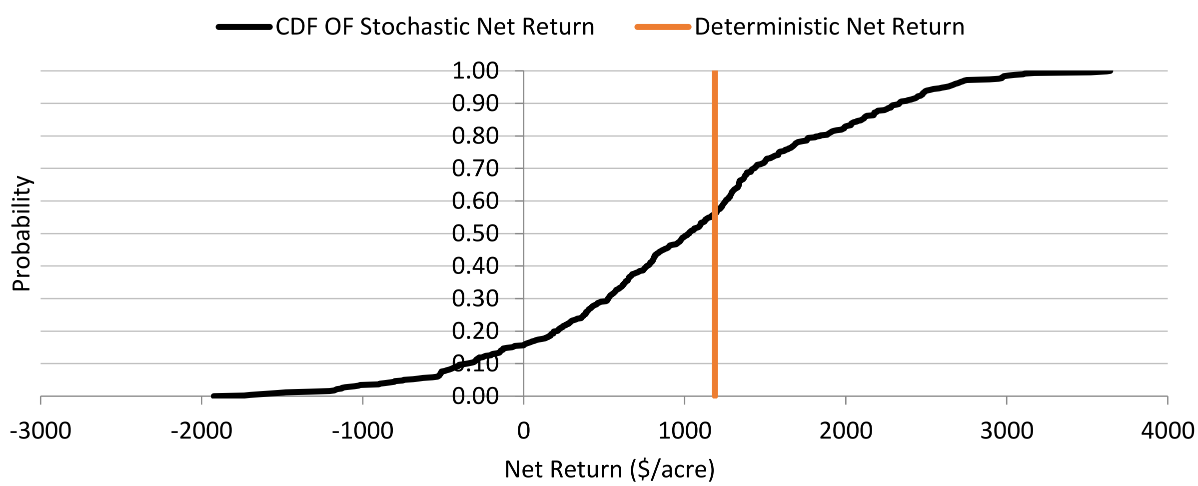
	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	1,188.25	984.86
S.D.	-	1,006.21
C.V.	-	102.17
Min	1,188.25	-1,924.33
Max	1,188.25	3,642.86

Compared with the deterministic net return value of $1,188.25, the stochastic average net return is $984.86 with a standard deviation (S.D.) of $1,006.21 and a coefficient of variation (C.V.) of 102.17 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return per-acre are -$1,924.33 and $3,642.86, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive.

The cumulative distribution function (CDF) for the net return of a squash farm on a per-acre basis, and the cut-off point for the net return obtained from the deterministic model (orange line) are illustrated in Figure 7.

Figure 7 indicates that there is a 56 percent chance of the stochastic net return being less than or equal to the deterministic net return ($1,188.25). The CDF of the net return indicates that there is a significant chance of a squash farm in MDC being profitable; it has an 84 percent chance of getting positive net returns. The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 7 indicates that there is an 83 percent probability of a squash farm getting a net return less than or equal to $2,000 per-acre. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a squash farm being less than or equal to $3,500 but more than or equal to $2,000 is 0.16 (0.99-0.83) or 16 percent.

Figure 7. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Squash Operation in Miami Dade County.



Cost and Returns Analysis for Nursery and Floriculture

The third commodity group considered in the present study is floriculture, specifically the flowering plants Begonia, Hibiscus, Chrysanthemum, and the groundcover Daylilly.

Begonia

A summarized version of the begonia enterprise budget is shown in Table 22; the extended/detailed version of the begonia enterprise budget can be found in Appendix 15. Under a marketable yield of 95,000 4-inch container plants produced on a 20,000 sq. ft. area, and an average grower's price of $2.75/plant, total revenue is $261,250. Factoring in direct and labor costs results in a gross return of $169,194.10, or about $1.78 per plant. After considering total production cost, net return is $133,994.10, or about $1.41 per plant.

Table 22. Deterministic Enterprise Budget for a Begonia Operation in Miami Dade County.

Item	Quantity	Value ($/unit)	Value ($)	Cost ($/unit)
Yield (4-inch container)	95,000			
Producer Price		2.75		
Total revenue			261,250.00	
Direct cost			55,268.00	0.58
Labor cost			36,787.90	0.39
Fixed cost			35,200.00	0.37
Total production cost			127,255.90	1.34
Gross return			169,194.10	1.78
Net return			133,994.10	1.41

Sensitivity Analysis. Table 23 illustrates a sensitivity analysis of the average net return of a 20,000 sq. ft. begonia operation in MDC. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return would increase from $133,994.10 (baseline scenario) to $189,379.10. Under the worst-case scenario where both yield and price decline by 10 percent, net return would fall from $133,994.10 (baseline scenario) to $84,784.10. Different combinations of changes in prices and yield, and their impact on the profitability of a begonia operation are illustrated in Table 23 as well.

Table 23. Sensitivity Analysis of Net Returns for a Begonia Operation in Miami Dade County.

Yield (plants/area)		Producer price ($/unit)				
		2.48 (-10%)	2.61 (-5%)	2.75 (Base)	2.89 (+5%)	3.03 (+10%)
85,500	(-10%)	84,784.10	95,899.10	107,869.10	119,839.10	131,809.10
90,250	(-5%)	96,564.10	108,296.60	120,931.60	133,566.60	146,201.60
95,000	(Base)	108,344.10	120,694.10	133,994.10	147,294.10	160,594.10
99,750	(+5%)	120,124.10	133,091.60	147,056.60	161,021.60	174,986.60
104,500	(+10%)	131,904.10	145,489.10	160,119.10	174,749.10	189,379.10

A 5 percent price increase has a large impact on the profitability of a begonia operation as net return increases by $14,630 over the base scenario. In contrast, a 5 percent yield increase results in a net return increase of $13,062.5 over the base scenario.

Stochastic budget analysis. Table 24 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 16.

Table 24. Deterministic and Stochastic Budgets to Assess the Profitability of a Begonia Operation in Miami Dade County.

	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	133,994.10	119,088.29
S.D.	-	21,839.62
C.V.	-	18.34
Min	133,994.10	47,465.90
Max	133,994.10	158,975.62

Compared with the deterministic net return value of $133,994.10, the stochastic average net return is $119,088.29 with a standard deviation (S.D.) of $21,839.62 and a coefficient of variation (C.V.) of 18.34 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return per-acre are $47,465.90 and $158,975.62, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive. The cumulative distribution function (CDF) for the net return of a begonia operation, and the cut-off point for the net return obtained from the deterministic model (orange line) are illustrated in Figure 8.

Figure 8. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a 20,000 sq. ft. Begonia Operation in Miami Dade County.

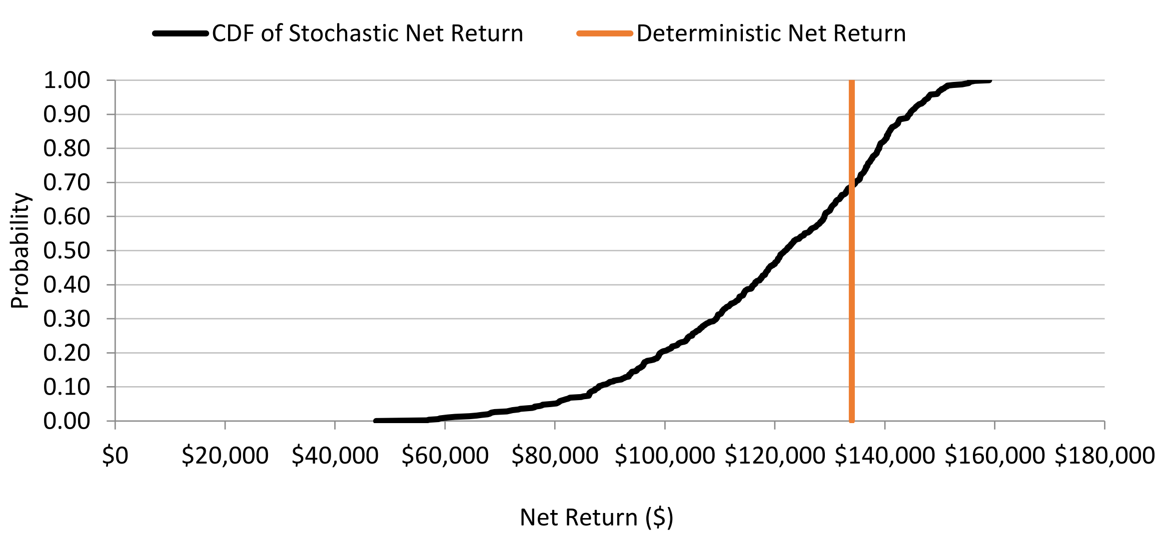


Figure 8 indicates that there is a 69 percent chance of the stochastic net return being less than or equal to the deterministic net return ($133,994.10). The CDF of the net return indicates that there is a significant chance of a begonia operation in MDC being profitable; under the range of prices and yields considered it has a 100 percent chance of getting positive net returns. The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 8 indicates that there is a 20 percent probability of a begonia operation getting a net return less than or equal to $100,000. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a begonia operation being less than or equal to $150,000 but more than or equal to $100,000 is 0.76 (0.96-0.20) or 76 percent.

Hibiscus

A summarized version of the hibiscus enterprise budget is shown in Table 25; the extended/detailed version of the hibiscus enterprise budget can be found in Appendix 17. Under a marketable yield of 2,250 3-gallon container plants per-acre, and an average grower's price of $10/plant, total revenue is $22,500. Factoring in direct and labor costs results in a gross return of $10,756.94, or about $4.78 per plant. After considering total production cost, net return is $9,031.94, or about $4.01 per plant.

Table 25. Deterministic Enterprise Budget for a Hibiscus Operation in Miami Dade County.

Item	Quantity	Value ($/unit)	Value ($)	Cost ($/unit)
Yield (3-gallon container)	2,250.00			
Producer Price		10.00		
Total revenue			22,500.00	
Direct cost			6,613.06	2.94
Labor cost			5,130.00	2.28
Fixed cost			1,725.00	0.77
Total production cost			13,468.06	5.99
Gross return			10,756.94	4.78
Net return			9,031.94	4.01

Sensitivity Analysis. Table 26 illustrates a sensitivity analysis of the average net return to a hibiscus grower in MDC on a per-acre basis. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return would increase from $9,031.94 (baseline scenario) to $13,756.94. Under the worst-case scenario where both yield and price decline by 10 percent, net return would fall from $9,031.94 (baseline scenario) to $4,756.94. Different combinations of changes in prices and yield, and their impact on the profitability of a hibiscus operation are illustrated in Table 26 as well. It is important to note that a 5 percent price increase has the same impact on profitability as a 5 percent yield increase as net return increases by $1,125 over the base scenario.

Table 26. Sensitivity Analysis of Net Returns for a Hibiscus Operation in Miami Dade County.

Yield (plants/acre)		Producer price ($/unit)				
		9.00 (-10%)	9.50 (-5%)	10.00 (Base)	10.50 (+5%)	11.00 (+10%)
2,025.00	(-10%)	4,756.94	5,769.44	6,781.94	7,794.44	8,806.94
2,137.50	(-5%)	5,769.44	6,838.19	7,906.94	8,975.69	10,044.44
2,250.00	(Base)	6,781.94	7,906.94	9,031.94	10,156.94	11,281.94
2,362.50	(+5%)	7,794.44	8,975.69	10,156.94	11,338.19	12,519.44
2,475.00	(+10%)	8,806.94	10,044.44	11,281.94	12,519.44	13,756.94

Stochastic budget analysis. Table 27 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 18.

Table 27. Deterministic and Stochastic Budgets to Assess the Profitability of a Hibiscus Operation in Miami Dade County.

	Deterministic Net Return ($/acre)	Stochastic Net Return ($/acre)
Mean	9,031.94	7,510.19
S.D.	-	2,879.34
C.V.	-	38.34
Min	9,031.94	(1,600.50)
Max	9,031.94	13,311.72

Compared with the deterministic net return value of $9,031.94, the stochastic average net return is $7,510.19 with a standard deviation (S.D.) of $2,879.34 and a coefficient of variation (C.V.) of 38.34 percent. The range of variation for the net return obtained from the stochastic budget varied significantly from a minimum of -$1,600.50 to a maximum of $13,311.72, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive. The cumulative distribution function (CDF) for the net return of a one-acre hibiscus operation, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 9.

Figure 9. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a Hibiscus Operation in Miami Dade County.

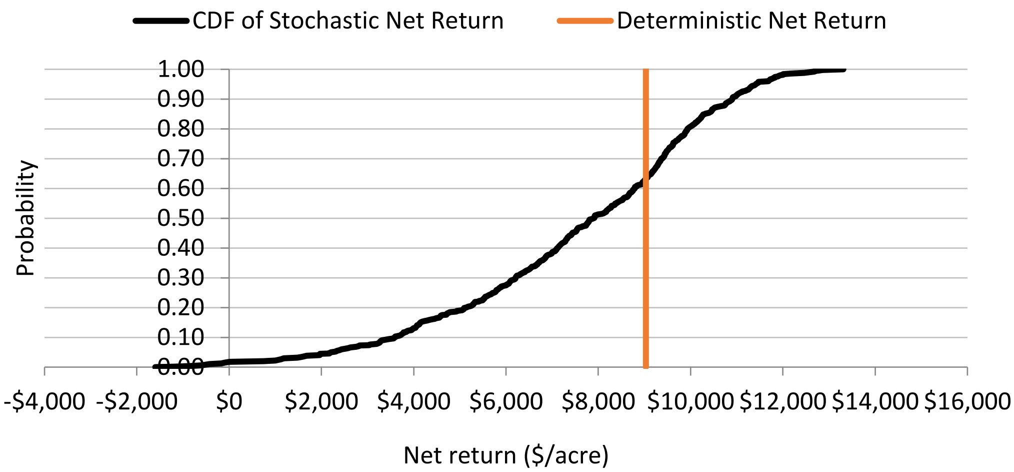


Figure 9 indicates that there is a 63 percent chance of the stochastic net return being less than or equal to the deterministic net return ($9,031.94). The CDF of the net return indicates that there is a significant chance of a hibiscus farm in MDC being profitable; it has a 98 percent chance of getting positive net returns under the range of prices and yield considered.

The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 9 indicates that there is a 19 percent probability of a hibiscus farm getting a net return less than or equal to $5,000. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a hibiscus farm being less than or equal to $7,000 but more than or equal to $5,000 is 0.19 (0.38-0.19) or 19 percent.

Chrysanthemum

A summarized version of the chrysanthemum enterprise budget is shown in Table 28, the extended/detailed version of the enterprise budget can be found in Appendix 19.

Table 28. Deterministic Enterprise Budget for a Chrysanthemum Operation in Miami Dade County.

Item	Quantity (units)	Value ($/unit)	Value ($)	Cost ($/plant)
Yield (1-gallon container)	45,000			
Producer Price		5.00		
Total revenue			225,000.00	
Direct cost			45,495.00	1.01
Labor cost			36,784.00	0.82
Fixed cost			35,200.00	0.78
Total production cost			117,479.00	2.61
Gross return			142,721.00	3.17
Net return			107,521.00	2.39

Under a marketable yield of 45,000 1-gallon container plants produced on a 20,000 sq. ft. area, and an average grower's price of $5.00/plant, total revenue is $225,000. Factoring in direct and labor costs results in a gross return of $142,721, or about $3.17 per plant. After considering total production cost, net return is $107,521 or about $2.39 per plant.

Sensitivity Analysis. Table 29 illustrates a sensitivity analysis of the average net return of a 20,000 sq. ft. chrysanthemum operation in MDC under different price and yield scenarios. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return would increase from $107,521 (baseline scenario) to $154,771. Under the worst-case scenario where both yield and price decline by 10 percent, net return would fall from $107,521 (baseline scenario) to $64,771. Different combinations of changes in prices and yield, and their impact on the profitability of chrysanthemums operation are illustrated in Table 29 as well. It is important to note that a 5 percent price increase has the same impact on profitability as a 5 percent yield increase as net return increases by $11,250 over the base scenario.

Table 29. Sensitivity Analysis of Net Returns for a Chrysanthemum Operation in Miami Dade County.

Yield (plants/area)		Producer price ($/unit)				
		4.5 (-10%)	4.75 (-5%)	5.00 (Base)	5.25 (+5%)	5.5 (+10%)
40500	(-10%)	64,771.00	74,896.00	85,021.00	95,146.00	105,271.00
42750	(-5%)	74,896.00	85,583.50	96,271.00	106,958.50	117,646.00
45,000	(Base)	85,021.00	96,271.00	107,521.00	118,771.00	130,021.00
47250	(+5%)	95,146.00	106,958.50	118,771.00	130,583.50	142,396.00
49500	(+10%)	105,271.00	117,646.00	130,021.00	142,396.00	154,771.00

Stochastic budget analysis. Table 30 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 20.

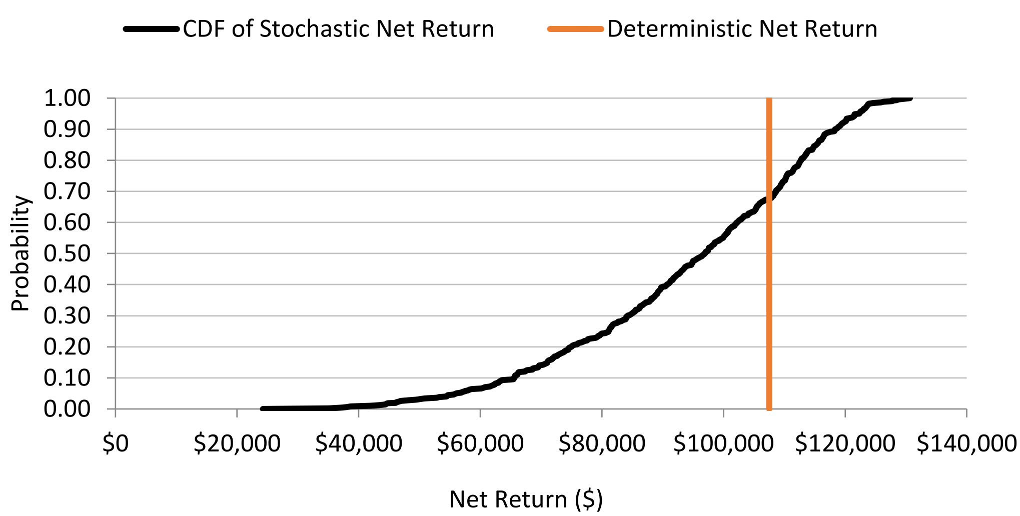
Table 30. Deterministic and Stochastic Budgets to Assess the Profitability of a Chrysanthemum Operation in Miami Dade County.

	Deterministic Net Return ($)	Stochastic Net Return ($)
Mean	107,521.00	93,914.55
S.D.	-	20,627.47
C.V.	-	21.96
Min	107,521.00	24,250.82
Max	107,521.00	130,660.44

Compared with the deterministic net return value of $107,521, the stochastic average net return is $93,914.55 with a standard deviation (S.D.) of $20,627.47 and a coefficient of variation (C.V.) of 21.96 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return are $24,250.82 and $130,660.44, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive. The cumulative distribution function (CDF) for the net return of a 20,000 sq. ft. chrysanthemum operation, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 10. Figure 10 indicates that there is a 67 percent chance of the stochastic net return being less than or equal to the deterministic net return ($107,521). The CDF of the net return indicates that there is a significant chance of a chrysanthemum operation in MDC being profitable; it has a 100 percent chance of getting positive net returns under the range of prices and yields considered.

The CDF may help us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 10 indicates that there is a 55 percent probability of a chrysanthemum operation getting a net return less than or equal to $100,000. Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a chrysanthemum operation being less than or equal to $100,000 but more than or equal to $120,000 is 0.37 (0.92-0.55) or 37 percent.

Figure 10. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a 20,000 sq. ft. Chrysanthemum Operation in Miami Dade County.



Daylily

A summarized version of the daylily enterprise budget is shown in Table 31; the extended/detailed version of the enterprise budget can be found in Appendix 21. Under a marketable yield of 45,000 1-gallon container plants produced on a 20,000 sq. ft. area, and an average grower's price of $5.00/plant, total revenue is $225,000. Factoring in direct and labor costs results in a gross return of $124,777, or about $2.77 per plant. After considering total production cost, net return is $107,177, or about $2.38 per plant.

Table 31. Deterministic Enterprise Budget for a Daylily Operation in Miami Dade County.

Item	Quantity	Value ($/unit)	Value $	Cost ($/unit)
Yield (1-gallon container)	45,000			
Producer Price		5.00		
Total revenue			225,000.00	
Direct cost			81,819.00	1.82
Labor cost			18,404.00	0.41
Fixed cost			17,600.00	0.39
Total production cost			117,823.00	2.62
Gross return			124,777.00	2.77
Net return			107,177.00	2.38

Sensitivity Analysis. Table 32 illustrates a sensitivity analysis of the average net return of a 20,000 sq. ft. daylily operation in MDC under different price and yield scenarios. Under the best-case scenario where both price and yield are assumed to increase by 10 percent, net return would increase from $107,177 (baseline scenario) to $154,427. Under the worst-case scenario where both yield and price decline by 10 percent, net return would fall from $107,177 (baseline scenario) to $64,427. Different combinations of changes in prices and yield, and their impact on the profitability of a daylily operation are illustrated in Table 32 as well.

Table 32. Sensitivity Analysis of Net Returns for a Daylily Operation in Miami Dade County.

Yield (units/area)		Producer price ($/unit)				
		4.5 (-10%)	4.75 (-5%)	5.00 (Base)	5.25 (+5%)	5.5 (+10%)
40500	(-10%)	64,427.00	74,552.00	84,677.00	94,802.00	104,927.00
42750	(-5%)	74,552.00	85,239.50	95,927.00	106,614.50	117,302.00
45,000	(Base)	84,677.00	95,927.00	107,177.00	118,427.00	129,677.00
47250	(+5%)	94,802.00	106,614.50	118,427.00	130,239.50	142,052.00
49500	(+10%)	104,927.00	117,302.00	129,677.00	142,052.00	154,427.00

It is important to note that a 5 percent price increase has the same impact on profitability as a 5 percent yield increase as net return increases by $11,250 over the base scenario.

Stochastic budget analysis. Table 33 shows the results of the deterministic and the stochastic budget; the details about the yield and price values used to conduct the simulation can be found in Appendix 22.

Table 33. Deterministic and Stochastic Budgets to Assess the Profitability of a Daylily Operation in Miami Dade County.

	Deterministic Net Return ($)	Stochastic Net Return ($)
Mean	107,177.00	91,260.75
S.D.	-	22,704.49
C.V.	-	24.88
Min	107,177.00	18,272.60
Max	107,177.00	129,048.16

Compared with the deterministic net return value of $107,177, the stochastic average net return is $91,260.75 with a standard deviation (S.D.) of $22,704.49 and a coefficient of variation (C.V.) of 24.88 percent. There is a wide range of variation for the net return obtained from the stochastic budget as the minimum and maximum net return are $18,272.60 and $129,048.16, respectively. The stochastic budget comes in agreement with the deterministic budget, namely that the average net return is positive. The cumulative distribution function (CDF) for the net return of a 20,000 sq. ft. daylily operation, and the cut-off point for the net return obtained from the deterministic model (orange line) are shown in Figure 11.

Figure 11. Cumulative Distribution function (CDF) of the Stochastic Net Return and Deterministic Net Return for a 20,000 sq. ft. Daylily Operation in Miami Dade County.

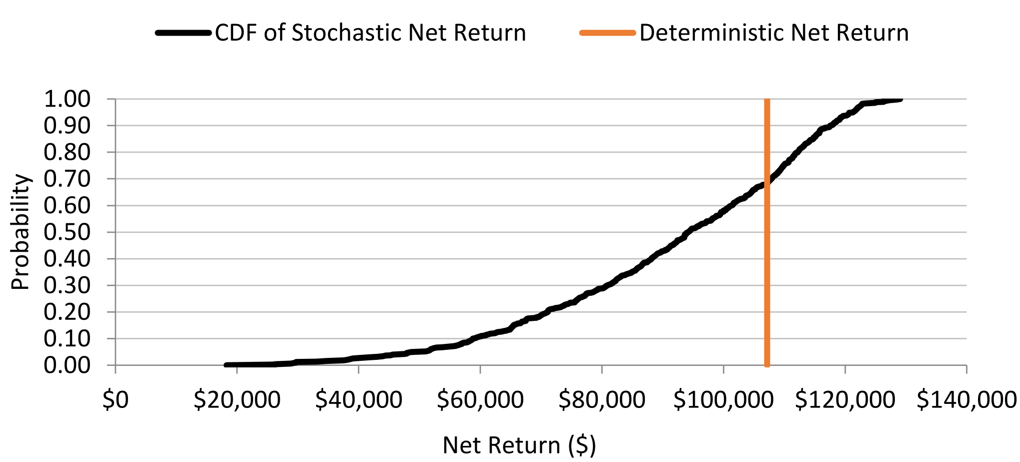


Figure 11 indicates that there is a 68 percent chance of the stochastic net return being less than or equal to the deterministic net return ($107,177). The CDF of the net return indicates that there is a significant chance of a daylily operation in MDC being profitable; it has a 100 percent chance of getting positive net returns under the prices and yields considered. The CDF allows us to determine the probability of getting a net return less than or equal to a particular value. For example, Figure 11 indicates that there is a 5 percent probability of a daylily operation getting a net return less than or equal to $50,000.

Additionally, the CDF allows us to estimate the probability of a net return falling between two values. As an example, the probability of the net return of a daylily operation being less than or equal to $70,000 but more than or equal to $50,000 is 0.13 (0.18-0.05) or 13 percent.

Conclusions

A summary of the profitability and profit margins for the major commodities grown in Miami-Dade County are shown in Table 34. The agricultural industry in MDC is resilient; even with the heavy competition from imports and the higher production costs, the fruit and vegetable commodities analyzed show a moderate to high chance of getting positive net returns based on Spring 2023 price and yields estimations.

Table 34. Summary of the Net Returns and Profit Margins for the Main Commodities Grown in Miami Dade County

Crop	Probability of positive Net Return (%)	Net Return ($/acre)*		Profit Margin (%)	
		Deterministic Budget	Stochastic Budget	Deterministic Budget	Stochastic Budget
Avocado	53	231.40	815.13	4.58	16.14
Mango	86	1,918.61	1,487.45	29.31	22.73
Carambola	60	1,714.00	4,525.60	8.86	23.40
Snap beans	54	191.00	145.11	5.78	4.39
Sweet corn	57	137.00	467.08	2.95	10.04
Tomato	59	910.00	1,775.49	6.32	12.40
Squash	84	1,188.25	984.86	13.50	11.22
Begonia*	100	133,994.10	119,088.29	51.29	45.58
Hibiscus	98	9,031.94	7,510.14	40.14	33.38
Chrysanthemum*	100	107,521.00	93,914.55	47.79	41.74
Daylily*	100	107,177.00	91,260.75	47.63	40.56

* Net returns for floriculture crops are expressed in terms of a 20,000 sq. ft. area; all others expressed as dollars per acre.

For fruit crops under consideration, the profit margin under the deterministic net return ranged from a low of 4.58% for avocados to a high of 29.31% for mangoes. Once risk is taken into consideration, the profit margin based on the average stochastic net return ranged from a low of 16.14% for avocados to a high of 23.40% for carambola.

For vegetable crops considered, the deterministic profit margin ranged from a low of 2.95% for sweet corn to a high of 13.50% for squash. Taking risk into consideration, then the profit margin based on the average stochastic net return ranged from a low of 4.39% for snap beans to a high of 12.40% for tomato.

For ornamental crops considered, the profit margin under the deterministic net return ranged from a low of 40.14% for hibiscus to a high of 51.29% for begonia. Once risk is taken into consideration, the profit margin based on the average stochastic net return ranged from a low of 33.38% for hibiscus to a high of 45.58% for begonia.

The profit margin based on the average stochastic net return tends to be higher for crops (e.g., avocado) which have benefited from more frequent trade disruption, supply chain issues and adverse weather events in competing regions. The resulting price volatility has improved the pricing conditions for local growers.

Ornamental crops are a special case as they exhibit higher net returns and profit margins compared to the main fruit and vegetables grown in MDC. Ornamental crop growers in MDC enjoy a mild winter season which results in a longer growing season. Additionally, MDC ornamental growers do not face import competition, which brings significant price pressure. However, the ornamental crop industry in MDC experiences a different type of competitive pressure as within-industry consolidation and increased price competition are some of the main issues to the industry.

Given the low levels of profitability for several of the major fruits and vegetable crops grown in the area, it is worth exploring some reasons why most growers keep operating under shrinking net returns due to increased foreign competition and higher operating costs.

Based on economic theory, as long as fruit and vegetable growers in MDC get positive net returns they will continue operating in the agricultural industry. Positive net returns mean that the production factors (e.g., capital and labor investments) are fairly compensated for their use in the production process and that a profit is being made. A shutdown/exit decision will take place when the growers do not recover their operating costs. If that is the case, then leaving the industry is the best alternative, in the short term their losses would be limited only to the fixed costs. From this profitability analysis conducted for the major crops grown in MDC, growers would continue to be involved in the agricultural industry.

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Appendices: Detailed Budget Data

Appendix 1.
Sample Budget for Avocado Production

Item	**Quantity (lbs.)**	**Value ($/acre)**	**Value ($/lb.)**
Revenue			
Marketable Yield (lbs./acre)	14,025		
Producer Price			0.36
Total revenue		5,049.00	
Operating Cost			
Fertilizers		500.00	
Insecticides		150.00	
Fungicides		250.00	
Herbicides		445.00	
Pruning		100.00	
Irrigation		120.00	
Mow and vine		230.00	
Laurel Wilt control		750.00	
Food Safety		50.00	
Miscellaneous			
Interest on operating capital 5%		130.00	
Total Operating Cost		2,725.00	0.19
Fixed Cost			
Cash overhead:			
Insurance		100.00	
Taxes		100.00	
Non- Cash overhead:			
Land rent		550.00	
Other overhead		445.00	
Total Fixed Cost		1,195.00	0.09
Total Pre-harvest Cost		3,920.00	0.28
Harvest and Marketing Cost			
Pick, haul, and grading		897.60	0.06
Total Harvesting and Marketing Cost		897.60	0.06
Total Cost		4,817.60	0.34
Gross Return		1,426.40	0.10
Estimated Net Return		231.40	0.02

Source: interview data, Crane, J. H. (2020) and De Oleo et al. (2017).

Appendix 2.

Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Avocado Prices and Yields.

Avocado Yield (lbs./acre) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	4675	14025	17675
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	0.00
	2	0.01	2,337.49
Minimum	3	0.02	4,675.00
	4	0.07	7,012.50
	5	0.16	9,350.00
	6	0.31	11,687.50
Mode	7	0.50	14,025.00
	8	0.69	14,937.50
	9	0.84	15,850.00
	10	0.93	16,762.50
Maximum	11	0.98	17,675.00
	12	0.99	18,587.50
Pseudo Max	13	1.00	19,500.00

Source: interview data, Crane, J. H. (2020) and De Oleo et al. (2017).

Avocado Price ($/lb.) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	0.24	0.36	0.84
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	0.18
	2	0.01	0.21
Minimum	3	0.02	0.24
	4	0.07	0.27
	5	0.16	0.30
	6	0.31	0.33
Mode	7	0.50	0.36
	8	0.69	0.48
	9	0.84	0.60
	10	0.93	0.72
Maximum	11	0.98	0.84
	12	0.99	0.96
Pseudo Max	13	1.00	1.08

Source: interview data.

Appendix 3
Sample Budget for Mango Production

Item	Quantity (lbs.)	Value ($/acre)	Value ($/lb.)
Revenue			
Marketable Yield (lbs./acre)	18,700		
Producer Price			0.35
Total revenue		6,545.00	
Operating Cost			
Fertilizers		792.65	
Insecticides		131.01	
Fungicides		238.20	
Herbicides		145.30	
Pruning and mowing		476.40	
Irrigation		119.10	
Food Safety		50.00	
Miscellaneous		-	
Interest on operating capital 5%		98.00	
Total Operating Cost		2,050.66	0.11
Fixed Cost			
Cash overhead:			
Insurance		100.00	
Taxes		100.00	
Non- Cash overhead:			
Land rent		550.00	
Other overhead		400.00	
Total Fixed Cost		1,150.00	0.06
Total Pre-harvest Cost		3,201.00	0.17
Harvest and Marketing Cost			
Pick, haul, and grading		1,425.39	0.08
Total Harvesting and Marketing Cost		1,425.39	0.08
Total Cost		4,626.39	0.25
Gross Return		3,068.95	0.16
Estimated Net Return		1,918.61	0.10

Source : Blare et al. (2022), Crane et al. (2020).

Appendix 4

Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Mango Prices and Yields.

Mango Yield (lbs./acre) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	6,233.35	18,700.00	21,193.00
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	0.02
	2	0.01	3,116.68
Minimum	3	0.02	6,233.35
	4	0.07	9,350.01
	5	0.16	12,466.67
	6	0.31	15,583.34
Mode	7	0.50	18,700.00
	8	0.69	19,323.25
	9	0.84	19,946.50
	10	0.93	20,569.75
Maximum	11	0.98	21,193.00
	12	0.99	21,816.25
Pseudo Max	13	1.00	22,439.50

Source : Blare et al. (2022)**,** Crane et al. (2020).

Mango Price ($/lb. GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	0.29	0.35	0.44
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	0.26
	2	0.01	0.27
Minimum	3	0.02	0.29
	4	0.07	0.31
	5	0.16	0.32
	6	0.31	0.34
Mode	7	0.50	0.35
	8	0.69	0.37
	9	0.84	0.40
	10	0.93	0.42
Maximum	11	0.98	0.44
	12	0.99	0.46
Pseudo Max	13	1.00	0.48

Source : USDA AMS (2023).

Appendix 5
Sample Budget for Carambola Production

Item	Quantity (lbs.)	Value ($/acre)	Value ($/lb.)
Revenue			
Marketable Yield (lbs./acre)	29,750		
Producer Price			0.65
Total revenue		19,337.50	
Operating Cost			
Fertilizers		1,000.00	
Insecticides		-	
Fungicides		-	
Herbicides		250.00	
Irrigation		185.00	
Mow and vine		-	
Labor cost		1,025.00	
Food Safety		50.00	
Miscellaneous			
Interest on operating capital 5%		126.00	
Total Operating Cost		2,636.00	0.09
Fixed Cost			
Cash overhead:			
Insurance		100.00	
Taxes		100.00	
Non- Cash overhead:			
Land rent		550.00	
Other overhead		850.00	
Total Fixed Cost		1,600.00	0.05
Total Pre-harvest Cost		4,236.00	0.14
Harvest and Marketing Cost			
Pick, haul, and grading		13,387.50	0.45
Total Harvesting and Marketing Cost		13,387.50	0.45
Total Cost		17,623.50	0.59
Gross Return		3,314.00	0.11
Estimated Net Return		1,714.00	0.06

Source: Crane, J. H. (2020) and Ballen et al. (2020).

Appendix 6
Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Carambola Prices and Yields.
Carambola Yield (lbs./acre) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	0.32	0.65	1.55
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	0.16
	2	0.01	0.24
Minimum	3	0.02	0.32
	4	0.07	0.40
	5	0.16	0.48
	6	0.31	0.57
Mode	7	0.50	0.65
	8	0.69	0.87
	9	0.84	1.10
	10	0.93	1.33
Maximum	11	0.98	1.55
	12	0.99	1.78
Pseudo Max	13	1.00	2.00

Source: interview data, Crane, J. H. (2020) and Ballen et al. (2020).

Carambola Price ($/lb.) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	16584	29750	33717
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	10,001.00
	2	0.01	13,292.49
Minimum	3	0.02	16,584.01
	4	0.07	19,875.50
	5	0.16	23,167.00
	6	0.31	26,458.50
Mode	7	0.50	29,750.00
	8	0.69	30,741.75
	9	0.84	31,733.50
	10	0.93	32,725.25
Maximum	11	0.98	33,717.00
	12	0.99	34,708.75
Pseudo Max	13	1.00	35,700.50

Source: interview data, and Ballen et al. (2020).

Appendix 7
Sample Budget for Snap Bean Production

Item	Quantity (boxes)	Value ($/acre)	Value ($/box)
Revenue			
Marketable Yield (boxes/acre)	220		
Producer Price			15.00
Total revenue		3,300	
Operating Cost			
Land preparation		60	
Seeds		221	
Fertilizers		175	
Insecticides		52	
Fungicides		85	
Herbicides		10	
Labor:			
General & irrigation		325	
Tractor operator		100	
Machinery operation		48	
Repair & maintenance		15	
Irrigation fuel and oil		150	
Irrigation repairs and maintenance		15	
Miscellaneous			
Interest on operating capital (5%)		63	
Total Operating cost		1,319	6.00
Fixed Cost			
Cash overhead:			
Insurance		50	
Taxes		40	
Non- Cash overhead:			
Land rent		550	
Other overhead		50	
Total Fixed Cost		690	3.14
Total Pre-harvest Cost		2,009	9.13
Harvest and Marketing Cost			
Pick, haul, and packing		1,100	5.00
Total Harvesting and Marketing Cost		1,100	5.00
Total Cost		3,109	14.13
Gross Return		881	4.00
Estimated Net Return		191	0.87

Source: interview data.

Appendix 8

Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Snap Bean Prices and Yields.

Snap Beans Yield (boxes/acre) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	167	200	267
	Interval	**Prob (Xi)**	**Xi**
Pseudo Min	1	0.00	150.50
	2	0.01	158.75
Minimum	3	0.02	167.00
	4	0.07	175.25
	5	0.16	183.50
	6	0.31	191.75
Mode	7	0.50	200.00
	8	0.69	216.75
	9	0.84	233.50
	10	0.93	250.25
Maximum	11	0.98	267.00
	12	0.99	283.75
Pseudo Max	13	1.00	300.50

Source: interview data.

Snap Bean Price ($/box) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	10.35	15	21.7
	Interval	**Prob (Xi)**	**Xi**
Pseudo Min	1	0.00	8.03
	2	0.01	9.19
Minimum	3	0.02	10.35
	4	0.07	11.51
	5	0.16	12.67
	6	0.31	13.84
Mode	7	0.50	15.00
	8	0.69	16.67
	9	0.84	18.35
	10	0.93	20.03
Maximum	11	0.98	21.70
	12	0.99	23.38
Pseudo Max	13	1.00	25.05

Source: interview data.

Appendix 9
Sample Budget for Sweet Corn Production

Item	Quantity (boxes)	Value ($/acre)	Value ($/box)
Revenue			
Marketable Yield (boxes/acre)	300		
Producer Price			15.50
Total revenue		4,650	
Operating Cost			
Land preparation			
Seeds		175	
Fertilizers		1,100	
Insecticides		300	
Fungicides		44	
Herbicides		28	
General labor		56	
Tractor operator		50	
Machinery operation		150	
Repair & maintenance		15	
Irrigation		100	
Miscellaneous		70	
Interest on operating capital 5%		104	
Total Operating cost		2,192	7.31
Fixed Cost			
Cash overhead:			
Insurance		70	
Taxes		138	
Non- Cash overhead:			
Land rent		550	
Other overhead			
Total Fixed Cost		758	2.53
Total Pre-harvest Cost		2,950	9.83
Harvest and Marketing Cost			
Pick, and haul		675	2.25
Corn crate		768	2.56
Sell corn		120	0.40
Total Harvesting and Marketing Cost		1,563	5.21
Total Cost		4,513	15.04
Gross Return		895	2.98
Estimated Net Return		137	0.46

Source: interview data.

Appendix 10
Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Sweet Corn Prices and Yields.
Sweet Corn Yield (boxes/acre) GRKS Distribution with the Following Parameters:

	Minimum	Mode	Maximum
	246	300	333
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	219.00
	2	0.01	232.50
Minimum	3	0.02	246.00
	4	0.07	259.50
	5	0.16	273.00
	6	0.31	286.50
Mode	7	0.50	300.00
	8	0.69	308.25
	9	0.84	316.50
	10	0.93	324.75
Maximum	11	0.98	333.00
	12	0.99	341.25
Pseudo Max	13	1.00	349.50

Source: interview data.

Sweet Corn Price ($/box) GRKS Distribution with the Following Parameters:

	Minimum	Mode	Maximum
	11.75	15.5	25.5
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	9.88
	2	0.01	10.81
Minimum	3	0.02	11.75
	4	0.07	12.69
	5	0.16	13.62
	6	0.31	14.56
Mode	7	0.50	15.50
	8	0.69	18.00
	9	0.84	20.50
	10	0.93	23.00
Maximum	11	0.98	25.50
	12	0.99	28.00
Pseudo Max	13	1.00	30.50

Source: interview data.

Appendix 11
Sample Budget for Tomato Production

Item	Quantity (boxes)	Value ($/acre)	Value ($/box)
REVENUE			
Marketable Yield (boxes/acre)	1,200		
Producer Price			12.00
Total revenue		14,400.00	
Operating Cost			
Land preparation		200.00	
Transplants 4000@$0.16		640.00	
Fumigant and nematicide		1,000.00	
Plastic mulch		450.00	
Stakes		-	
Fertilizers		900.00	
Insecticides		1,000.00	
Fungicides		840.00	
Herbicides		100.00	
Labor:			
General & irrigation		1,000.00	
Tractor operator		200.00	
Machinery operation		500.00	
Repair & maintenance		200.00	
Irrigation fuel and oil		50.00	
Irrigation repairs and maintenance		25.00	
Other			
Interest on operating capital 5%		355.00	
Total Operating Cost		7,460.00	6.22
Fixed Cost			
Cash overhead:			
Insurance		500.00	
Taxes		50.00	
Non- Cash overhead:			
Land rent		600.00	
Other overhead		200.00	
Total Fixed Cost		1,350.00	1.13
Total Pre-harvest Cost		8,810.00	7.34
Harvest and Marketing Cost			
Packing material		1,680.00	1.40
Wash/grade/pick		3,000.00	2.50
Total Harvesting and Marketing Cost		4,680.00	3.90
Total Cost		13,490.00	11.24
Gross Return		2,260.00	1.88
Estimated Net Return		910.00	0.76

Source: interview data.

Appendix 12
Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Tomato Prices and Yields.
Tomato Yield (boxes/acre) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	935	1200	1600
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	802.50
	2	0.01	868.75
Minimum	3	0.02	935.00
	4	0.07	1001.25
	5	0.16	1067.50
	6	0.31	1133.75
Mode	7	0.50	1200.00
	8	0.69	1300.00
	9	0.84	1400.00
	10	0.93	1500.00
Maximum	11	0.98	1600.00
	12	0.99	1700.00
Pseudo Max	13	1.00	1800.00

Source: interview data.

Tomato Price ($/box) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	6.2	12	20.5
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	3.30
	2	0.01	4.75
Minimum	3	0.02	6.20
	4	0.07	7.65
	5	0.16	9.10
	6	0.31	10.55
Mode	7	0.50	12.00
	8	0.69	14.12
	9	0.84	16.25
	10	0.93	18.38
Maximum	11	0.98	20.50
	12	0.99	22.63
Pseudo Max	13	1.00	24.75

Source: interview data.

Appendix 13
Sample Budget for Squash Production

Item	Quantity (boxes)	Value ($/acre)	Value ($/box)
Revenue			
Marketable Yield (boxes/acre)	675		
Producer Price			13.00
Total revenue		8,775.00	
Operating Cost			
Land preparation		25.00	
Seeds		510.00	
Fertilizers		390.00	
Insecticides		455.00	
Fungicides		650.00	
Herbicides		50.00	
Pollination		45.00	
Labor:			
General & irrigation		475.00	
Tractor operator		100.00	
Machinery operation		455.00	
Repair & maintenance		114.00	
Irrigation fuel and oil		100.00	
Irrigation repairs and maintenance		25.00	
Interest on operating capital 5%		170.00	
Total Operating cost		3,564.00	5.28
Fixed Cost			
Cash overhead:			
Insurance		30.00	
Taxes		50.00	
Non- Cash overhead:			
Land rent		650.00	
Other overhead		100.00	
Total Fixed Cost		830.00	1.23
Total Pre-harvest Cost		4,394.00	6.51
Harvest and Marketing Cost			
Packing material		1,323.00	1.96
Wash/grade/pick		1,869.75	2.77
Total Harvesting and Marketing Cost		3,192.75	4.73
Total Cost		7,586.75	11.24
Gross Return		2,018.25	2.99
Estimated Net Return		1,188.25	1.76

Appendix 14
Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Squash Prices and Yields.
Squash Yield (boxes/acre) GRKS Distribution with the Following Parameters:

	Minimum	Mode	Maximum
	560	675	865
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	502.50
	2	0.01	531.25
Minimum	3	0.02	560.00
	4	0.07	588.75
	5	0.16	617.50
	6	0.31	646.25
Mode	7	0.50	675.00
	8	0.69	722.50
	9	0.84	770.00
	10	0.93	817.50
Maximum	11	0.98	865.00
	12	0.99	912.50
Pseudo Max	13	1.00	960.00

Source: interview data.

Squash Price ($/box) GRKS Distribution with the Following Parameters:

	Minimum	Mode	Maximum
	9.6	13	14.1
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	7.90
	2	0.01	8.75
Minimum	3	0.02	9.60
	4	0.07	10.45
	5	0.16	11.30
	6	0.31	12.15
Mode	7	0.50	13.00
	8	0.69	13.27
	9	0.84	13.55
	10	0.93	13.83
Maximum	11	0.98	14.10
	12	0.99	14.38
Pseudo Max	13	1.00	14.65

Source: interview data.

Appendix 15
Sample Budget for Begonias Production

	Quantity	Yield	value ($)	Cost ($/unit)
Revenue				
4-inch container		95,000		
Price ($/unit)				2.75
Total Revenue			261,250.00	
Direct Costs:				
Seeds/plants/veg. material			14,000.00	
Pots/containers			9,000.00	
Growing media			3,400.00	
Fertilizers			10,179.00	
Insecticides			897.00	
Fungicides			1,344.00	
Other chemicals			448.00	
Tags			16,000.00	
Other				
Total Direct Cost			55,268.00	0.58
Labor Cost:				
Unskilled labor (hours) @ $11/hour	2,549.00		28,039.00	
Pest control labor (hours) @$13/hour	165.30		2,148.90	
Skilled labor (hours) @$15/hour	440.00		6,600.00	
Total labor cost			36,787.90	0.39
Fixed Cost:				
Fixed cost			35,200.00	
Total Fixed Cost			35,200.00	0.37
Total Production cost			127,255.90	1.34
Gross Return			169,194.10	1.78
Net Return			**133,994.10**	**1.41**

Source: Khachatryan H. and X. Wei (2021)

Appendix 16

Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Begonia Prices and Yields.

Begonia Yield (4-inch container plants) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	79,165.00	95,000.00	96,665.00
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	71,247.50
	2	0.01	75,206.24
Minimum	3	0.02	79,165.01
	4	0.07	83,123.75
	5	0.16	87,082.50
	6	0.31	91,041.25
Mode	7	0.50	95,000.00
	8	0.69	95,416.25
	9	0.84	95,832.50
	10	0.93	96,248.75
Maximum	11	0.98	96,665.00
	12	0.99	97,081.25
Pseudo Max	13	1.00	97,497.50

Source: Khachatryan H. and X. Wei (2021)

Begonia Price ($/4-inch container plant) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	2.20	2.75	2.93
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	1.93
	2	0.01	2.06
Minimum	3	0.02	2.20
	4	0.07	2.34
	5	0.16	2.47
	6	0.31	2.61
Mode	7	0.50	2.75
	8	0.69	2.79
	9	0.84	2.84
	10	0.93	2.89
Maximum	11	0.98	2.93
	12	0.99	2.98
Pseudo Max	13	1.00	3.02

Source: Khachatryan H. and X. Wei (2021)

Appendix 17
Sample Budget for Hibiscus Production

	Quantity	Unit cost ($)	Yield	value ($/acre)	$/unit
Revenue					
3-gallon container plants			2,250.00		
Price ($/unit)					10.00
Total Revenue				22,500.00	
Direct Costs:					
Seeds/plants/veg. material	2500	0.1		250.00	
Pots/containers	2500	0.25		625.00	
Growing media (Cubic Feet)	1150	2		2,300.00	
Fertilizers (lbs.)	1408	1.3		1,830.40	
Insecticides (Oz)	12	25.72		311.21	
Fungicides (gal)	3	128		392.45	
Other chemicals				25.00	
Tags	2500	0.16		400.00	
Irrigation				164.00	
Other				-	
Interest (5%)				315.00	
Total Direct Costs				6,613.06	2.94
Labor Costs:					
Unskilled labor (hours)/ $/hour	384.00	11.00		4,224.00	
Pest control labor (hours)/ $/hour	48.00	12.00		576.00	
Skilled labor (hours)/$/hour	22.00	15.00		330.00	
Total Labor Costs				5,130.00	2.28
Fixed Costs:					
Depreciation				100.00	
Taxes				100.00	
Insurance				100.00	
Other cash expenses				400.00	
Other expenses:					
Land/greenhouse rental				1,000.00	
Other				25.00	
Total Fixed Costs				1,725.00	0.77
Total Production Cost				13,468.06	5.99
Gross Return				10,756.94	4.78
Net Return				**9,031.94**	**4.01**

Source: interview data.

Appendix 18
Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Hibiscus Prices and Yields.
Hibiscus Yield (3-gallon container plants) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	1,875.00	2,250.00	2,325.00
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	1,687.50
	2	0.01	1,781.25
Minimum	3	0.02	1,875.00
	4	0.07	1,968.75
	5	0.16	2,062.50
	6	0.31	2,156.25
Mode	7	0.50	2,250.00
	8	0.69	2,268.75
	9	0.84	2,287.50
	10	0.93	2,306.25
Maximum	11	0.98	2,325.00
	12	0.99	2,343.75
Pseudo Max	13	1.00	2,362.50

Source: interview data.

Hibiscus Yield ($/3-gallon container plant) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	6.67	10.00	11.30
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	5.01
	2	0.01	5.84
Minimum	3	0.02	6.67
	4	0.07	7.50
	5	0.16	8.33
	6	0.31	9.17
Mode	7	0.50	10.00
	8	0.69	10.32
	9	0.84	10.65
	10	0.93	10.98
Maximum	11	0.98	11.30
	12	0.99	11.63
Pseudo Max	13	1.00	11.95

Source: interview data.

Appendix 19
Sample Budget for Chrysanthemum Production

	Yield	Quantity	Value ($)	$/unit
Revenue				
1-gallon container	45,000			
Price ($/unit)				5.00
Total revenue			225,000.00	
Direct Cost:				
Seeds/plants/veg. material			2,500.00	
Pots/containers			12,500.00	
Growing media			13,400.00	
Fertilizers			6,367.00	
Insecticides			910.00	
Fungicides			1,364.00	
Other chemicals			454.00	
Tags			8,000.00	
Other				
Total Direct Cost			45,495.00	1.01
Labor Cost:				
Unskilled labor (hours) @ $11/hour		2,549.00	28,039.00	
Pest control labor (hours) @$13/hour		165.00	2,145.00	
Skilled labor (hours) @$15/hour		440.00	6,600.00	
Total labor cost			36,784.00	0.82
Fixed Cost:				
Fixed cost			35,200.00	
Total Fixed Cost			35,200.00	0.78
Total Production Cost			117,479.00	2.61
Gross Return			142,721.00	3.17
Net Return			**107,521.00**	**2.39**

Source: Khachatryan H. and X. Wei (2022)

Appendix 20

Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Chrysanthemum Prices and Yields.

Chrysanthemum Yield (1-gallon container plants) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	36000	45,000.00	46500
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	31,500.00
	2	0.01	33,749.99
Minimum	3	0.02	36,000.00
	4	0.07	38,250.00
	5	0.16	40,500.00
	6	0.31	42,750.00
Mode	7	0.50	45,000.00
	8	0.69	45,375.00
	9	0.84	45,750.00
	10	0.93	46,125.00
Maximum	11	0.98	46,500.00
	12	0.99	46,875.00
Pseudo Max	13	1.00	47,250.00

Source: Khachatryan H. and X. Wei (2022)

Chrysanthemum Price ($/1-gallon container plant) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	3.99	5	5.34
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	3.49
	2	0.01	3.74
Minimum	3	0.02	3.99
	4	0.07	4.24
	5	0.16	4.49
	6	0.31	4.75
Mode	7	0.50	5.00
	8	0.69	5.08
	9	0.84	5.17
	10	0.93	5.26
Maximum	11	0.98	5.34
	12	0.99	5.43
Pseudo Max	13	1.00	5.51

Source: Khachatryan H. and X. Wei (2022)

Appendix 21
Sample Budget for Daylily Production

	Yield	Quantity	value ($)	$/unit
Revenue				
1-gallon container	45,000			
Price ($/unit)				5.00
Total Revenue			225,000.00	
Direct Costs:				
Seeds/plants/veg. material			43,000.00	
Pots/containers			12,500.00	
Growing media			13,400.00	
Fertilizers			3,444.00	
Insecticides			492.00	
Fungicides			737.00	
Other chemicals			246.00	
Tags			8,000.00	
Other			-	
Total Direct Cost			81,819.00	1.82
Labor Cost:				
Unskilled labor (hours) @ $11/hour		1,275.00	14,025.00	
Pest control labor (hours) @$13/hour		83.00	1,079.00	
Skilled labor (hours) @$15/hour		220.00	3,300.00	
Total Labor Cost			18,404.00	0.41
Fixed Cost:				
Fixed cost			17,600.00	
Total Fixed Cost			17,600.00	0.39
Total Production Cost			117,823.00	2.62
Gross Return			124,777.00	2.77
Net Return			**107,177.00**	**2.38**

Source: Khachatryan H. and X. Wei (2022)

Appendix 22

Minimum, Middle, and Maximum Input Values for the GRKS Distribution to Generate Daylily Prices and Yields.

Daylily Yield (1-gallon container plants) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	36,000.00	45,000.00	46,500.00
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	31,500.00
	2	0.01	33,749.99
Minimum	3	0.02	36,000.00
	4	0.07	38,250.00
	5	0.16	40,500.00
	6	0.31	42,750.00
Mode	7	0.50	45,000.00
	8	0.69	45,375.00
	9	0.84	45,750.00
	10	0.93	46,125.00
Maximum	11	0.98	46,500.00
	12	0.99	46,875.00
Pseudo Max	13	1.00	47,250.00

Source: Khachatryan H. and X. Wei (2022)

Daylily Price ($/1-gallon container plant) GRKS Distribution with the Following Parameters:

	Minimum	**Mode**	**Maximum**
	3.75	5.00	5.32
	Interval	**Prob(Xi)**	**Xi**
Pseudo Min	1	0.00	3.13
	2	0.01	3.44
Minimum	3	0.02	3.75
	4	0.07	4.06
	5	0.16	4.37
	6	0.31	4.69
Mode	7	0.50	5.00
	8	0.69	5.08
	9	0.84	5.16
	10	0.93	5.24
Maximum	11	0.98	5.32
	12	0.99	5.40
Pseudo Max	13	1.00	5.48

Source: Khachatryan H. and X. Wei (2022)