IMPACT OF IRRIGATION AND NUTRIENT MANAGEMENT PROGRAMS ON FRUIT YIELDS, NITROGEN LOAD, AND CROP VALUE OF FRESH MARKET TOMATO GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES

By

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To my Mother

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS 4

LIST OF TABLES 8

LIST OF FIGURES 10

ABSTRACT 11

CHAPTER

1 INTRODUCTION 13

Importance of Fresh Market Tomato Production in Florida 13
Statement of the Problem, Rationale and Significance 13

2 REVIEW OF LITERATURE 16

Importance of Best Management Practices, Total Maximum Daily Load, Florida Watershed Restoration Act 16
Factors Affecting Tomato Yield 19
Nutrient Load and Tools for Determination of Nutrient Load 20
Factors Affecting Nutrient Load 27
Conclusion and Objectives 28

3 NUTRIENT MANAGEMENT PROGRAMS FOR FRESH MARKET TOMATOES GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES. I. SOIL MOISTURE, PLANT NUTRITIONAL STATUS, AND YIELD DISTRIBUTION 36

Introduction 36
Materials and Methods 41
Experimental Setup 41
Data Collection 43
Irrigation volume data 43
Soil moisture data 43
Petiole sap data 44
Yield data 44
Data Analysis 45
Results and Discussion 45
Weather Conditions 45
Raised Plant Bed Soil Moisture 46
Tomato Plant Petiole Sap NO_3^--N Concentration 47
Tomato Plant Petiole Sap K^+ Concentration 48
Tomato Yield and Grade Distribution 50

Early Fruit Yield 50
Total Season Fruit Yields 51
Conclusion 54

4 NUTRIENT MANAGEMENT PROGRAMS FOR FRESH MARKET TOMATOES GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES. II. DETERMINATION OF NUTRIENT LOAD 69

Introduction 69
Materials and Methods 76
Experimental Setup 76
Drainage Lysimeters Installation 78
Drainage Lysimeters Sampling, Sample Analysis, and Load Calculation 78
Soil Sampling Sampling, Sample Analysis, and Load Calculation 79
Data Analysis 80
Results and Discussion 81
Weather Conditions 81
Seasonal Total-N Load Estimate Based on Drainage Lysimeter 81
Soil-profile Total-N Load Estimate Based on Soil Sampling 83
Relationship Between Seasonal Total-N Load Measured with Drainage Lysimeters and Soil-Profile Total-N Measured with Soil Sampling 86
Conclusion 87

5 NUTRIENT MANAGEMENT PROGRAMS FOR FRESH MARKET TOMATOES GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES. III. ECONOMIC INSIGHTS 96

Introduction 96
Materials and Methods 98
Fresh Market Tomato Production System 98
Fresh Market Tomato Production Model for University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) Based Recommendations 100
Methodology of Partial Budget Analysis of Irrigation-Nutrient Management Programs 100
Results and Discussion 101
Fresh Market Tomato Production Costs 101
Marginal Analysis of the Value of Extra Fertilizer and Irrigation 103
Effect of Irrigation-Nutrient Management Programs on Gross Returns from Fresh Market Tomato Production 105
Irrigation management 105
Fertilization management 105
Benefits from chicken litter 106
Partial Budget Analysis of Irrigation-Nutrient Management Programs 107
Economic Returns versus Nutrient Loading 107
Conclusion 108

6 CONCLUSION 122

LIST OF REFERENCES 126

BIOGRAPHICAL SKETCH 137

LIST OF TABLES

Table		page
2-1	Advantages and limitations of different procedures used for measuring nutrient loads.	30
2-2	Published estimates of nitrogen (nitrate, ammonium and total N) leaching in selected crops.	31
3-1	Irrigation-nutrient (N-P-K) management programs for spring 2005-2006 ‘Florida 47’ fresh market tomato production with raised-bed plasticulture system.	56
3-2	Number of sampling days when soil volumetric water content at 6 inches from the drip tape was between 0 to 13% for fresh market tomatoes grown in 2005 and 2006 on Blanton-Foxworth-Alpin Complex soil series.	57
3-3	Effects of irrigation and nutrient management programs on ‘Florida 47’tomato fruit yields during spring of 2005 and 2006.	59
4-1	Published estimates of nitrogen use efficiency (NUE) in selected crops.	89
4-2	Effects of depth of soil sampling in a ‘Florida 47’tomato field during spring of 2005 and 2006 on nitrogen loads based on mean, bed, and maximum wetted widths.	90
4-3	Effects of irrigation-nutrient management programs in a ‘Florida 47’tomato field during spring of 2005 and 2006 on nitrogen loads based on soil sampling with three different wetted width estimates.	91
5-1	Price of US #1 tomatoes during spring of 2005 and 2006 fresh market tomato production with raised-bed plasticulture system in North Florida.	111
5-2	Estimated costs of irrigation-nutrient management programs for spring 2005 and 2006 ‘Florida 47’ fresh market tomato production with raised-bed plasticulture system.	112
5-3	Estimated costs to produce and harvest ‘Florida 47’ tomatoes with raised-bed plasticulture system using University of Florida/Institute of Food and Agricultural Sciences irrigation-nutrient management program in spring of 2005 and 2006.	113
5-4	Season average prices of tomato grades for District 4 Florida’s shipment and sales.	115
5-5	Effects of irrigation and nutrient management programs on ‘Florida 47’tomato fruit yields, gross returns, and gross returns relative to the University of Florida/Institute of Food and Agricultural Sciences recommended program irrigation-nutrient management program during spring of 2005 and 2006 with raised-bed plasticulture system.	116

5-6 Total negative effects, total positive effects, and net returns of the irrigation-nutrient management programs relative to the UF/IFAS recommended program for fresh market tomato production during spring of 2005 and 2006 with raised-bed plasticulture system. 118

5-7 Net returns and changes in total-N load of irrigation-nutrient management programs relative to the University of Florida/ Institute of Food and Agricultural Sciences recommended program for 'Florida 47' fresh market tomato production during spring of 2005 and 2006 with raised-bed plasticulture system. 119

LIST OF FIGURES

Figure page

2-1 Fresh market tomato production in the United States 33

2-2 Vegetable production in Florida 34

3-1 N fertigation schedule used in the 2005-2006 fresh market tomato production experiment. 61

3-2 Irrigation schedule for spring 2005-2006 ‘Florida 47’ fresh market tomato production with raised-bed plasticulture system. 62

3-3 Historical and 2005-2006 weather patterns during tomato growing season in Live Oak, FL. 63

3-4 Effects of irrigation and nutrient management programs on petiole sap concentrations recorded for the different programs and the sufficiency ranges recommended for the corresponding growth stages during 2005 and 2006 65

3-5 Distribution of tomato fruit grades for the early yields during the 2005 and 2006 growing seasons. 67

3-6 Distribution of tomato fruit grades for the total season yields during the 2005 and 2006 growing seasons. 68

4-1 Schematics of the 3-feet long lysimeter designs used in the 2005 and 2006 fresh market tomato production experiment 93

4-2 Effects of irrigation-nutrient management programs on mean leachate volume (L) collected, and mean nitrate load recorded during the 2005 and 2006 growing seasons with drainage lysimeters. 94

5-1 Effect of season average market prices of tomato grades for District 4 Florida’s shipment and sales of U.S. One or Better 25-lb tomato cartons and fresh market tomato yields recorded in 2005 and 2006 with the UF/IFAS irrigation-nutrient management program on net profits 120

5-2 Relationship between additional break-even yield and increase in nitrogen fertilizer costs due to increased nitrogen fertilizer application at different season average market prices of tomato grades for District 4 Florida’s shipment and sales of U.S. One or Better 25-lb tomato cartons. 121

Abstract of Dissertation Presented to the Graduate School
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Because of the importance of agriculture to Florida's economy, and the federal and state water quality legislation, Florida's vegetable growers need specific guidelines to comply with these new regulations and remain competitive. Regulators also need science-based data documenting the reduction in pollution achieved by implementation of Best Management Practices. To better understand the impact of irrigation-nutrient management programs (INMP) on fresh market tomato production, simultaneous experiments were conducted to determine the effects of INMPs on 1) tomato yields, 2) tomato seasonal total-N load, and 3) economic insights into tomato production as determined with partial budget analysis (PBA). A 2-year experiment was conducted at Live Oak, Florida during springs of 2005 and 2006 with selected INMPs created by a combination of preplant fertilizer source (Chicken Litter (CL) or 13-1.8-10.8), fertilizer rate (100% or 200%), and irrigation rate (100% or 300%). The University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) recommended INMP was 100% Fertigation-100% Irrigation.

CL as a preplant nutrient source increased early-yields, and did not differ significantly from the UF/IFAS INMP for nutrient loads. 300% INMP reduced total fruit yields (920-1242 25-

lb cartons/acre), but did not differ significantly from the UF/IFAS INMP for nutrient loads. Based on the PBA, relative to the UF/IFAS INMP, 300% INMP not only increased the cost of the program ($17.18/acre), but also resulted in reduced returns ($1701/acre-$4112/acre). The effects of 200% fertigation rate on tomato plants varied with year. Early and total tomato yields with UF/IFAS and 200% INMP were not significantly different in both years. The high fertigation alone INMP (200% Fertigation-100% Irrigation) resulted in highest total-N load in 2006. Though statistically not significant, it also resulted in numerical higher net returns relative to the UF/IFAS INMP ($55/acre-$561/acre. We can conclude that CL can be used as an alternative preplant fertilizer source. We can also conclude that growers should not use high irrigation/high fertigation-high irrigation rates to ensure adequate soil moisture levels in the crop root zone as it results in net losses relative to the UF/IFAS INMP. Instead, they should better manage irrigation water application.

CHAPTER 1
INTRODUCTION

Importance of Fresh Market Tomato Production in Florida

Tomato (*Solanum lycopersicum* L.) production in Florida accounts for approximately 39% of the national fresh market tomato production (Figure 2-1), and has an annual value of approximately $464 million (USDA-NASS, 2008). Fresh market tomatoes are the number one vegetable crop in Florida (Figure 2-2) in total harvested acres (37,800-42,000 acres during 2005-2007) and total value ($464-805 million during 2005-2007). In North Florida, fresh market tomatoes are typically grown as a spring crop with raised beds, black plastic mulch, drip irrigation, greenhouse-grown transplants (Olson et al., 2007), and harvested 2-4 times at the mature green stage to ensure highest quality (Sargent et al., 2005). Extensive research has been done to determine the fertilizer and irrigation requirements of drip-irrigated plastic mulched tomatoes. Placement, application scheduling, rate, and source, of N and K fertilizers are also known to affect fresh market tomato yields and quality. Based on research, fertilizer recommendations for tomato production have been established in several states. The current base fertilization recommendations for tomato production in Florida on soils testing very low in Melich-1 P and K are 66 and 187 lb/acre of P and K. For nitrogen, the fertilization recommendation based on research and crop nutrient requirement is 200 lb/acre nitrogen (N), and includes a detailed fertigation schedule. A supplemental application of 30 and 17 lb/acre of N and K fertilizer is recommended after a leaching rain (3 inches of rainfall in 3 days or 4 inches in 7 days) event (Olson et al., 2007).

Statement of the Problem, Rationale and Significance

Sand, gravel and muck soils are the major soil types in Florida. The majority of the fresh market tomato production in Florida is on sandy soils. These soils have low water holding capacity (Fares and Alva, 2000), and therefore to counteract this problem the tomato growers using drip-irrigation often over-irrigate to maintain required soil moisture levels in the crop root zone. However, N-P-K fertilizers are highly water soluble, and due to the excessive irrigation practices that the growers follow, the nutrients are leached away from the crop root zone making them unavailable to the tomato plants. To counteract the loss of nutrients from the crop root zone, the growers generally tend to apply high rates of fertilizers to ensure adequate nutrient supply to the crop. This trend of excessive irrigation and fertilization has led to increased levels of nitrate and phosphate nutrients in Florida's groundwater and fresh water bodies.

With the adoption of the Federal Clean Water Act (FCWA) in 1977 (US Congress, 1977), states are required to assess the impact of non point sources of pollution on surface and ground waters, and establish programs to minimize them. Section 303(d) of the FCWA also requires states to identify impaired water bodies and establish Total Maximum Daily Loads (TMDLs) for pollutants entering into these water bodies (FDACS, 2005; Gazula et al., 2007). One way of achieving TMDLs is through Best Management Practices (BMPs). BMPs are practices or combinations of practices determined by the coordinating agencies, based on research, field-testing, and expert review, to be the most effective and practicable means, including economic and technological considerations, for improving water quality in agricultural and urban discharges. As a result there has been an increased educational effort to encourage growers to follow the UF/IFAS recommendations for fertilizer applications by improving irrigation management. Because of the TMDL/BMP legislation and the importance of agriculture to the Florida economy, vegetable growers in the state need specific guidelines to comply with these new regulations and to remain competitive. Regulators also need science-based data that document the reduction in pollution achieved by BMP implementation.

Therefore, to better understand the impact of irrigation and nutrient management practices on fresh market tomato production, a series of experiments were conducted simultaneously with selected irrigation-nutrient management programs. The goal of these experiments was to determine the production, environment, and economic impact of selected irrigation-nutrient management programs.

CHAPTER 2
REVIEW OF LITERATURE

Importance of Best Management Practices, Total Maximum Daily Load, Florida Watershed Restoration Act

The BMPs developed for vegetable crops grown in Florida are described in the manual titled "Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops". The manual, which is electronically accessible at http://www.floridaagwaterpolicy.com, was adopted by reference in Rule No 5M-8.004 of the Florida Administrative Code on February 8, 2006 (FDACS, 2008). The Florida Administrative Code is the official compilation of the rules and regulations of Florida regulatory agencies. The purpose of this rule is to achieve pollutant reduction through the implementation of non-regulatory and incentive-based programs determined to reduce adverse impacts to Florida's water.

BMPs are defined in s. 373.4595(2)(a), F.S. as "practices or combinations of practices determined by the coordinating agencies, based on research, field-testing, and expert review, to be the most effective and practicable on-location means, including economical and technological considerations, for improving water quality in agricultural and urban discharges". The 5M-8 rule of the Florida Administrative Code (FDACS, 2008) includes information about the approved BMPs, presumption of compliance, notice of intent to implement, and record keeping requirements. The statutory benefits for enrolling in the BMP program are: (1) obtaining a presumption of compliance with water quality standards (s. 403.067 (7) (d) Florida Statutes.), (2) receiving a waiver of liability from the reimbursement of cost and damages associated with the evaluation, assessment, or remediation of nutrient contamination of ground water (s. 376.307), and (3) eligibility for cost-share programs (s. 570.085 (1)). The BMP program for vegetables applies to the entire state of Florida, except for the Lake Okeechobee Priority Basin (under rule

5M-3 F.A.C.) and the EAA and C-139 basin (under rule 40E-63, F.A.C.) where pre-existing regulations are already in place.

The BMP programs for all major agricultural commodities of Florida have been developed under the provisions of the 1999 Florida Watershed Restoration Act (FWRA .s. 403.067 F.S.). The FWRA specifically outlines the process for the Florida Department of Environmental Protection (FDEP, 2005a) to develop and implement total maximum daily loads (TMDLs) for impaired waters of the state. TMDLs are defined as the maximum amount of a pollutant that a body of water can receive and still meet the water quality standards as established by the Clean Water Act of 1972. Section 303(d) of the Clean Water Act requires states to submit lists of surface waters that do not meet applicable water quality standards and to establish TMDLs for these waters on a prioritized schedule, "taking into account the severity of the pollution and the uses to be made of such waters".

The purpose of the FWRA was to better coordinate the numerous pollution control efforts that were implemented prior to 1999 and develop a standard to address future water quality issues. The FWRA requires that TMDLs be developed for all pollution sources “agricultural and urban” to ensure water quality standards are achieved. Once a TMDL is established for a pollutant in a watershed, a 5-year implementation plan, also called basin management action plan (BMAP) is developed. BMAPs are the strategies for restoring impaired waters by reducing pollutant loadings to meet the allowable loadings established in a TMDL (FDEP, 2005b). The FWRA affects all Floridians; thus, in order to effectively implement the TMDL program, the FDEP coordinates its efforts with a variety of entities including the Florida Department of Agriculture and Consumer Services, the Water Management Districts, the local Soil and Water Conservation Districts, University of Florida Institute of Food and Agricultural Sciences

(UF/IFAS), the environmental community, the agricultural community, and other concerned citizens.

In theory, BMP measures are not laws and they are strictly voluntary. However, they need to be effective at improving water quality. As part of the BMP implementation, growers perform an environmental assessment of their operations. This process identifies which BMPs should be considered to achieve the greatest economic and environmental benefit. The adopted BMPs may be a single practice or grouping of practices that, when implemented, are designed to improve water quality. The BMPs that are selected for each parcel of land with a tax ID are specified on a Notice of Intent to Implement and submitted to FDACS. If the practices are not yet implemented, the dates when they will be implemented are included on the Notice of Intent. Once enrolled in the BMP program, landowners must maintain records and provide documentation regarding the implementation of all BMPs (e.g. fertilizer application dates and amounts or design and construction details of a water control structure).

One of the most innovative elements of the FWRA and the associated agricultural BMP program is the Presumption of Compliance with water quality standards to landowners who voluntarily implement adopted BMPs that have been verified to be effective by FDEP. This component of the FWRA provides a powerful incentive to encourage landowners to enroll in BMP programs since landowners are protected from cost recovery by the state if water quality standards are not met. This unique approach to addressing water quality concerns has been well received by the environmental and agricultural communities alike and as a result is becoming the primary method for addressing water quality concerns. In addition, growers enrolled in the BMP program become eligible for cost-sharing funds to implement specific BMP practices.

In 2009, the Florida Legislature will assess the success of this non-regulatory program by examining the participation and enrolment of agricultural operations on a regional and commodity basis. By participating in BMP programs, growers are telling the Florida Legislature that the Florida agricultural industry has endorsed the challenge to remain in business while minimizing environmental impact. By making the BMP program a success, growers are also telling the Florida legislature that there is no need for a more stringent regulatory program.

Factors Affecting Tomato Yield

Extensive research has been done to determine the fertilizer and irrigation requirements of drip-irrigated plastic mulched tomatoes. Placement, application scheduling, rate, and source, of N and K fertilizers are also known to affect fresh market tomato yields and quality. With plastic mulched raised-bed tomato production, Csizinsky (1979) reported significantly higher tomato yields when fertilizer was banded than when it was broadcasted. However, the reports on effects of placement of fertilizers on tomato yields are highly variable. In a study done by Cook and Sanders, (1990), broadcast or banded placement of fertilizers had no effect on tomato fruit size, number or total yields. In a similar study done on fine sandy soils, the placement of fertilizer had no effect on marketable yields at one location. However, at the second location banded placement of fertilizers resulted in significantly higher marketable yields (Persaud et al., 1976). With drip irrigation on sandy soils, it has been shown that the highest tomato yields were obtained with 50% of N-K fertilizer applied at preplant and the remaining through fertigation (Dangler and Locascio, 1990). Further work done by Locascio et al., (1985; 1989; 1997a) on application scheduling effects on N-K fertilizers on tomato yields showed that the response varied with the soil type. On fine sandy soils, total early market yields, and total marketable tomato yields were highest with N-K applied 40% at preplant and 60% by fertigation, while on fine sandy loam and loamy fine sand soil types split application of N-K fertilizer had no effect on tomato fruit yields. Persaud et al. (1976) showed that mean yield increased linearly with an increase in N- K rate. Optimal rate of K for maximum tomato yields with drip irrigation and preplant broadcast application was in the range of 62-125 lb/acre (Persaud et al., 1976).

Crop water requirements may be determined based on U.S. Weather Service Class A pan evaporation. On fine sandy soils, fresh market tomato yields were significantly higher with irrigation volumes of 0.75 and 1.0 times pan evaporation than with higher irrigation volumes of 2.0 times pan evaporation and significantly lower with irrigation volumes 0.25 and 0.50 times pan evaporation (Locascio et al., 1981; Locascio and Smajstrla, 1996). However, the effect of irrigation rate varied with rainfall during the season, and also with soil type. Fruit yields were significantly higher with irrigation during extremely dry seasons, while in extremely wet seasons, irrigation had no effect on fruit yield (Locascio et al., 1996). On coarse textured soils tomato yields were higher with 0.5 than with 1.0 times pan evaporation, and maximum yields were recorded at 0.75 times pan evaporation (Locascio and Smajstrla, 1989). On the other hand, on fine textured soils, yields were the same with 0.5 and 1.0 times pan evaporation (Locascio et al., 1989; Olson and Rhoads, 1992).The rate of water application (0.5-2.0 gallons/hr water applied/emitter) had no effect on tomato plant growth and yield. Increased frequency and reduced duration of daily irrigation resulted in increased tomato yields (Csizinsky and Overman, 1979). However, under similar conditions, increasing the frequency of irrigation had no effect on total tomato yields (Locascio et al., 1985).

Nutrient Load and Tools for Determination of Nutrient Load

Quantifying nutrient load from vegetable production systems is the first step towards monitoring and understanding groundwater pollution in the field. Nutrient load is defined as the mass of a chemical entering or leaving an area, and is calculated as the product of the volume of water that the chemical is transported in and the concentration of the chemical in the water (Rice and Izuno, 2001). Nutrient load can be determined indirectly or directly. The indirect approaches of measuring load include nutrient flow models (Kyllmar et al., 2005) and nutrient balances (Öborn et al., 2003; Parris, 1998). Nutrient flow models are important tools for evaluating the impact of nutrient leaching on water quality at the watershed level, and play an important role in designing agricultural and environmental policies. For example, nutrient models used for determination of N leaching from agricultural land can be classified into statistical regression models, and process-based models, such as ANIMO, SOILN, and DAISY (Kyllmar et al., 2005). Nutrient balances measure the difference between nutrient inputs into and outputs from an agricultural system (Parris, 1998), and can be used as a tool for sustainable nutrient management (Öborn et al., 2003). However, they are only an indirect indication of nutrient losses in the agro-ecosystem (Oenema et al., 2003), and seldom allow the determination of nutrient loads at the field level. Knowledge of nutrient loads at the field level will be needed in the implementation of the Total Maximum Daily Loads legislation (Federal Clean Water Act Section 303 d. (U.S. Congress, 1977)).

The direct approaches to measuring load at the field level are resin traps, leachate lysimeters, or soil sampling (Table 2-1). The essential components of resin traps are the ion exchange resins used to create nutrient filters, and the soil core (usually PVC pipes filled with soil) inside which the resins are buried (such as A400 anion exchange resin or C100 cation exchange resin, Purolite Co., Bala Cynwyd, Pa.; Balkcom et al., 2001). Before starting the monitoring of nutrient leaching, resin traps are buried in the soil below the crop root zone. As water flows through the soil layer and the soil cores containing the resin trap, leached nutrients are intercepted by ion exchange. After resin trap retrieval, nutrients are extracted and quantified. This method provides nutrient quantity intercepted by the surface of the resin trap which can be extrapolated to field size. The two main types of leachate lysimeters are suction cup lysimeters and drainage lysimeters (Abdou and Flury, 2004). Suction cup lysimeters consist of a porous ceramic tip connected to an air-tight buried chamber that is accessible through two sealed tubes. Suction cup lysimeters are installed below the crop root zone, usually between the 19.7 inch and 59.1 inch depths. Lysimeter operation generally consists of two steps. First, a soil-water sample is collected by creating a 5.8 to 7.3 PSI vacuum inside the chamber with a hand-held pump. Water moves from the soil into the chamber through the porous cup because of the difference in pressures. After approximately 24 hrs, samples are retrieved using a vacuum pump (Webster et al., 1993). The leachate collected from these lysimeters is from the soil surrounding the porous ceramic tip, but the exact volume of soil it is collected from is unknown. Hence, this technique only gives the concentration of nutrients in solution and cannot be used alone to calculate a nutrient load. Further knowledge of the actual volume of soil the water is collected from needs to be gained. In contrast to suction cup lysimeters, drainage lysimeters collect leachate from macropore flow or when the soil above the lysimeter becomes saturated or exceeds the field capacity (Zhu et al., 2002). These lysimeters consist of two main components, a collection container and a storage container. The collection container is any container filled with soil, and the storage container holds the leachate water from the collection container. Drainage lysimeters are installed below the crop root zone by digging holes in the ground. The storage container is installed below the collection container such that the water collected inside the collection container flows into the storage container by gravity (Migliaccio et al., 2006), and the leachate that is collected inside the storage container is retrieved with a pump. Drainage lysimeters allow the measurement of both concentration and volume of nutrients being leached and thus can be used for load calculation at the field level. For leachate samples, load is calculated by multiplying nutrient concentration in each sub-sample (mg/L) by the volume of leachate collected, by the collection container volume (feet^3, Width × Length × Depth), and by a correction factor for unit homogeneity. Currently, there are no standard guidelines for the dimensions of the drainage lysimeter collection container, the fill inside the collection container (which also enhance collection efficiency), and the capacity of the storage container. Hence, generally cultural practices and availability of materials have dictated the design of a drainage lysimeter. Consequently, it is often difficult to separate treatment effects (cultural practices) from lysimeter effects in many research reports.

Ideally, a drainage lysimeter should have an optimum collection area where the collection container collects leachate from the entire root zone below crop root system being tested, and should account for plant to plant and emitter to emitter variability (in case of drip irrigation). Leachate collection efficiency may be calculated by dividing total leachate volume collected by total water applied for that time period (Zhu et al., 2002), and factors that may improve collection efficiency are the size of the collection container, and the presence of a wick. Previous work done with large plate lysimeters has shown that collection containers with collection surfaces of 0.17, 0.54 to 2.16 feet^2 had increased collection efficiencies from 10%, 13%, to 26%-36%, respectively (Radulovitch and Sollins, 1987). In a study comparing zero-tension (leachate collected by free drainage) pan lysimeters and wick lysimeters installed at a depth of 51.2 inches below the soil surface (silt loam soil type), wick lysimeters collected 2.7 times more leachate than drainage lysimeters did, thereby increasing efficiency. The higher efficiency was attributed to the breaking of soil water tension by the wick (Zhu et al., 2002).

Frequency of leachate collection and storage of leachate samples are two other factors that may affect load measurement. According to David and Gertner (1987) the leachate collected in the storage container should be retrieved at frequent intervals, multiple times a week, to minimize variability in within site nutrient concentration measurements and prevent changes in the chemical composition of the leachate. Significant increases in NH_4-N concentrations were reported at 68°F due to mineralization reactions, and significant increases in NO_3-N concentrations were seen at -4°F and acidic pH due to oxidation of NO_2^- (Clough et al., 2001). If leachate samples are being stored before analysis, the optimum storage conditions are at 39.2°F without acidification. These conditions minimize transformations of NO_2^- to NO_3^-, and minimize overestimation of NO_3^- concentrations (Clough et al., 2001).

Soil sampling is another method for direct load measurement. Typically, a soil sample used for load determination consists of a 5-feet deep soil core divided into five subsamples, each 1-foot long. A known amount of distilled water is added to the sample to saturate it. After thorough mixing of the sample, chemical extraction or analysis is performed. Generally, the NH_4-N and NO_3-N concentrations in soil samples are determined using modified EPA method 350.1 and EPA method 353.2 respectively (USEPA, 1993). The chemical concentrations are then converted to original field water content basis (Ahmed et al., 2001). Nutrient load is then calculated by multiplying nutrient concentration in each sub-sample (mg/kg soil) by the wetted soil volume (feet^3, Width × Length × Depth), by soil bulk density (assumed to be homogenous), and by a correction factor for unit homogeneity. The bulk density of soils can be measured in the laboratory (USDA, 2004), or soil bulk density estimates may be found in soil survey reports published by the Natural Resources Conservation Service (USDA-NRCS, 2008). The length (total L of mulched bed per unit area) and depth (length of the soil sub-sample) of the wetted soil volume are well known. However, width estimates of the wetted soil volume are not well known and may vary with the irrigation program and soil type. Moreover, factors which affect the volume of the wetted zone, such as soil physical properties and their spatial variability, initial moisture content, width of raised plant bed, and irrigation length (Clark and Smajstrla, 1993; Santos et al., 2003; Simonne et al., 2005; Simonne et al., 2006) also affect the width of wetted zone. Farneselli et al. (2008) reported estimates of mean (28.7, 23.6, 18.5, 13.4, and 8.3 inches for the 5.9, 18.1, 29.9, 42.1 and 53.9 inch depths, respectively), and maximum (40.9, 33.1, 25.2, 17.3, and 9.8 inches for 1-foot depth increments) wetted widths that can be used for calculating mean and maximum nutrient loads from raised plant beds. However, their results were based on a single irrigation event without a crop, and depending on either the mean, bed or maximum wetted width, could result in nutrient load from 19-35 lb/acre. On the other hand, as there are no reported estimates of actual in-field wetted widths for different crop species, the mean and maximum wetted width estimates reported by Farneselli et al. (2008), and the bed width of the raised plant bed are currently the best estimates of wetted widths in Florida sandy soils.

A great number of similarities exist in the methods and sampling procedures used for collecting or monitoring nutrient concentrations. Also, the construction design of lysimeters, and the methodology of soil sampling procedures are explained in great detail. However, when nutrient concentrations are converted from mg/kg (for soil sampling) and mg/L (for lysimeters) to nutrient loads on a per-acre basis (aerial, or cropped), most articles do not give a detailed methodology of load calculation (Abad et al., 2004; Aparicio et al., 2008; Daudèn and Quílez, 2004; Lecompte et al., 2008; Macaigne et al., 2008; Oikeh et al., 2003; Poudel et al., 2002; Ramos et al., 2002; Rajput and Patel, 2006; Sainju et al., 1999; Vázquez et al., 2006; Yaffa et al., 2000; Zotarelli et al., 2008; Zvomuya et al., 2003).

With soil sampling as a method to monitor nutrient leaching, several reports do not convert the NO_3-N concentration in the soil samples to NO_3-N load on per-acre basis (Daudèn and

Quílez, 2004; Macaigne et al., 2008; Poudel et al., 2002; Rajput and Patel, 2006; Yaffa et al., 2000). While some of the reports that measure NO_3-N load with soil sampling on per-unit area basis mention both the NO_3-N analytical procedure and the soil bulk density values (Halvorson et al., 2002; Zvomuya et al., 2003), some mention just the NO_3-N analytical procedure used (Abad et al., 2004; Sainju et al., 1999), and others mention neither the NO_3-N analytical procedure used nor the soil bulk density values (Oikeh et al., 2003). For NO_3-N load calculated using drainage lysimeters, while Syvertsen and Jifon (2001) gave the dimensions of the lysimeters used, they failed to report the NO_3-N analytical procedure and reported their results as NO_3-N concentration/lysimeter rather than NO_3-N load on per-unit area basis. For bell pepper production on plasticulture system, Romic et al. (2003) on the other hand reported NO_3-N load measured with drainage lysimeters on per-unit area basis. However they failed to mention whether the NO_3-N load values reported are on a cropped or aerial area basis.

With suction cup lysimeters (SCL), where drainage cannot be estimated directly assumptions are made that the volume of water retrieved by applying a vacuum is equivalent to the drainage water volume. Aparicio et al. (2008) calculated NO_3-N losses with the following equation, $NL = DC/100$, where NL is the NO_3-N losses at various soil depths, D is drainage water estimated using the LEACH-W model, and C is the NO_3-N concentration (analytical method not mentioned) in the soil solution extracted with the SCL. Vázquez et al. (2006), Zhu et al. (2005), and Zvomuya et al. (2003) on the other hand estimated NO_3-N losses from each sampling interval as the product of NO_3-N concentration in the soil solution and the amount of drainage. Vázquez et al. (2006) and Zvomuya et al. (2003) calculated drainage with the following equation, $D = P+I-\Delta S-E$, where D is the amount of daily drainage, P is the precipitation, I is the irrigation water applied, ΔS is the change in soil water storage between consecutive days, and E is the evapotranspiration. However, Zhu et al. (2005) measured drainage directly using modified lysimeters. The three publications also varied in their methodology for analyzing NO_3-N concentrations. While Vázquez et al. (2006) estimated NO_3-N concentration in the soil solution samples spectrophotometrically after reduction in cadmium solution (Keeney and Nelson, 1982), Zhu et al. (2005) estimated NO_3-N concentration in the soil solution samples colorimetrically with the Bran and Luebbe Model TRAACS 2000 continuous-flow analyzer. On the other hand Zvomuya et al. (2003) used the diffusion-conductivity method (Carlson et al., 1990) to estimate NO_3-N concentration in the soil solution samples. As mentioned earlier, with suction cup lysimeters drainage cannot be measured directly.

Factors Affecting Nutrient Load

Nutrient load or leaching is influenced by several natural and cultural factors. Some of the natural factors are climate, hydrology, soil characteristics, and topography, and some of the cultural factors are tillage, mulching, fertilization (type of fertilizer, rate, placement, and timing of application) and irrigation (quantity, rate, frequency, and method of application) management.

Factors that affect nutrient load or leaching (natural and cultural factors) also affect the variations in N leaching. Climatic conditions and fertilization affected variations in NO_3-N leaching by ±65%, crop rotations by ±20-25% (Krysanova and Haberlandt, 2002), fertilizer inputs alone affected variations in NO_3-N leaching by ±40% (Mertens and Huwe, 2002), and agricultural land management affected variations in N leaching by ±48% (Schmidt et al., 2008). Hengsdijk and van Ittersum (2001) showed the uncertainties associated with future modeling of NO_3-N leaching losses as functions of crop characteristics, yield levels, and crop residue-nitrogen to be -36% and +70%, -30% and +40%, and -64% and +67%, respectively. A study done by David and Gertner (1987) to identify the sources of variation in soil solution collected by tension plate lysimeters, found that the CV for volume of leachate and NO_3-N concentration measured during the study was 122% and 218% respectively. Moreover, they found that the variability in volume and NO_3-N concentration recorded within a site, soil horizon, and pit, over each period of time accounted for 18% and 15% of total variability, the variability in volume and NO_3-N concentration within a period of time re-measurement accounted for 55% and 32% of the total variability, and variation in pits within a site accounted for 50% of the total variability for NO_3-N concentration. Hansen et al. (1999) found that variability in agricultural land management resulted in CV ranging from 20% to 40%. Due to variability in N-load results with location, cropping system, and soil type site specific in-field load estimates are the best predictors of total-N load. However, very few estimates of nutrient load from agricultural production are available in Florida (Table 2-2). Moreover, as previously mentioned, the information on in-field nutrient load lacks consistency in method of measurement, and there is no mention of the wetted width used in conversion of nutrient concentrations from soil and leachate samples into nutrient load on a per-hectare basis.

Conclusion and Objectives

Extensive research has been done to determine the fertilizer and irrigation requirements of drip-irrigated plastic mulched tomatoes, and detailed methodology and research work is available for determination of nutrient load from different vegetables. However, due to variability in N-leaching results with location, cropping system, and soil type, site specific in-field load estimates are the best predictors of total-N leaching. Currently, very few estimates of nutrient load from agricultural production are available in Florida, and the research information on in-field nutrient load lack consistency in method of measurement. Moreover, there are no research reports on the economic impact of the fertilizer and irrigation BMP’s on fresh market tomato production.

Therefore, to better understand the impact of irrigation and nutrient management practices on fresh market tomato production, by using an integrated fertilization/irrigation approach, a series of experiments were conducted simultaneously with selected irrigation-nutrient management programs. The goal of these experiments was to determine if BMPs (UF/IFAS recommendations) can minimize the negative impact of vegetable production (fertilizer losses and inefficient irrigation) on the environment while maintaining or improving current yields and crop value of an economically important vegetable crop - fresh market tomatoes (*Solanum lycopersicum* L.). The specific objectives of this study were to

- Determine the effects of the irrigation and nutrient management programs on moisture levels in tomato beds, on plant nutritional status (NO_3^--N and K^+), and fresh market tomato production (Chapter 3).
- Determine the combined and individual effects of irrigation and nutrient management programs on tomato seasonal total-N load and soil-profile total-N load as measured with drainage lysimeters and with soil sampling, and determine the relationship between seasonal total-N load and soil-profile total-N load measured with soil sampling and with drainage lysimeters (Chapter 4).
- Determine the economical impact of irrigation-nutrient management programs on tomato crop yields (Chapter 5).

Table 2-1. Advantages and limitations of different procedures used for measuring nutrient loads.

	Resin Traps	Soil Sampling	Suction Cup Lysimeters	Drainage Lysimeters
Advantages	Small structures Easy to install and simple to build Require minimal labor for collecting samples	Not space bound Simple procedure	Permanent structures Easy to install and simple to build Require minimal labor for collecting samples	Permanent structures Simple to build Require minimal labor for collecting samples Give both concentration and volume
Limitations	Space bound Capture lower volumes of leachate than actual - underestimate load Need to be installed every season	Gives only concentration and not volume Require intensive labor for collecting samples Leaves hole in ground	Space bound Gives only concentration and not volume Protracted sampling time Interfere with tillage	Space bound Lack universal design Hard to install Disturb soil profile Might interfere with tillage Require constant maintenance

Table 2-2. Published estimates of nitrogen (nitrate, ammonium and total N) leaching in selected crops.

Crop	Soil Type	Location	Method[z]	Estimate	Original Unit	Standardized N Load Estimate[t] (lb/acre)	Reference
Artichoke	Loam[y]	Spain	SS	287-406 NO_3-N	kg/ha	256-363	Ramos et al., 2002
Carrot	Loamy sand	California	RT	0.97 NO_3-N	mg/kg of soil	0.87	Allaire-Leung et al., 2001
				0.26 NH_4-N		0.23	
Cauliflower	Loam[y]	Spain	SS	168-272 NO_3-N	kg/ha	150-243	Ramos et al., 2002
Corn	Silt Loam	Argentina	SCL[x]	0-94 NO_3-N	kg/ha	0-84	Aparicio et at., 2008
Corn	Silt Loam-Loam	California	SS	14-62 mineral-N[u]	mg/kg of soil	19-83	Poudel et al., 2002
Corn	Fine loamy	Nigeria	SS	13-114 mineral-N	kg/ha	12-102	Oikeh et al., 2003
Corn	Silty Clay Loam	Spain	SS	1-14 NO_3-N	mg/kg of soil	1.3-19	Daudèn & Quílez, 2004
Corn	Sandy	Washington	M	3-28 NO_3-N	kg/ha	3-25	Peralta and Stockle, 2001
Onion	Clay Loam	Colorado	SS	25-286 NO_3-N	kg/ha	22-255	Halvorson et al., 2002
Onion	Sandy Loam	India	SS	25-95 NO_3-N	mg/kg of soil	34-127	Rajput and Patel, 2006
Onion	Loam[y]	Spain	SS	198-474 NO_3-N	kg/ha	177-423	Ramos et al., 2002
Orange	Fine Sand	Florida	DL	174-252 mineral-N	g/lysimeter	NE[s]	Syvertsen and Jifon, 2001
Potato	Loamy Sand	Minnesota	SS	20-58 mineral-N	kg/ha	18-52	Zvomuya et al., 2003
			SCL	4-228 NO_3-N	kg/ha	4-204	
Potato	Loamy Sand	Canada	SS	8-120 NO_3-N	mg/kg	11-161	Macaigne et al., 2008
Potato	Loam[y]	Spain	SS	60-308 NO_3-N	kg/ha	54-275	Ramos et al., 2002
Potato	Sandy	Washington	M	3-69 NO_3-N	kg/ha	3-62	Peralta and Stockle, 2001
Tomato[w]	Silt Loam-Loam	California	SS	26-42 mineral-N	mg/kg of soil	35-56	Poudel et al., 2002
Tomato[w]	Calcareous	Spain	SCL	155-421 NO_3-N	kg/ha	138-376	Vázquez et al., 2006
Tomato	Sandy Loam	France	SS	50-800	mg/L	NE	Lecompte et al., 2008
Tomato	Sandy Loam	Georgia	SS	10-110 mineral-N	mg/kg of soil	13-147	Yaffa et al., 2000
Tomato	Sandy Loam	Georgia	SS	7-250 NO_3-N	kg/ha	6-223	Sainju et al., 1999
Tomato	Sand	Florida	SS	5-30 NO_3-N	kg/ha	4.5-27	Zotarelli et al., 2007
			DL	5-37 NO_3-N	kg/ha	4.5-33	
			SCL	3-4 NO_3-N	kg/ha	2.7-3.6	
Bell Pepper	Gleysol hydroameliorated	Croatia	DL	1-16 NO_3-N	kg/ha	0.9-14	Romic et al., 2003

Table 2-1. Continued

Crop	Soil Type	Location	Method	Estimate	Original Unit	Standardized N Load Estimate[t] (lb/acre)	Reference
Bell Pepper	Sand	Florida	SS	9-38 NO_3-N	kg/ha	8-34	Zotarelli et al., 2007
			DL	6-37 NO_3-N	kg/ha	5-33	
			SCL	2-21 NO_3-N	kg/ha	1.8-19	
Hot Pepper	Sandy Loam	China	SCL	17-54 NO_3-N	g/m^2	NE	Zhu et al., 2005
Wheat	Loam	Spain	SS	54-1211 NO_3-N	kg/ha	48-1081	Abad et al., 2004
Zucchini	Sand	Florida	SS	21-34 NO_3-N	kg/ha	19-30	Zotarelli et al., 2007
			DL	20-26 NO_3-N	kg/ha	18-23	
			SCL	11-15 NO_3-N	kg/ha	10-13	
Zucchini	Sand	Florida	SCL[v]	2-45 NO_3-N	kg/ha	1.8-40	Zotarelli et al., 2008

[z] SS - Soil Sampling, RT - Resin Traps, SCL - Suction Cup Lysimeters, M - Modeling with CropSyst, DL Drainage Lysimeters

[y] Loam, sandy loam, clayey loam

[x] Drainage estimated with LEACH_W model

[w] Processing tomato

[v] Water collected by drainage into container

[u] Mineral nitrogen (NO_3^--N+NH_4^+-N)

[t] N load estimates calculated based on 2-feet bed width and 1450 lb/feet^3 soil bulk density.

[s] NE: Not estimable based on information in original report.

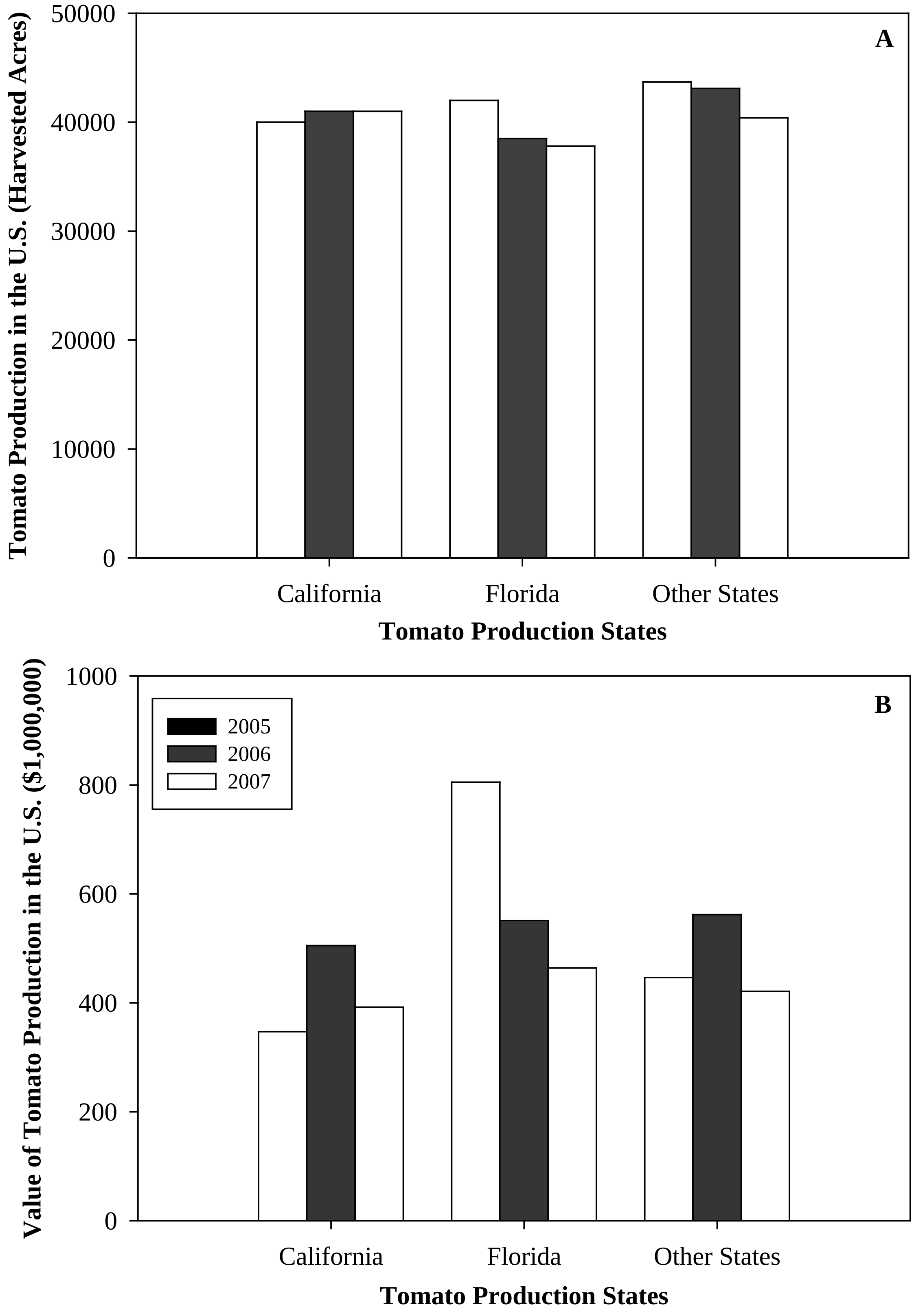


Figure 2-1. Fresh market tomato production in the United States A) harvested area, and B) value of production in $1,000,000.

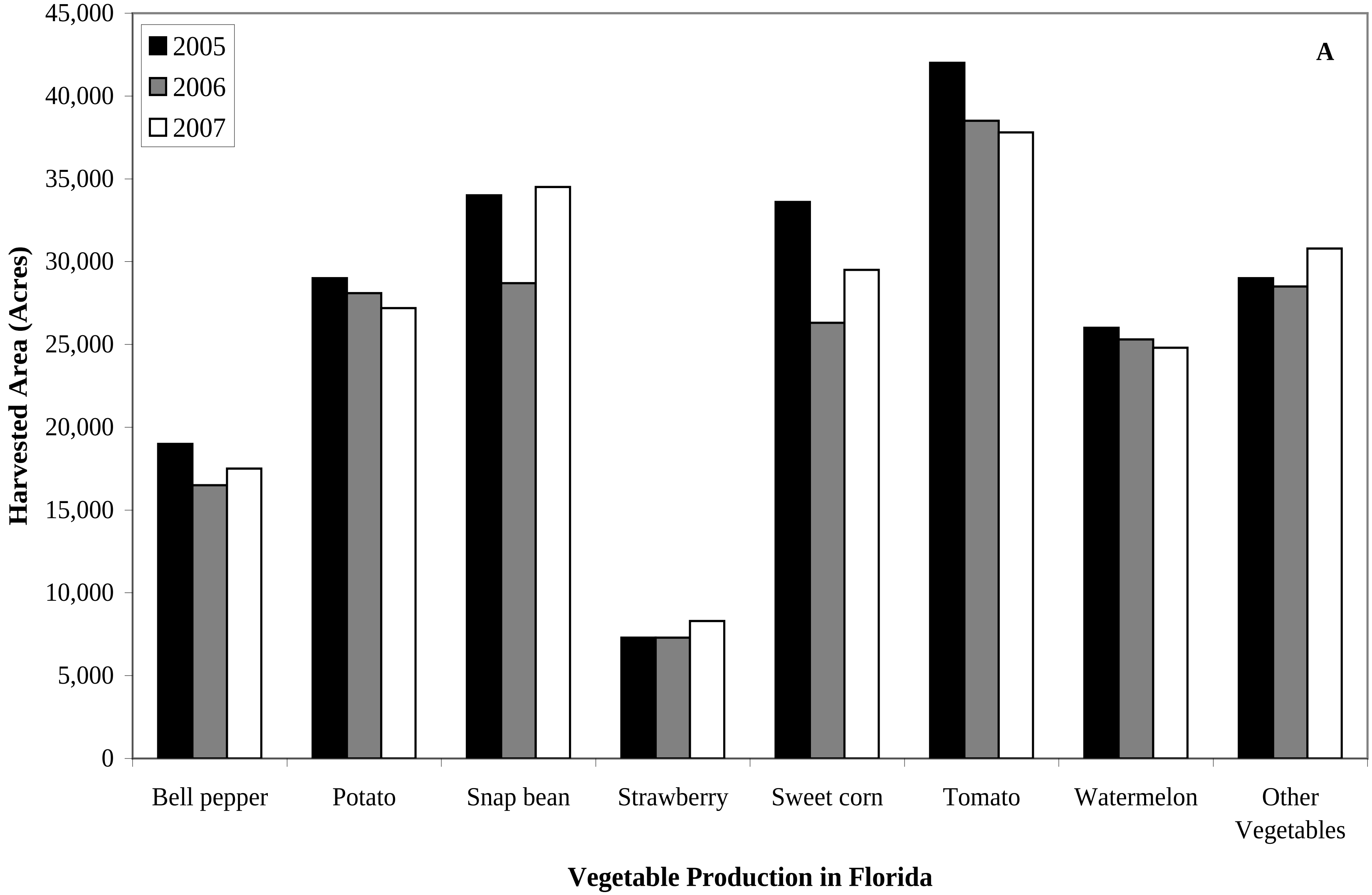


Figure 2-2. Vegetable production in Florida A) harvested area, and B) value of production ($1,000,000).

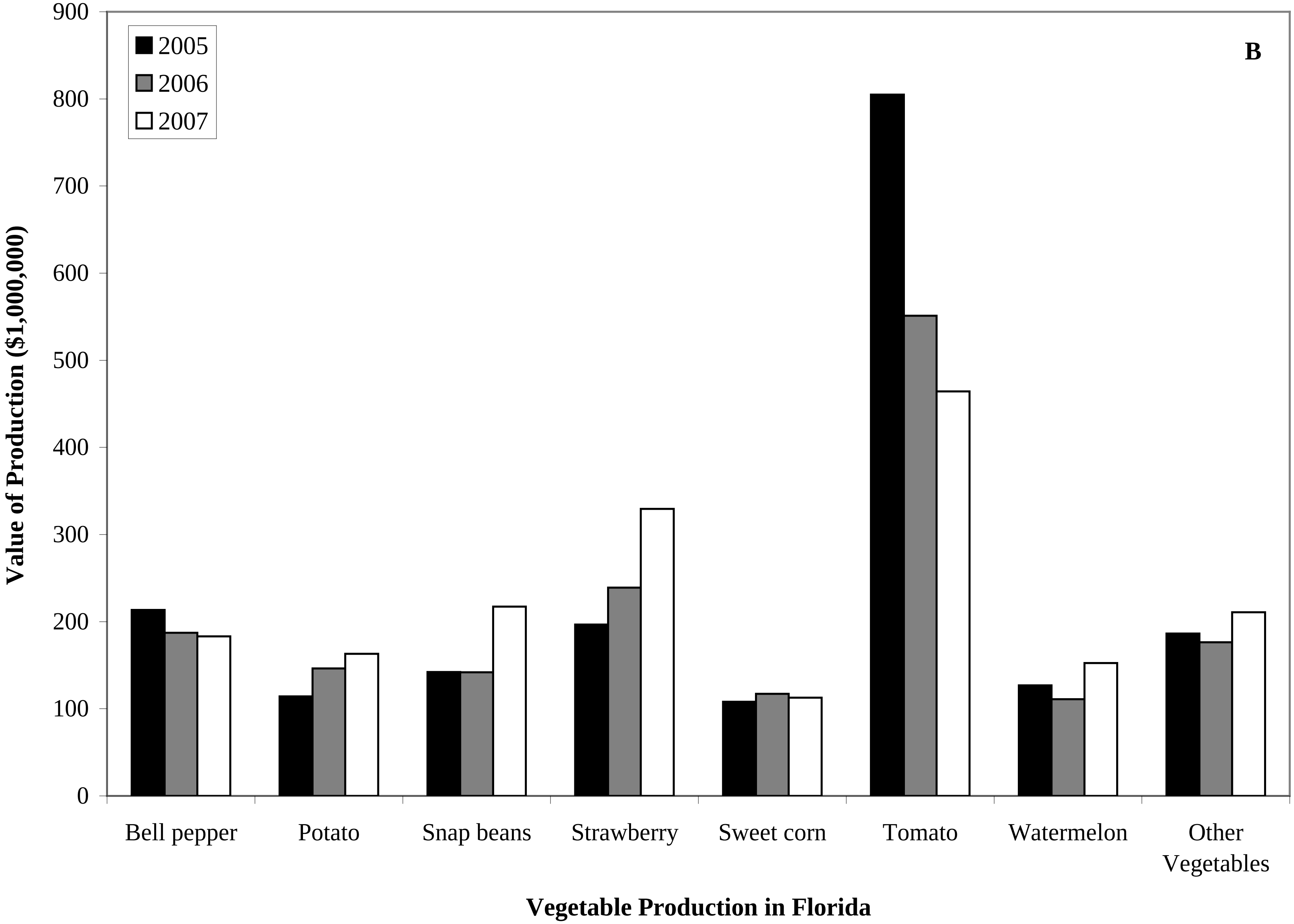


Figure 2-2. Continued

CHAPTER 3
NUTRIENT MANAGEMENT PROGRAMS FOR FRESH MARKET TOMATOES GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES. I. SOIL MOISTURE, PLANT NUTRITIONAL STATUS, AND YIELD DISTRIBUTION

Introduction

Tomato (*Solanum lycopersicum* L.) production in Florida accounts for approximately 39% of the national fresh market tomato production, and has an annual value of approximately \$464 million (USDA-NASS, 2008). In North Florida, fresh market tomatoes are typically grown as a spring crop with raised beds, black plastic mulch, drip irrigation, and greenhouse-grown transplants (Olson et al., 2007). Moreover, the fruit are harvested 2-4 times at the mature green stage to ensure highest quality (Sargent et al., 2005). Extensive research has been done to determine the fertilizer and irrigation requirements of drip-irrigated plastic mulched tomatoes. Placement, application scheduling, rate, and source, of N and K fertilizers are also known to affect fresh market tomato yields and quality. Csizinsky (1979) reported significantly higher tomato yields when placement of fertilizers was banded than broadcasted. However, the reports on effects of placement of fertilizers on tomato yields are highly variable. In a study done by Cook and Sanders, (1990), broadcast or banded placement of fertilizers had no effect on tomato fruit size, number or total yields. In a similar study done on fine sandy soils, the placement of fertilizer had no effect on marketable yields at one location. However, at the second location banded placement of fertilizers resulted in significantly higher marketable yields (Persaud et al., 1976). With drip irrigation on sandy soils, the highest tomato yields were obtained with part of N-K fertilizers applied at preplant and the remaining through fertigation (Dangler and Locascio, 1990; Locascio and Myers, 1975). Further work done by Locascio et al., (1985; 1989; 1997a) on application scheduling effects on N-K fertilizers on tomato yields showed that the response varied with the soil type. On fine sandy soils, total early market yields, and total marketable tomato yields were highest with N-K applied 40% at preplant and 60% by fertigation, while on fine sandy loam and loamy fine sand soil types split application of N-K fertilizers had no affect on tomato fruit yields. Mean yield increased linearly with an increase in N-K rate (Persaud et al., 1976).Optimal rate of K for maximum tomato yields with drip irrigation and preplant broadcast application was in the range of 62.25-124.5 lb/acre.

Crop water requirements may be determined based on U.S. Weather Service Class A pan evaporation. Fresh market tomato yields were significantly higher with irrigation volumes of 0.75 and 1.0 times pan evaporation than with higher irrigation volumes of 2.0 times pan evaporation and significantly lower with irrigation volumes lower than 0.25 and 0.50 1.0 times pan evaporation (Locascio et al., 1981; Locascio and Smajstrla, 1996). However, the effect of irrigation rate varied with rainfall during the season, and also with soil type. Fruit yields were significantly higher with irrigation during extremely dry seasons, while in extremely wet seasons, irrigation had no effect on fruit yield (Locascio et al., 1996). On coarse textured soils tomato yields were higher with 0.5 than with 1.0 times pan evaporation, and maximum yields were recorded at 0.75 times pan evaporation (Locascio and Smajstrla, 1989). On the other hand, on fine textured soils, yields were the same with 0.5 and 1.0 times pan evaporation (Locascio et al., 1989; Olson and Rhoads, 1992). The rate of water application (0.5-2.0 gallons/hr water applied/emitter) had no effect on tomato plant growth and yield. Increased frequency and reduced duration of daily irrigation resulted in increased tomato yields (Csizinsky and Overman, 1979). However, under similar conditions, increasing the frequency of irrigation had no effect on total tomato yields (Locascio et al., 1985).

Based on research and soil testing, fertilizer recommendations for tomato production have been established in several states in the United States. The current base fertilization recommendations for tomato production in Florida on soils testing very low in Melich-1 P and K are 66 and 187 lb/acre of P and K, and for nitrogen the fertilization recommendation based on research and crop nutrient requirement is 200 lb/acre nitrogen (N), and includes a detailed fertigation schedule. A supplemental application of 30 and 17 lb/acre of N and K fertilizer is recommended after a leaching rain (3 inches of rainfall in 3 days or 4 inches in 7 days) event (Olson et al., 2007). For irrigation management the it is recommended to have a target water volume (gallons/100 ft/day), to adjust irrigation water volume based on weather and plant age, to fine tune schedule by monitoring soil moisture levels, to know how much water the root zone can store, to know the role of rain in supplying water to the vegetable crop, and to keep records (Simonne et al., 2007).

The poultry industry in the U.S. has an annual value of $32 billion, and the poultry industry in Florida has an annual value of $270 million (USDA-NASS, 2008). The major production areas are located in the south-eastern United States (Alabama, Arkansas, Georgia, Mississippi, North Carolina, and Virginia). The annual market weight of poultry production in the U.S. is approximately 58 billion pounds (USDA-NASS, 2008) which in-turn yields 29 - 41 billion pounds of poultry litter (Mitchell and Donald, 1999). Poultry litter which comprises bird feces, bedding material, feathers, and remains of feed, is not only a good source of the plant macro nutrients N, P, K, calcium, magnesium, and sulfur, but is also a source of some of the micro nutrients like boron, copper, iron, manganese, and zinc (Mitchell and Donald, 1999). The N-P-K ratios in poultry litter vary from region to region and also with the type of litter. Based on the reported N-P-K ratios, N ranged from 1.3-6%, P 1.1-3%, and K 1-2 % in layer litter (Mitchell and Donald, 1999; Nicholson et al., 1996), and N ranged from 3-6%, P 2-3%, and K 2-3% for broiler/turkey litter (Mitchell and Donald, 1999; Nicholson et al., 1996; Stephenson et al., 1990).

Poultry litter can be transported cost effectively up to a distance of 164 miles from the production facility (Paudel et al., 2004). With the increasing cost of inorganic fertilizers, poultry litter can be used as a viable alternative fertilizer source by agricultural enterprises within the 164-mile radius. Higher (20 to 36%) tomato fruit yields have been obtained with chicken litter (CL) than with inorganic fertilizers (Brown et al., 1995; Togun and Akanbi, 2003). Moreover, tomatoes grown with CL had earlier fruit set and development, and larger fruit size than those grown with inorganic fertilizers (Brown et al., 1995). Studies have also shown that CL (75%) along with inorganic fertilizers (25%) resulted in higher yields than CL or inorganic fertilizer alone (Ramadan, 2007). At the same time, work done by Ghorbani et al., (2008) showed no significant difference in tomato fruit yields when grown with CL or with inorganic fertilizers. However, they reported lower disease incidence and higher marketable yields after 6 weeks in storage with CL (14,288 lb/acre) than with inorganic fertilizer (6,251 lb/acre). Previous work done by Studstill et al. (2006), on the viability of CL as a preplant fertilizer in muskmelon production, found that depending on the muskmelon cultivar, total marketable yields may be increased by 15%. However, CL had no effect on muskmelon early marketable yields. Besides its use as a fertilizer source, studies have also shown that CL (Kaplan and Noe, 1993; Riegel et al., 1996) and CL combined with soil solarization suppress root knot nematodes (*Meloidogyne arenaria* and *incognita*) (Kaskavalc, 2007; Stevens et al., 2003). Growers generally apply poultry litter at rates that supply the crop's entire N requirement, resulting in over-application of either P or K. Most of the soils in Florida have high P levels and crops often do not respond to P application (Carrijo and Hochmuth, 2000; Hochmuth et al., 1993a, 1993b; Locascio et al., 1996; Rhoads et al., 1990; Rhue and Everett, 1987; Shuler and Hochmuth, 1995). However, for soils testing very-low, low, and medium in Melich-1 P, the current Univ. of Florida/IFAS Extension

Service (IFAS) recommendations for P fertilization is broadcast application of all P in the at preplant (Olson et al., 2007). Therefore, there is considerable potential for CL as a preplant fertilizer source to supply only part of the N requirement, and no more than the 22 lb/acre of P as starter amount.

Given the low water holding capacity of Florida's coarse textured soils the drip-irrigating fresh market tomato growers oftentimes over-irrigate to maintain adequate moisture levels within the plant root zone. N-P-K fertilizers are highly water soluble, and as growers mismanage the irrigation water application, they generally tend to over-fertigate to compensate the loss of nutrients from the plant root zone. With the adoption of the Federal Clean Water Act (FCWA) of 1977 (US Congress, 1977), states are required to assess the impact of non point sources of pollution on surface and ground waters, and establish programs to minimize them. Section 303(d) of the FCWA also requires states to identify impaired water bodies and establish Total Maximum Daily Loads (TMDLs) for pollutants entering into these water bodies (FDACS, 2005; Gazula et al., 2007). The TMDLs are implemented through Best Management Practices (BMPs). As a result there has been an increased educational effort to encourage growers to follow the IFAS recommendations for irrigation and fertilizer applications.

Therefore, the objectives of this study were to 1) determine the effect of irrigation rate on moisture levels in the tomato beds, 2) determine the effect of the irrigation-nutrient management programs on plant nutritional status (NO_3^--N and K^+), 3) determine the effect of CL used as a preplant fertilizer source on fresh market tomato yield, and 4) assess the combined and individual effects of irrigation-nutrient management programs on marketable fresh market tomato yield.

Materials and Methods

A two-year experiment was conducted at the North Florida Research and Education Center-Suwannee Valley in Live Oak, Fla. on Blanton-Foxwort-Alpin Complex soil series (Weatherspoon, 2006) during 2005 and 2006. Similar cultural practices were followed during both years. Drainage lysimeters were installed at 2-feet depth in March, 2004 under the raised plant beds for all irrigation-nutrient management programs to monitor nutrient leaching from all treatments (results reported in Chapter 4). Preliminary data collected from the lysimeters in 2004 had high CV, therefore a modified drainage lysimeter design was added prior to the start of the experiment in March, 2005.

Experimental Setup

A winter rye (*Secale cereale* L.) crop was planted in the fall of both 2004 and 2005 at the rate 50 lbs of seed/acre. The winter rye crop was roto-tilled two weeks before field preparation. The field was prepared by disking and plowing the soil, after which the beds were tracked in the soil. Preplant fertilizer treatments CL and 13-1.8-10.8 (standard fertilizer blend) at the rate of 50 and 41.5 lbs of N-K/acre (50% of the total N in the CL is available the first year to supply 30% of the N recommended rate preplant were applied as the source preplant fertilizers at bed preparation to the respective treatments. The CL had a N-P-K analysis of 1.25-1.12-1.66 and 1.25-1.5-1.91 respectively in 2005 and 2006 respectively. CL was applied to the same plots each year. The field was then bedded (with 6-ft centers), fumigated with methyl bromide, and then drip tape was laid followed by black plastic mulch. Separate drip tapes were installed for the irrigation and nutrient management programs. The irrigation and fertigation system was installed after 14 days of field preparation. The main irrigation and fertigation line ran through the middle of the field and at the head of all plots. Each experimental plot (unit) consisted of three one hundred and fifty foot-long raised plasticulture beds formed on 6-ft centers. The large plot size was chosen for implementation of the current trial, to test for leaching of nutrients with drainage lysimeters (data reported separately), and to represent grower field conditions. On April 8th, 2005 and April 5th, 2006 6-week old (Days After Transplanting (DAT) = 0) 'Florida 47' transplants were transplanted onto the plasticulture system with a 18-in within row spacing, and establishing plant a population of 5,808 plants/acre.

The irrigation-nutrient management programs were a combination of source of preplant fertilizer, fertilizer rate, and irrigation rate (Table 3-1). The current IFAS recommendation for N and K for commercial tomato production was used as the 100% fertigation rate and twice that amount for the 200% fertigation rate. Split application of fertilizer treatments through the drip tape was done weekly throughout the growing season.

The standard flow rate used by growers in the area was used for supplying the irrigation. The 100% and 300% irrigation rate was achieved by installing one and three drip tapes to the respective experimental plots (24 gph/100-ft/hr at 12 psi, (12-in emitter spacing; John Deere Water Technologies, San Marcos, CA)). Separate drip tapes were also installed for fertigation. For the 100% and 200% fertigation rate one and two drip tapes were installed respectively. Based on the irrigation-nutrient management program, the total number of drip tapes in each program ranged from 2 to 5. Based on the volume of water applied, daily irrigation was applied either as a single application or split application (two times per day). For the 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 200% Fertigation-100% Irrigation irrigation-nutrient management programs which received 100% irrigation rate, the total amount of irrigation water applied per acre was 439,085 gallons or 16.17 acre-inches. For the 100% Fertigation-300% Irrigation, 200% Fertigation-300% Irrigation, and 200% Fertigation-300% Irrigation-ML irrigation-nutrient management programs which received 300% irrigation rate, the total amount of irrigation water applied per acre was 1,317,254 gallons or 48.51 acre-inches. As fertigation and irrigation were applied either on a weekly or daily basis, the amount of fertilizer or water to be applied at any given time tends to have very narrow differences between them with narrow differences in rate treatments. Therefore, for this experiment we chose the standard IFAS rate and much higher rates of fertilizer and irrigation management to ensure that even with the split application of the treatments there would still be a large difference within them on a daily basis. The detailed fertigation and irrigation schedule for the different irrigation-nutrient management programs are shown in Figures 3-1 and 3-2. Current recommendations for commercial tomato production for pest and disease control and all other production practices were followed (Olson et al., 2007).

Data Collection

Irrigation volume data: Two water meters were installed on the sub-main irrigation lines which combined to form the main irrigation line running through the middle of the experimental field. Water meters were read weekly to calculate amount of water applied and to monitor the water flow rate in the main irrigation lines.

Soil moisture data: Soil volumetric water content (VWC) was monitored weekly at 8:00 a.m. before the first daily irrigation cycle for a total of ten sampling times during the entire crop growth cycle, using Time Domain Reflectometry (TDR) moisture probes (Hydrosense; Campbell Scientific, Logan, UT). Readings were taken at 6 inches from the drip tape on the opposite side of the tomato plants from the three rows of each experimental unit. The sampling dates were 6, 13, 20, 28, 34, 41, 48, 55, 62, and 69 DAT in 2005, and 22, 29, 36, 44, 49, 57, 63, 71, 78, and 85 DAT in 2006. Based on the plant growth stage the sampling days were categorized as vegetative and reproductive stages, which corresponded to the plant growth stage before and after flowering respectively. In 2005, four VWC readings were taken during the vegetative stage (14, 21, 28

April and 6 May), and six VWC readings were taken during the reproductive stage (12, 19, 26 May and 2, 9, 16 June). In 2006, two VWC readings were taken during the vegetative stage (27 April, 3 May), and seven VWC readings were taken during the reproductive stage (18, 23, 31 May and 6, 14, 21, 28 June). Based on soil moisture release curve for sandy soils, soil moisture levels were classified as very dry if the VWC readings taken were 0-4%, dry 5-8%, optimum 9-12%, and too wet when >13%.

Petiole sap data: Plant nutritional status was monitored with petiole fresh sap analysis three times for both years (4, 7, 9 WAT in 2005, and 5, 9, 11 WAT in 2006). Ten petioles from recent fully expanded leaves were collected from each plot. Petioles were then cut into 0.4-in sections, crushed with a garlic press, and two to three drops of sap were placed on the sensor pads of two ion specific electrode meters (Cardy, Spectrum Technologies, Plainfield, IL) for determination of NO_3^--N and K concentrations (Hochmuth, 1994). Both meters were calibrated at the beginning of the experiment and for every 20 samples using standard solutions provided with the meters (Studstill et al., 2006). The press and the meters were rinsed with deionized water and dried between each sample.

Yield data: Twenty-foot long sections located in the middle bed and representative of each experimental unit were marked for yield measurements. Mature green tomatoes were harvested at 66, 74, 81, and 88 DAT in 2005, and at 65, 85, and 91 DAT in 2006 and fruits were then graded as extra-large, large, medium, and culls (USDA, 1991). The tomato fruits in each grade were counted and then weighed. Weight of fruits from each grade were then converted to 25-lb carton/acre (A) by multiplying with the factor 17.44 (fruit weights from raised bed plots 20-feet long on 5-feet centers and with 13 plants each at 18-inch within row spacing were converted into fruit weights from 1-acre raised beds on 5-feet centers and 5,808 plants at 18-inch within row spacing) in order to compare the total yields with yields reported by growers. Total marketable yield was calculated as the sum of extra-large, large, and medium grades. Total season yields were calculated as the sum of yields from all harvests and early season yields were calculated as the sum of first and second harvest yields (Locascio et al., 1985).

Data Analysis

The experimental design was a randomized complete block design with four replications. Soil VWC, petiole NO_3^--N, and K^+ concentrations, and marketable yield responses to irrigation-nutrient management programs were determined using ANOVA and treatment means were compared using Duncan's multiple range test (SAS, 2008). The orthogonal contrasts "Nitrogen rate (100% vs 200%)", "Preplant fertilizer source (CL vs Inorganic Fertilizer)", and "Irrigation rate (100% vs 300%)" were used to test the significance of the difference between rate of fertilizer applied, source of preplant fertilizer, and irrigation rate.

Results and Discussion

Weather Conditions

The monthly average air temperatures and monthly average rainfall were different for 2005 and 2006. From April to July, 2005 the monthly average air temperatures were relatively lower than normal for North Florida (Figure 3-3A). During 2006 the monthly average air temperature for April was normal, while from May to July they were lower than normal for North Florida (Figure 3-3A). Cumulative weekly average maximum and minimum temperatures were relatively higher in 2006 and comparatively lower in 2005 (Figure 3-3B). Rainfall was relatively higher than seasonal levels during April, June, July, and was lower than normal in May 2005. During 2006 rainfall was relatively lower than normal in April, May, July, and higher than normal in June (Figure 3-3C). Rainfall events of more than 1-inch during 2005 occurred on 22, 58, 64, 65, 82, and 86 DAT recording 1.83, 1.44, 1.66, 1.04, 2.46, and 2.35 inches, respectively, and accounted for 59% of total rainfall recorded from April 8 to July 5, 2005. During 2006 rainfall events of more than 1-inch occurred on 3, 57, 68, 69, and 81 DAT recording 1.28, 1.59, 1.6, 2.25, and 1.47 inches, respectively and accounted for 67% of total rainfall recorded from April 5 to July 5, 2006 (FAWN, 2008). Since, the rainfall events mentioned above did not meet the leaching rainfall amounts of 3 inches of rainfall in three days or 4 inches in seven days (Olson et al., 2007) the plots did not require supplemental fertilizer application. Based on the above weather information, 2005 was a relatively cooler and wet year, while 2006 had normal temperatures for North Florida. However, in 2006 the early part of the tomato growing season (April-May) was dry while the latter part was wet (June-July).

Raised Plant Bed Soil Moisture

For soil VWC at 6 inches from the drip tape, the interaction year x treatment was significant for most of the growth stages ($p < 0.01$). Therefore the data from both years were analyzed separately. In 2005, the irrigation-nutrient management programs did not have a significant effect ($p \geq 0.20$) on soil moisture levels during the vegetative stage and the reproductive stages. In 2006, though the irrigation-nutrient management programs had a significant effect ($p \leq 0.22$) on the VWC in the raised plant bed, the actual number of days that the treatments differed by were very minimal (1 day during the vegetative stage, and 1-2 days during the reproductive stage) (Table 3-2.). These results suggest that increasing the irrigation management from 100-300% did not result in a substantial increase in soil moisture levels within the plant bed. Similar study done by Locascio et al. (1989) found higher soil moisture levels with higher irrigation levels (1.0 times pan evaporation) than with lower irrigation levels (0.5 times pan evaporation) (6-7% by weight versus 3.5-4.8% by weight). Although, the higher irrigation resulted in higher soil moisture levels, significantly higher yields were recorded with the lower irrigation treatment (Locascio et al., 1989).

Tomato Plant Petiole Sap NO_3^--N Concentration

The interaction year x treatment was significant ($p < 0.01$) for all the growth stages when petiole sap NO_3^--N concentrations were measured. Therefore the data from both years were analyzed separately. In 2005, highest petiole sap NO_3^--N concentrations were seen for 200% Fertigation-100% Irrigation treatment at first open flowers stage, 100% Fertigation-CL,100% Irrigation and 200% Fertigation-100% Irrigation treatments at fruits two-inch diameter stage, and 100% Fertigation-CL,100% Irrigation treatment at first harvest stage (Figure 3-4A). The orthogonal contrasts N rate (100% vs 200%) and preplant fertilizer source (CL vs 13-1.8-10.8) were not significant for all three growth stages. However the orthogonal contrast between irrigation rate (100% vs 300%) was significant for all three growth stages ($p \leq 0.01$), suggesting that irrigation rate and not fertilizer rate or preplant fertilizer source affected the changes in petiole NO_3^--N concentrations (Figure 3-4A). Based on the calculated means for 100% and 300% irrigation, the petiole NO_3^--N concentrations were significantly higher ($p \leq 0.01$) at the lower irrigation rate of 100% (1558, 728, 711 mg/L NO_3^--N at first open flowers, fruits two-inch diameter, and first harvest growth stages respectively) than at the higher irrigation rate of 300% (1242, 389, 347 mg/L NO_3^--N) at first open flowers, fruits two-inch diameter, and first harvest growth stages times respectively).

In 2006, highest petiole sap NO_3^--N concentrations were seen for 100% Fertigation-CL,100% Irrigation treatment at first open flowers stage ($p < 0.01$). At first harvest stage 100% Fertigation-CL,100% Irrigation treatment and 200% Fertigation-100% Irrigation treatment recorded the highest petiole sap NO_3^--N petiole sap concentrations ($p < 0.01$). However, at the second harvest stage the treatments did not vary significantly in their petiole sap NO_3^--N concentrations ($p = 0.30$). At first open flowers and first harvest growth stages the orthogonal contrasts between preplant fertilizer source (CL vs 13-1.8-10.8), fertigation rate (100% vs

300%), and irrigation rate (100% vs 300%) were all significant, suggesting that the changes in the petiole sap NO_3^--N concentrations were affected by all three factors i.e. fertilizer rate, irrigation rate, and source of preplant fertilizer. The average daily temperatures were relatively higher in 2006 than in 2005 (Figure 3-3A) which may have attributed to the difference in the plant response to the treatments during the two years.

In 2005, petiole sap NO_3^--N concentrations were diagnosed as “insufficient” (Hochmuth, 1994) 200% Fertigation-300% Irrigation and 100% Fertigation-300% Irrigation treatments at fruits two-inch diameter stage, and for 100% Fertigation-300% Irrigation treatment at first harvest stage, which were all high-irrigation treatments. Similarly, in 2006, all three treatments with high-irrigation (300%) which were 100% Fertigation-300% Irrigation, 200% Fertigation-300% Irrigation, and 200% Fertigation-300% Irrigation-ML had petiole sap NO_3^--N concentrations which were diagnosed as “insufficient” at first open flowers and second harvest growth stage. At first harvest growth stage both 100% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML treatments had petiole sap NO_3^--N concentrations which were diagnosed as “insufficient”. These results suggest that irrigation rate, more than fertilizer rate affected the concentration of NO_3^--N in tomato petiole sap and an increase in irrigation rate resulted in lower petiole sap NO_3^--N concentrations (Figure 3-4A). These results also suggest that instead of managing nutrients and irrigation separately, better plant nutrition can be achieved by combining the nutrient and irrigation management.

Tomato Plant Petiole Sap K^+ Concentration

The interaction year x treatment was significant ($p < 0.05$) for all the growth stages when petiole sap K^+ concentrations were measured. Therefore the data from both years were analyzed separately. In 2005, the petiole sap K^+ concentrations did not vary with treatments at all three growth stages (first open flowers, fruits two-inch diameter, and first harvest, respectively).

In 2006, highest K^+ concentrations in the plant were seen with 100% Fertigation-CL,100% Irrigation treatment at all three growth stages (*p* <0.03 respectively). The orthogonal contrasts between preplant fertilizer sources (CL vs 13-1.8-10.8) were significant for all three growth stages (*p* <0.01). Moreover, the calculated means for CL (4800, 4425, 5200 mg/L of K^+) were higher than the means for 13-1.8-10.8 (4125, 3750, 3155 mg/L of K^+) for all these growth stages, suggesting that the high K^+ concentrations recorded in the petiole with the 100% Fertigation-CL,100% Irrigation treatment were a result of the preplant fertilizer source treatment. At first harvest stage the orthogonal contrasts for all three comparisons fertigation rate (100% vs 300%), preplant fertilizer source (CL vs 13-1.8-10.8), and irrigation rate (100% vs 300%) were significant (Figure 3-4B).

In 2005, the K^+ concentrations recorded in the plant at first open flowers growth stage were diagnosed as "insufficient" for all treatments (Hochmuth, 1994). At fruits two-inch diameter growth stage except for the 200% Fertigation-100% Irrigation treatment all the other treatments had K^+ concentrations higher than the sufficiency range. At first harvest growth stage all the treatments had K^+ concentrations higher than the sufficiency range. In 2006, all the treatments at all the three growth stages had K^+ concentrations higher than the sufficiency ranges (Figure 3-4B). The results varied with year, depending on the growing conditions the changes in the petiole sap K^+ concentrations were affected either by irrigation treatments or by all three factors i.e. fertilizer rate, irrigation rate, and source of preplant fertilizer source.

In 2006, CL as a preplant fertilizer source resulted in significantly higher K^+ concentrations in the plant. In both 2005 and 2006, the calculation of the amount of CL applied to the respective treatment plots was based on the amount of N present in it. However, as the CL used in the experiment had higher levels of K (CL N-K analysis for 2005 and 2006 was 1.25-2.0

and 1.66-1.91 respectively) than N, higher amount of K was applied with the CL than with the other five irrigation-nutrient management program (24.9 and 34.86 lb higher in 2005 and 2006 respectively). Although the effects of this higher amount of K from the CL were not seen in 2005 (a relatively cool and wet year), the higher K in the CL irrigation-nutrient management program resulted in significantly higher levels of K^+ concentration in the tomato plants in 2006 (a relatively hot and dry year). In 2006, a cumulative effect of increased fertigation (200%) was seen by the first harvest stage, higher petiole K^+ concentrations were recorded with the higher (200%) than with the lower (100%) fertigation management program. This increase in petiole sap concentration with increase in fertilizer corresponds to similar results reported by Locascio et al., (1997b) where significant linear increase in leaf K^+ concentration with increase in K rates were seen.

Tomato Yield and Grade Distribution

As the interaction year x treatment was significant for most of the harvests and grade distributions ($p < 0.05$), data were analyzed separately by year. Total marketable tomato yields recorded in 2005 ranged from 1,242-1,883 25-lb cartons/acre, and in 2006, the total marketable tomato yields ranged from 920-1,424 25-lb cartons/acre. Total marketable tomato yields recorded in 2005 were relatively higher than the yields recorded in 2006.

Early Fruit Yield: Early marketable fruit yields were influenced by treatment during 2005 and 2006 (Table 3-3). In 2005, highest early marketable fruit yields were obtained with 100% Fertigation-CL,100% Irrigation treatment (1,127 25-lb carton/acre), and no significant differences were found between the remaining five irrigation-nutrient management programs. Based on orthogonal contrasts, in 2005, early marketable fruit yields were not significantly affected by fertigation rate ($p = 0.89$) (100% and 200%) and irrigation rate ($p = 0.21$) (100% and 300%). Further, there were no significant differences between the IFAS irrigation-fertigation program (100% Fertigation-100% Irrigation) and increased fertigation program (200% Fertigation-100% Irrigation) for early yields. However, early marketable fruit yields varied significantly ($p = 0.03$) with preplant fertilizer source, fruit yields higher by 211 25-lb cartons were recorded with CL than with inorganic fertilizer source 13-1.8-10.8. As previously discussed, the CL preplant program supplied higher amount of P and K. These higher amounts of nutrients might have resulted in significantly higher early marketable yields.

In 2006, highest early marketable fruit yields were obtained with 200% Fertigation-100% Irrigation treatment (1,219 25-lb carton/acre), and lowest yields were recorded with100% Fertigation-CL,100% Irrigation treatment (826 25-lb carton/acre). Based on the orthogonal contrasts, early marketable fruit yields were not significantly influenced by irrigation rate (p = 0.31) (100% and 300%). However, preplant fertilizer source had a significant effect on early marketable fruit yields ($p = 0.02$). Yields were higher by 276 25-lb cartons with inorganic fertilizer source 13-1.8-10.8 than with CL. Moreover, fertigation rate also had a significant effect on early marketable fruit yields ($p = 0.04$), yields were higher by 169 25-lb cartons with 200% rather than with the 100% fertigation rate. However, similar to 2005, there were no significant differences between the IFAS irrigation-fertigation program (100% Fertigation-100% Irrigation) and increased fertigation program (200% Fertigation-100% Irrigation) for early yields.

Total Season Fruit Yields: In 2005 and 2006, treatment had a significant effect ($p < 0.01$) on the total marketable yield (all harvests) (Table 3-3). In 2005, highest total marketable yields were seen with 100% Fertigation-CL,100% Irrigation (1,883 25-lb carton/acre) and the lowest with 100% Fertigation-300% Irrigation treatment (1,242 25-lb carton/acre). Based on the orthogonal contrasts, preplant fertilizer source (CL and 13-1.8-10.8) and fertigation rate (100% and 200%) did not have a significant effect on total marketable yields (p = 0.49 and 0.09 respectively).

Similar to the early yield results, there were no significant differences between the IFAS irrigation-fertigation program (100% Fertigation-100% Irrigation) and increased fertigation program (200% Fertigation-100% Irrigation) for total yields. However, irrigation rate (100% vs 300%) had significant effect on total marketable yields (p <0.01), yields were higher by 337 25-lb cartons with 100% rather than with the 300% irrigation rate.

In 2006, highest total marketable yields were seen with 200% Fertigation-100% Irrigation treatment (1,424 25-lb cartons) and lowest yields were recorded with 100% Fertigation-300% Irrigation treatment (920 25-lb cartons). Based on the orthogonal contrasts, preplant fertilizer source (CL and 13-1.8-10.8) did not have a significant effect on total marketable yields (p = 0.86). However, fertigation rate (100% and 200%) and irrigation rate (100% and 300%) had a significant effect on total marketable yields (p = 0.03 and p <0.01 respectively). Yields were higher by 197 25-lb cartons with 200% rather than with the 100% fertigation rate, and higher yields (by 280 25-lb cartons) were recorded with lower irrigation rate of 100% than with the higher rate of 300%. However, there were no significant differences between the IFAS irrigation-fertigation program (100% Fertigation-100% Irrigation) and increased fertigation program (200% Fertigation-100% Irrigation) for total yields. In 2006, the tomato transplants in CL treatment plots showed symptoms of burn damage during the 1st and 2nd week after transplanting. The CL used in 2005 and 2006 had very similar nutrient analysis. However, as the electrical conductivity information was not reported for both the samples, it was found later that the CL was aged in 2005 while the CL used in 2006 was un-aged. This burn damage might have affected the early tomato yields in 2006, resulting in a significant reduction in total early marketable tomato yields when compared to the same preplant programs’ results in 2005.

Based on the results from both years, preplant fertilizer source did not have a significant effect on total marketable tomato yields, which was contrary to Studstill et al.’s (2006) findings with CL as a preplant fertilizer source in muskmelon. Moreover, with fresh market tomatoes, depending on the age of the CL used as a preplant fertilizer source, early marketable yields may be increased by +18%.

Although irrigation rate (100% and 300%) did not have a significant effect on early yields, based on the results from both years, the total marketable yields were significantly lower (by 280-337 25-lb cartons/acre) with the higher irrigation of 300%. The percentage of early marketable fruits in 2006 were significantly higher ($p = 0.03$) with 100% than with 300% irrigation rate, and the percentage of total marketable fruit in 2005 were significantly higher with 100% than with 300% irrigation rate ($p < 0.01$). These results suggest that the higher irrigation rate may have resulted in higher number of defective fruits (Table 3-3). These results also suggest that in a relatively cool and wet year (2005) the higher irrigation rate (300%) results in a significant reduction in the total season percentage of marketable fruits, and in a relatively hot and dry year (2006) the higher irrigation rate (300%) results in a significant reduction in the total early percentage of marketable fruits. As a consequence of the loss in marketable fruits, the total season yields from both years were lower with the high irrigation rate of 300%. These results were similar to previous research on fine sandy soils where higher season yields were reported with irrigation at 0.5 rather than with 1.0 times pan evaporation (Kafkafi and Bar-Yosef, 1980; Locascio et al., 1981; Locascio et al., 1989).

Fresh market tomato yield response to fertilizer rate varied with year. In 2005, a relatively cool and wet year, there were no significant differences between the 100% and 200% fertilizer rates for early and total season yield response. Moreover, there were no significant differences between the IFAS irrigation-fertigation program (100% Fertigation-100% Irrigation) and the increased fertigation program (200% Fertigation-100% Irrigation) for early and total fruit yields. However in 2006, a relatively warm and dry year, significantly higher yields were recorded with the 200% than the 100% fertilizer rate for both early and total season yields. These results suggest that the response of fresh market tomato yield to fertilizer rates varies with the climatic conditions from one year to the next. Similar variability in yield responses to fertilizer rates with climatic conditions has also been reported by other research (Rhoads et al., 1999).

Conclusion

The effects of irrigation-nutrient management programs were evaluated on raised plant bed soil moisture levels, tomato plant petiole NO_3-N and K^+ concentrations, and yield and grade distribution of fresh market tomatoes grown with plasticulture. The results from this study suggest that CL resulted in highest early-yields. Therefore CL can be used as an alternative fertilizer source at preplant. The study also looked at the effects of increased irrigation management program on tomato production. Applying higher irrigation (300%) reduced water stress in the plant bed for only for 1-2 days during the cropping cycle. However, it also resulted in “insufficient” NO_3^--N and K^+ petiole concentrations, which further resulted in lower total fruit yields. Therefore, if increased irrigation water application is needed, approaches that increase the irrigation time (such as lower flow rate or lower drip tape operating pressure or more cycles throughout the day) should be used. The effects of fertigation rates on tomato plants varied with year. The higher fertigation rate (200%) did not have any significant effect on plant nutrient levels and tomato yields. Further, early and total tomato yield responses to the IFAS irrigation-fertigation program (100% Fertigation-100% Irrigation) and the increased fertigation program (200% Fertigation-100% Irrigation) were not significantly different in both years. However, in a relatively hot-dry year, the higher fertigation rate significantly increased early and total marketable tomato fruit yields. We can conclude that over-irrigating has a negative impact on tomato production and tomato plant response to fertilizer rates varies with growing conditions.

Table 3-1. Irrigation-nutrient (N-P-K) management programs for spring 2005-2006 'Florida 47' fresh market tomato production with raised-bed plasticulture system.

Number	Irrigation-Nutrient Management Programs	PrePlant Fertilization		Injected Fertigation		Total	
		Source	Amount (lb/acre)	Source	Amount (lb/acre)	Amount (lb/acre)	Rate (%)[z]
		2005					
1	100% Fertigation-CL[y],100% Irrigation	CL	50-44.7-66.4[x]	8-0-6.6	186-0-154	236-44.7-242[x]	100
2	100% Fertigation, 100% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	186-0-154	236-6.8-195.5	100
3	100% Fertigation, 300% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	186-0-154	236-6.8-195.5	100
4	200% Fertigation, 100% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	371-0-307	421-6.8-348.5	200
5	200% Fertigation, 300% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	371-0-307	421-6.8-348.5	200
6	200% Fertigation, 300% Irrigation-ML[w]	13-1.7-10.7	50-6.8-41.5	8-0-6.6	371-0-307	421-6.8-348.5	200
		2006					
1	100% Fertigation-CL,100% Irrigation	CL	50-59.8-92	8-0-6.6	186-0-154	236-59.8-217	100
2	100% Fertigation-100% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	186-0-154	236-6.8-195.5	100
3	100% Fertigation-300% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	186-0-154	236-6.8-195.5	100
4	200% Fertigation-100% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	371-0-307	421-6.8-348.5	200
5	200% Fertigation-300% Irrigation	13-1.7-10.7	50-6.8-41.5	8-0-6.6	371-0-307	421-6.8-348.5	200
6	200% Fertigation-300% Irrigation-ML	13-1.7-10.7	50-6.8-41.5	8-0-6.6	371-0-307	421-6.8-348.5	200

[z] Because the treatments were only applied to the injected portion of the N-K nutrient management program, the program rates were labeled as 100% and 200% although they were 100% and 175% of the total N-K applied.

[y] For program 100% Fertigation-CL,100% Irrigation the source of the preplant fertilizer was chicken litter. The other programs had 13-1.7-10.7 as the source of preplant fertilizer.

[x] The N-P-K analysis of the CL was different in 2005 and 2006 (1.25-1.12-1.66 and 1.25-1.5-1.91 respectively). Therefore, the total N-P-K applied at preplant with the CL varied from 2005 and 2006. In 2005 the N-P-K amount was 50-44.7-66.4 lb, while in 2006 it was 50-59.8-92 lb.

[w] An additional program for estimating nitrate load using drainage lysimeters installed in the ground was carried out at the same time as the current study. The lysimeters installed under programs 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation were of the same design, and the lysimeters installed under the program 200% Fertigation-300% Irrigation-ML were modified (ML) in design and varied from the above lysimeters. To maintain the integrity of the predetermined programs data from 200% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML (which received the same above ground programs) were not combined.

Table 3-2. Number of sampling days when soil volumetric water content (%) at 6 inches from the drip tape was between 0-4, 5-8, 9-12, and >13% for fresh market tomatoes grown in 2005 and 2006 on Blanton-Foxworth-Alpin Complex soil series.

	No of Sampling Days							
	Vegetative Stage[z]				Reproductive Stage[y]			
Irrigation-Nutrient Management Programs	0-4%	5-8%	9-12%	>13%	0-4%	5-8%	9-12%	>13%
	2005[x]							
100% Fertigation[w]-CL[v],100% Irrigation	1	3	1	0	2	4	0	0
100% Fertigation, 100% Irrigation	1	3	1	0	2	4	0	0
100% Fertigation, 300% Irrigation	1	3	1	0	1	4	0	0
200% Fertigation, 100% Irrigation	1	3	1	0	2	4	0	0
200% Fertigation, 300% Irrigation	1	3	1	0	1	5	0	0
200% Fertigation, 300% Irrigation-ML[u]	1	3	1	0	2	4	0	0
p-values: Program	1.00	0.25	0.25	0.00	0.31	0.37	0.20	0.00
	2006							
100% Fertigation-CL,100% Irrigation	1.2 c	1.3 b	1.4 ab	1.2 a	2.1 b	3.3 ab	0.5 bc	0
100% Fertigation, 100% Irrigation	2.3 a	2.4 a	0.3 c	0.0 b	1.8 bc	4.3 a	0.0 c	0
100% Fertigation, 300% Irrigation	1.3 bc	2.8 a	0.8 bc	0.1 b	0.5 d	4.4 a	1.0 ab	0
200% Fertigation, 100% Irrigation	2.8 b	2.9 a	0.3 c	0.0 b	3.3 a	2.4 b	0.3 bc	0
200% Fertigation, 300% Irrigation	1.4 bc	2.3 a	1.3 ab	0.0 b	0.6 d	3.7 a	1.7 a	0
200% Fertigation, 300% Irrigation-ML	1.2 c	2.1 a	1.8 a	0.0 b	0.8 d	3.7 a	1.5 a	0
p-values: Program	0.38	<0.01	0.02	<0.01	<0.01	0.06	0.04	0.22
Irrigation Contrast Means								
100%	0.06	1.28	0.39	0.28	3.39	4.03	0.47	0.11
300%	0.06	1.22	0.72	0.00	0.92	5.08	1.94	0.06
p-values: Irrigation Contrast	1.00	0.74	0.02	<0.01	<0.01	0.03	<0.01	0.52

[z] The vegetative stage corresponds to the plant stage before flowering. During 2005 there were four VWC readings recorded during the vegetative stage (14, 21, 28 April and 6 May), and during 2006 there were two VWC readings recorded during the vegetative stage (27 April, 3 May).

[y] The reproductive stage corresponds to the plant stage after flowering. During 2005 there were six VWC readings recorded during the reproductive stage (12, 19, 26 May and 2, 9, 16 June), and during 2006 there were seven VWC readings recorded during the reproductive stage (18, 23, 31 May and 6, 14, 21, 28 June).

[x] The interaction term for year x treatment was significant for the effect of treatment on number of sampling days when soil volumetric water content (VWC) at 6 inches from the drip tape was between 0-4, 5-8, 9-12, and greater than 13% ($p \leq 0.05$). Therefore the data from both years were analyzed separately.

[w] Fertigation: Nitrogen-Potassium rate.

[v] For program 100% Fertigation-CL,100% Irrigation the source of the preplant fertilizer was chicken litter, while the rest of the programs had 13-1.8-10.8 as the source of preplant fertilizer.

[u] An additional program for estimating nitrate load using drainage lysimeters installed in the ground was carried out at the same time as the current study. The lysimeters installed under programs 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation were of the same design, and the lysimeters installed under the program 200% Fertigation-300% Irrigation-ML were modified (ML) in design and varied from the above lysimeters. To maintain the integrity of the predetermined programs data from 200% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML (which received the same above ground programs) were not combined.

Table 3-3. Effects of irrigation and nutrient management programs on ‘Florida 47’tomato fruit yields (25-lb carton/acre) during spring of 2005 and 2006[z].

Irrigation-Nutrient Management Program	Early Marketable 25-lb carton/acre[y]	Percent Early Marketable (%)	Total Marketable 25-lb carton/acre	Percent Total Marketable (%)[x]
	2005			
100% Fertigation[w]-CL[v],100% Irrigation	1,127 a	92 a	1,883 a	84 ab
100% Fertigation-100% Irrigation	916 b	92 a	1,783 ab	84 a
100% Fertigation-300% Irrigation	800 b	87 b	1,242 c	78 c
200% Fertigation-100% Irrigation	831 b	89 ab	1,820 ab	82 abc
200% Fertigation-300% Irrigation	904 b	92 a	1,556 b	80 bc
200% Fertigation-300% Irrigation-ML[u]	959 ab	92 a	1,677 ab	81 abc
p-values: Program	0.02	0.03	<0.01	0.02
Contrast Preplant source (CL vs 13-1.8-10.8)	0.03	0.87	0.49	0.88
Contrast Fertigation rate (100% vs 200%)	0.89	0.62	0.09	0.82
Contrast Irrigation Rate (100% vs 300%)	0.21	0.43	<0.01	<0.01
	2006			
100% Fertigation-CL,100% Irrigation	826 c	80 ab	1,291 ab	64
100% Fertigation-100% Irrigation	1,102 ab	76 bc	1,271 ab	64
100% Fertigation-300% Irrigation	866 bc	72 c	920 c	63
200% Fertigation-100% Irrigation	1,219 a	83 a	1,424 a	67
200% Fertigation-300% Irrigation	1,086 abc	78 abc	1,161 abc	71
200% Fertigation-300% Irrigation-ML	1,000 abc	77 abc	1,064 bc	68
p-values: Program	<0.01	0.02	<0.01	0.12
Contrast Preplant source (CL vs 13-1.8-10.8)	0.02	0.26	0.86	0.97
Contrast Fertigation rate (100% vs 200%)	0.04	<0.01	0.03	0.03
Contrast Irrigation Rate (100% vs 300%)	0.31	0.03	<0.01	0.12

[z] The interaction term for year x irrigation and nutrient management program was significant for fruit yields ($p \leq 0.05$), therefore the data from both years were analyzed separately.

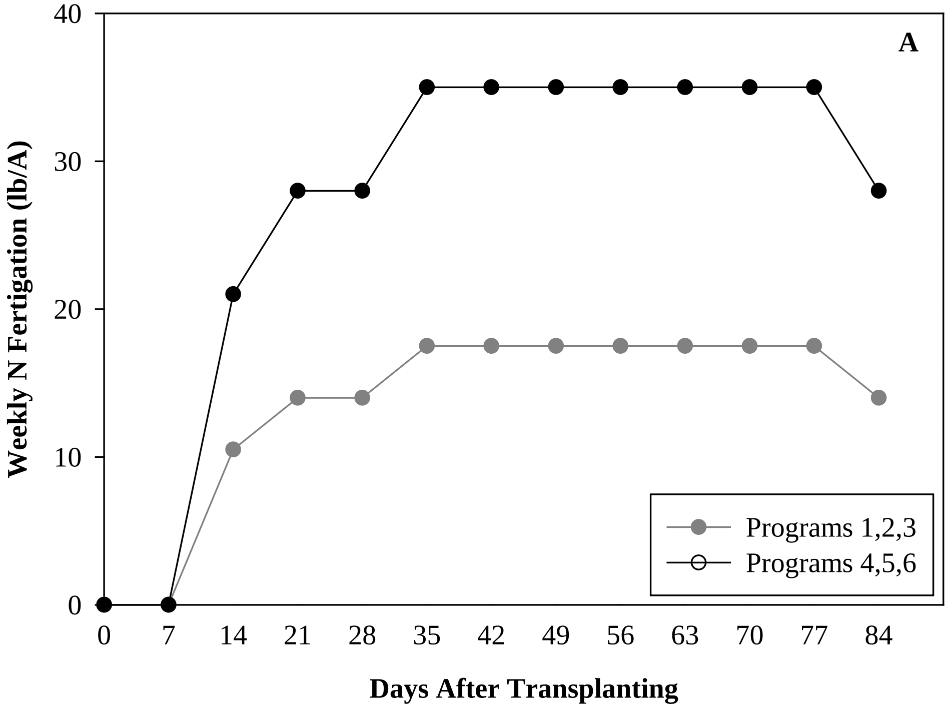
[y] Means followed by different letters within each column are significantly different at the 0.05 level, according to Duncan's multiple range test.

[x] Percent early and total marketable yields were calculated by dividing the early and total marketable yields by total early (early marketable + early culls) and total total yields (total marketable + total culls).

[w] Fertigation: Nitrogen-Potassium rate.

[v] For program 100% Fertigation-CL,100% Irrigation the source of the preplant fertilizer was chicken litter, while the rest of the programs had 13-1.8-10.8 as the source of preplant fertilizer.

u An additional program for estimating nitrate load using drainage lysimeters installed in the ground was carried out at the same time as the current study. The lysimeters installed under programs 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation were of the same design, and the lysimeters installed under the program 200% Fertigation-300% Irrigation-ML were modified (ML) in design and varied from the above lysimeters. To maintain the integrity of the predetermined programs data from 200% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML (which received the same above ground programs) were not combined.



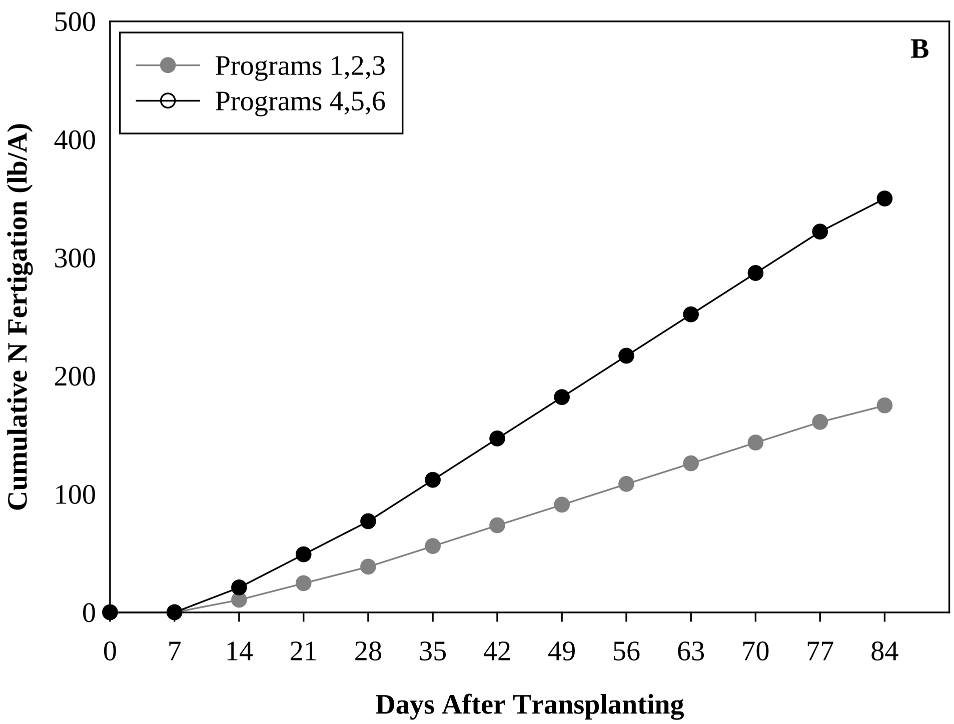


Figure 3-1. N fertigation (lb/acre) schedule used in the 2005-2006 fresh market tomato production experiment A) weekly, and B) cumulative. (Note: the irrigation and nutrient management programs were 1) 100% Fertigation-CL,100% Irrigation, 2) 100% Fertigation-100% Irrigation, 3) 100% Fertigation-300% Irrigation, 4) 200% Fertigation-100% Irrigation, 5) 200% Fertigation-300% Irrigation, and 6) 200% Fertigation-300% Irrigation-ML).

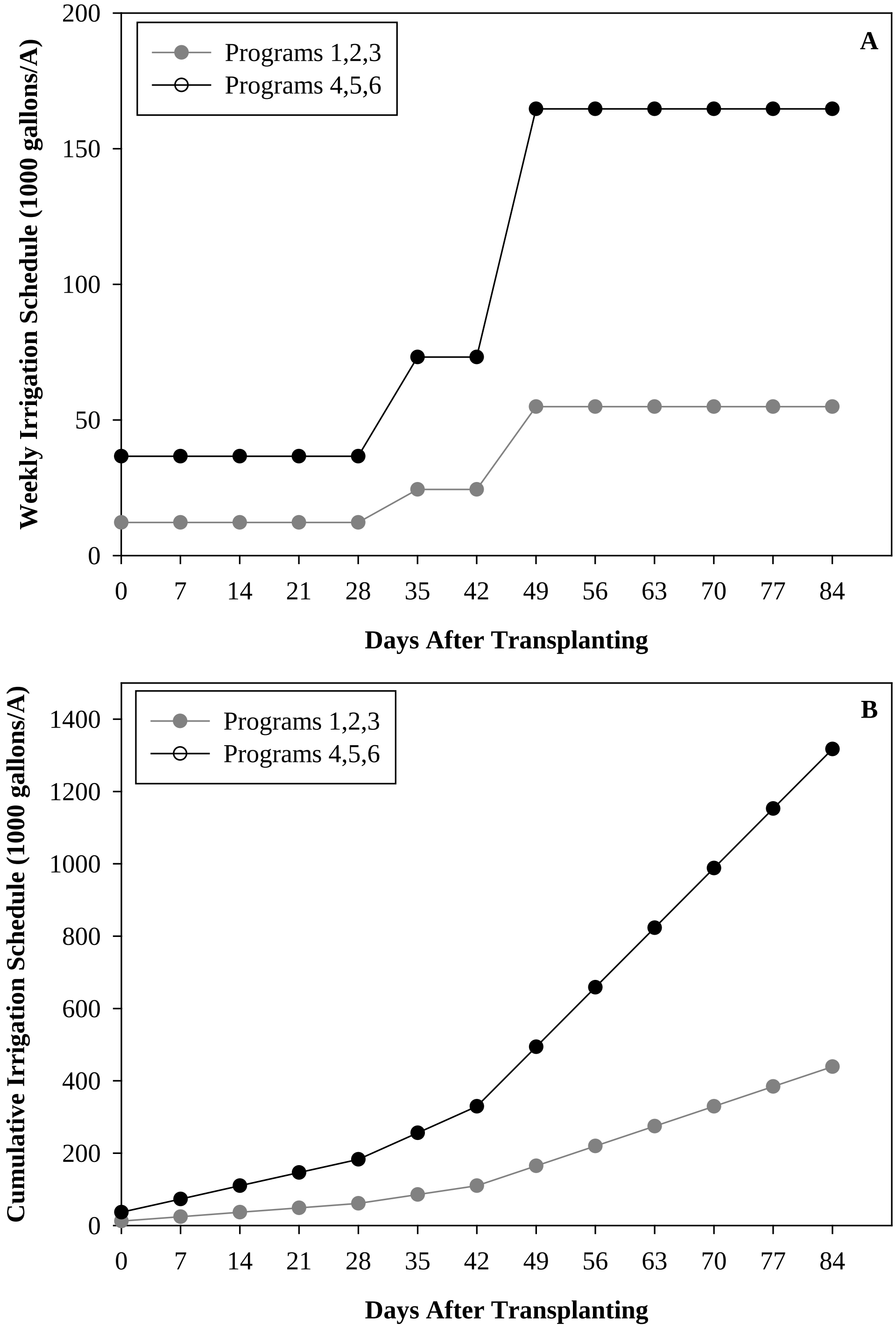


Figure 3-2. Irrigation (1000 gallons/acre) schedule for spring 2005-2006 'Florida 47' fresh market tomato production with raised-bed plasticulture system. A) Weekly, and B) cumulative. (Note: the irrigation and nutrient management programs were 1) 100% Fertigation-CL,100% Irrigation, 2) 100% Fertigation-100% Irrigation, 3) 100% Fertigation-300% Irrigation, 4) 200% Fertigation-100% Irrigation, 5) 200% Fertigation-300% Irrigation, and 6) 200% Fertigation-300% Irrigation-ML).

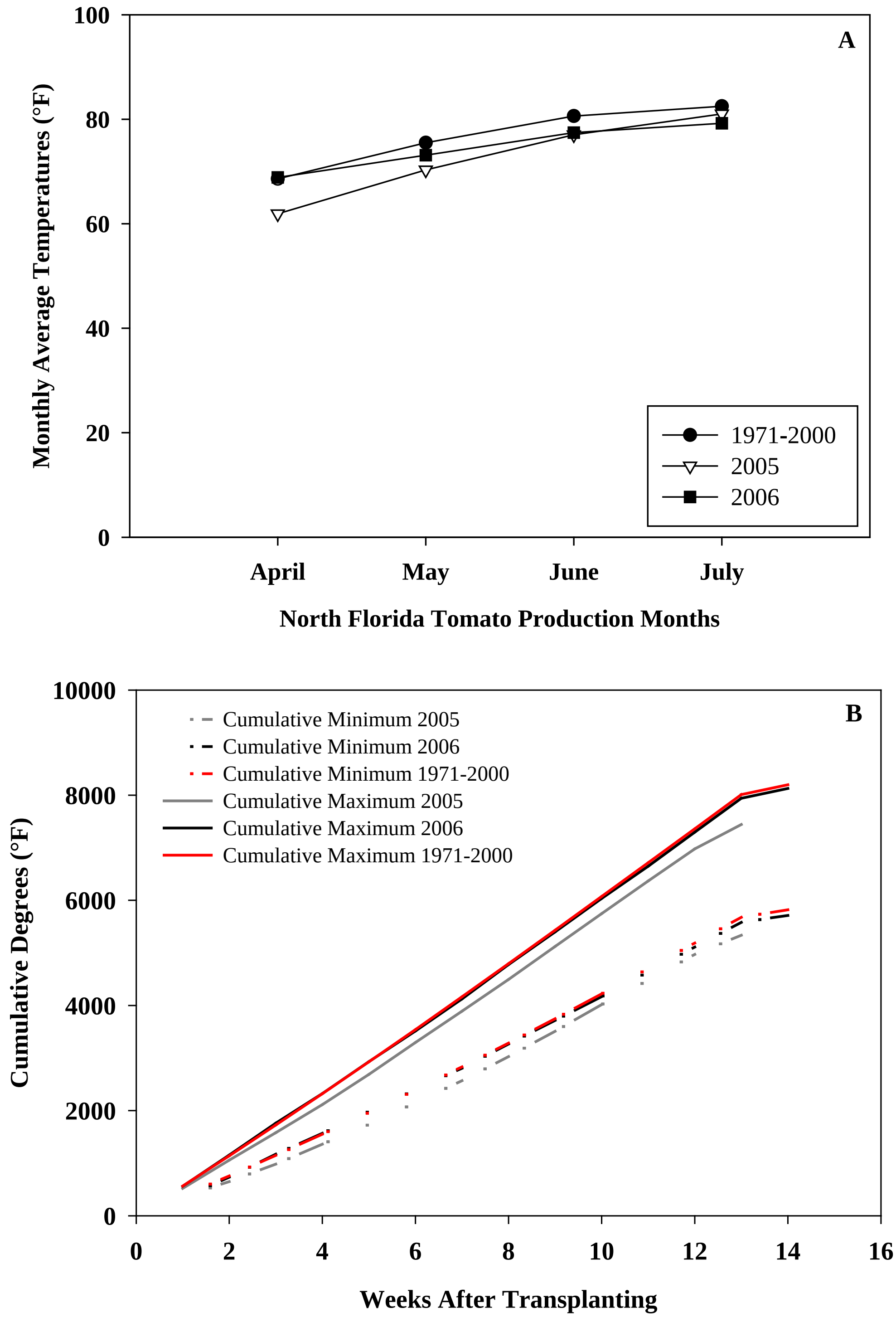


Figure 3-3. Historical and 2005-2006 weather patterns during tomato growing season in Live Oak, FL (April - July) A) monthly average temperatures (°F). B) cumulative weekly temperatures (°F), and C) monthly average rainfall (inches) (Note: the weather information was obtained from The Southeast Regional Climate and the Florida Automated Weather Network).

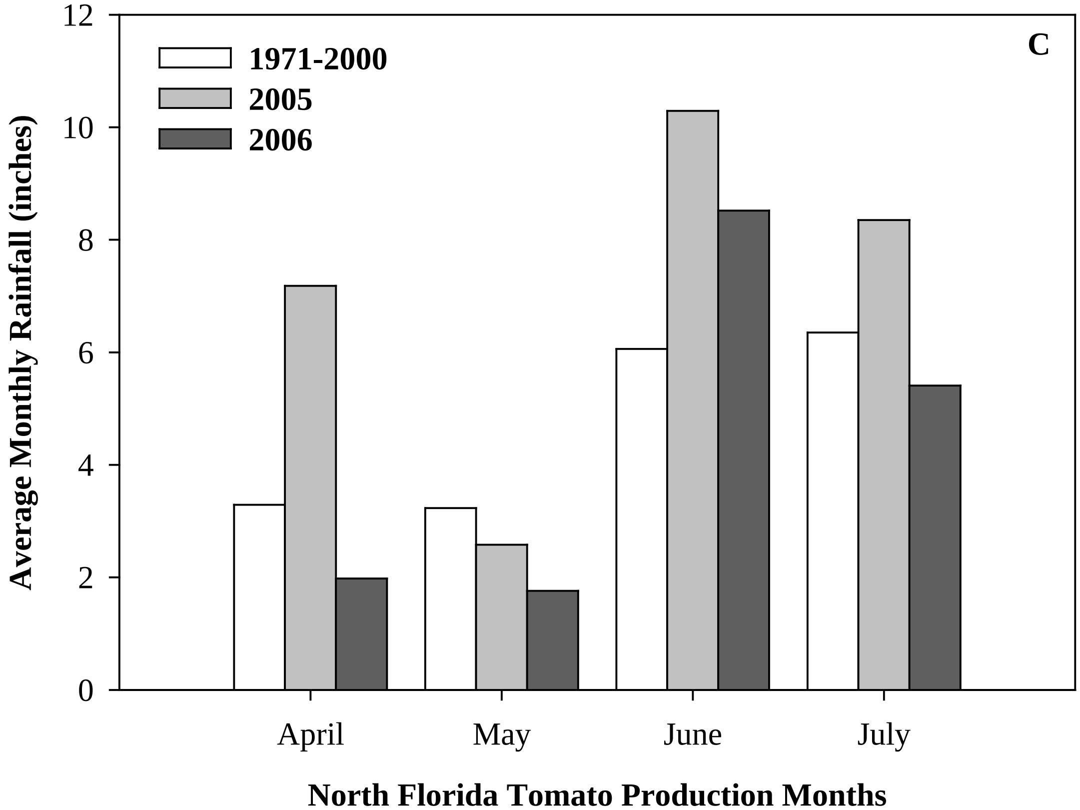


Figure 3-3. Continued

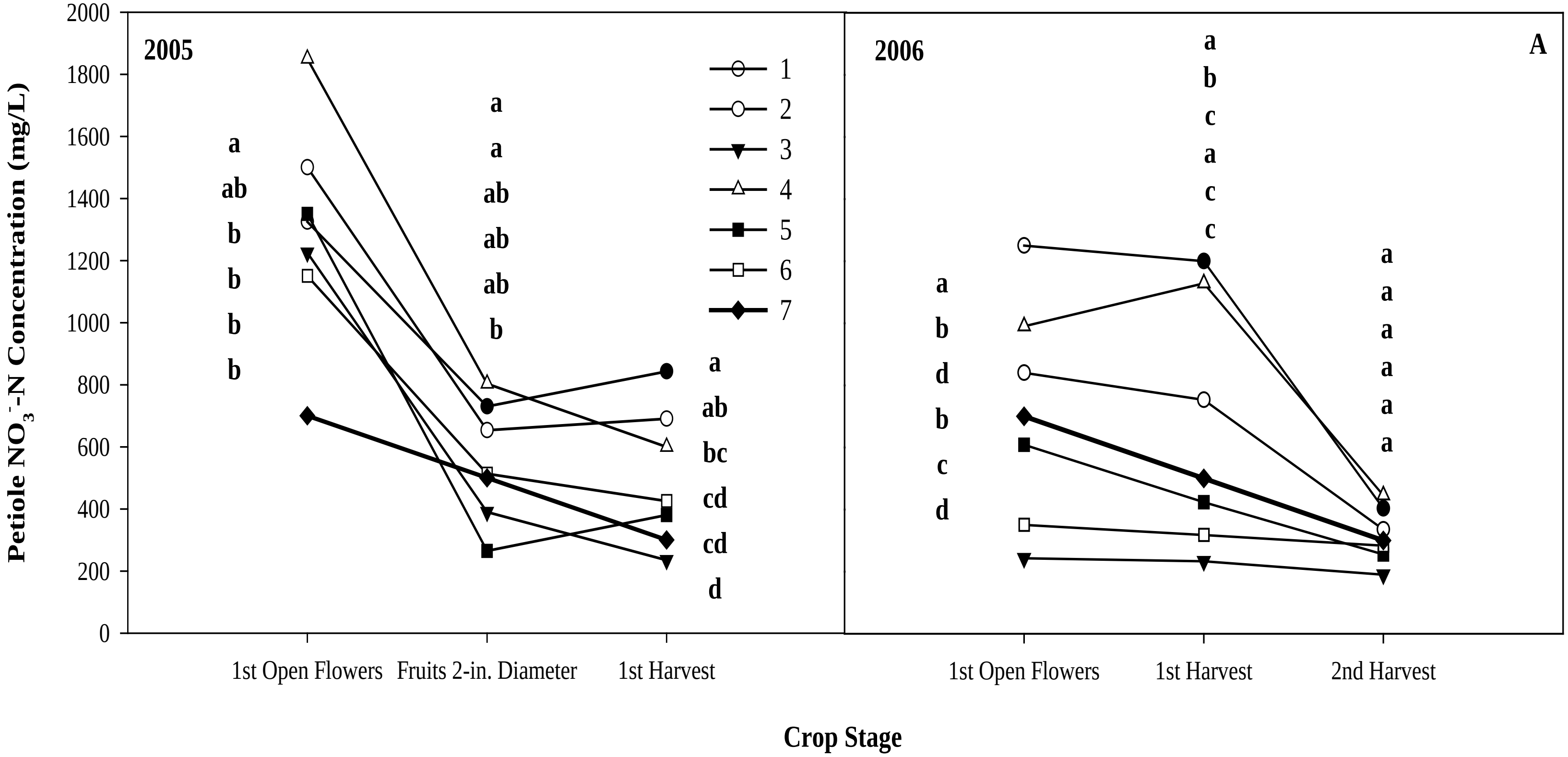


Figure 3-4. Effects of irrigation and nutrient management programs on petiole sap concentrations recorded for the different programs and the sufficiency ranges recommended for the corresponding growth stages during 2005 and 2006 A) NO_3^--N, and B) K^+. (Note: the irrigation and nutrient management programs were 1) 100% Fertigation-CL,100% Irrigation, 2) 100% Fertigation-100% Irrigation, 3) 100% Fertigation-300% Irrigation, 4) 200% Fertigation-100% Irrigation, 5) 200% Fertigation-300% Irrigation, 6) 200% Fertigation-300% Irrigation-ML, and 7) Sufficiency Range).

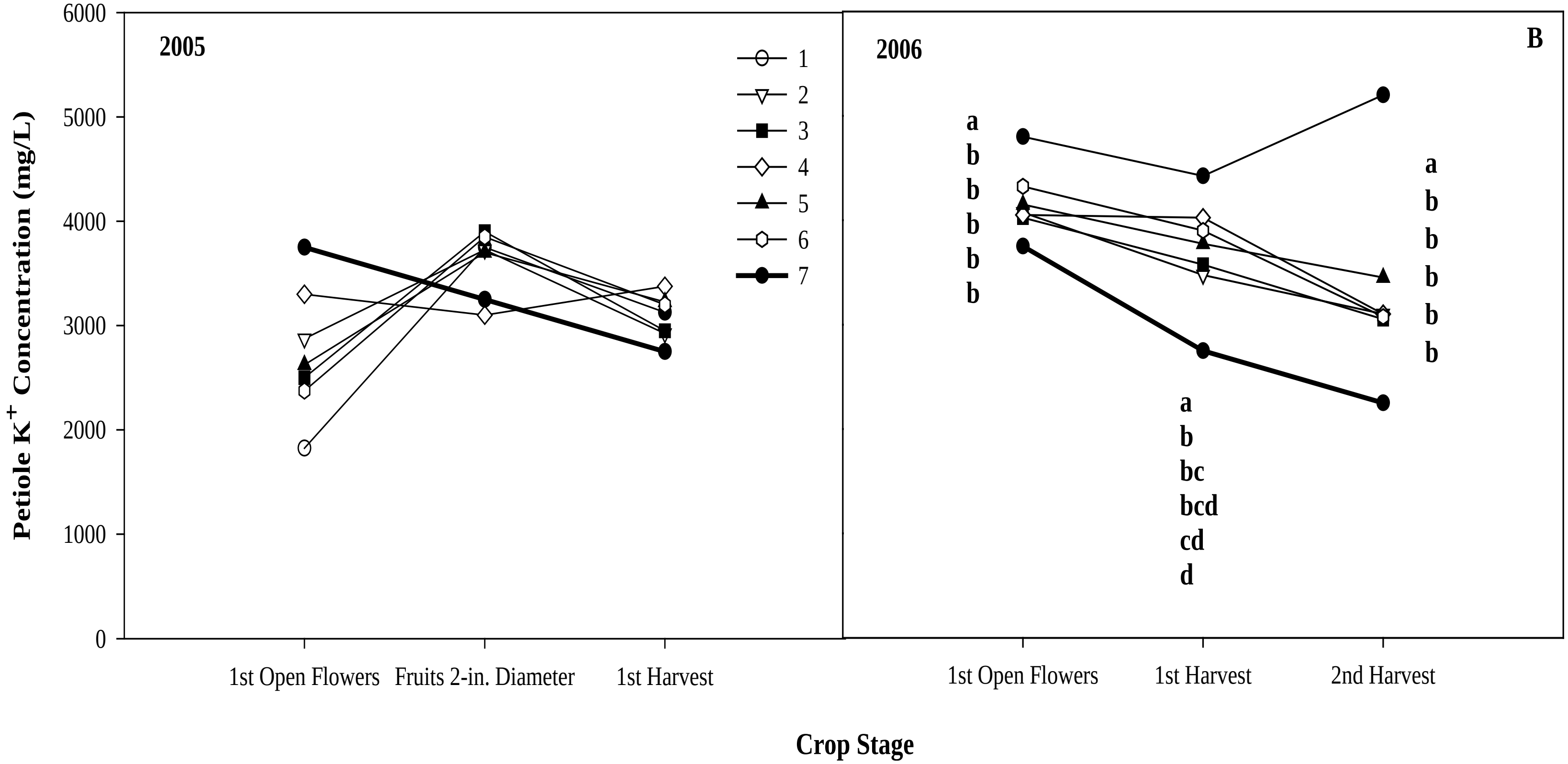


Figure 3-4. Continued

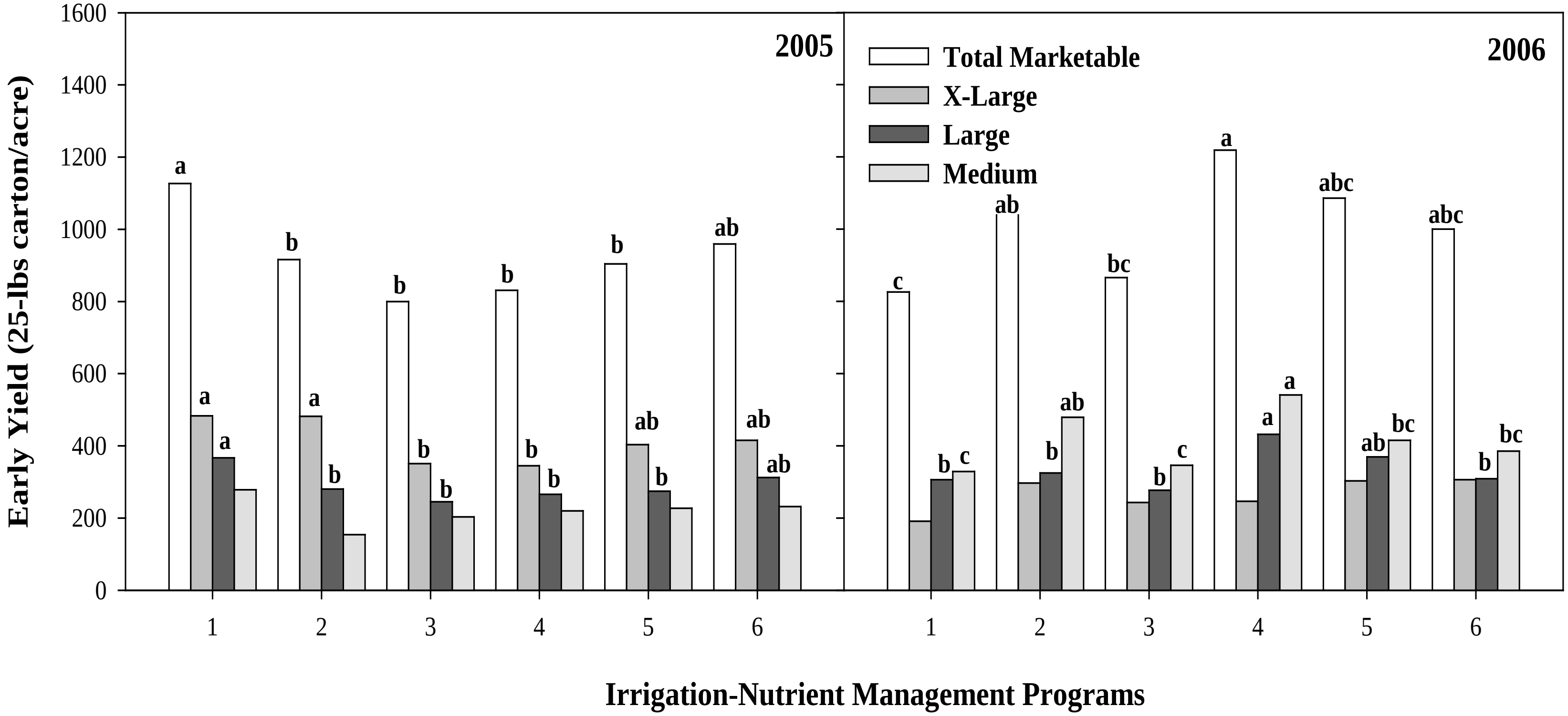


Figure 3-5. Distribution of tomato fruit grades for the early yields during the 2005 and 2006 growing seasons. (Note: the irrigation and nutrient management programs were 1) 100% Fertigation-CL,100% Irrigation, 2) 100% Fertigation-100% Irrigation, 3) 100% Fertigation-300% Irrigation, 4) 200% Fertigation-100% Irrigation, 5) 200% Fertigation-300% Irrigation, and 6) 200% Fertigation-300% Irrigation-ML).

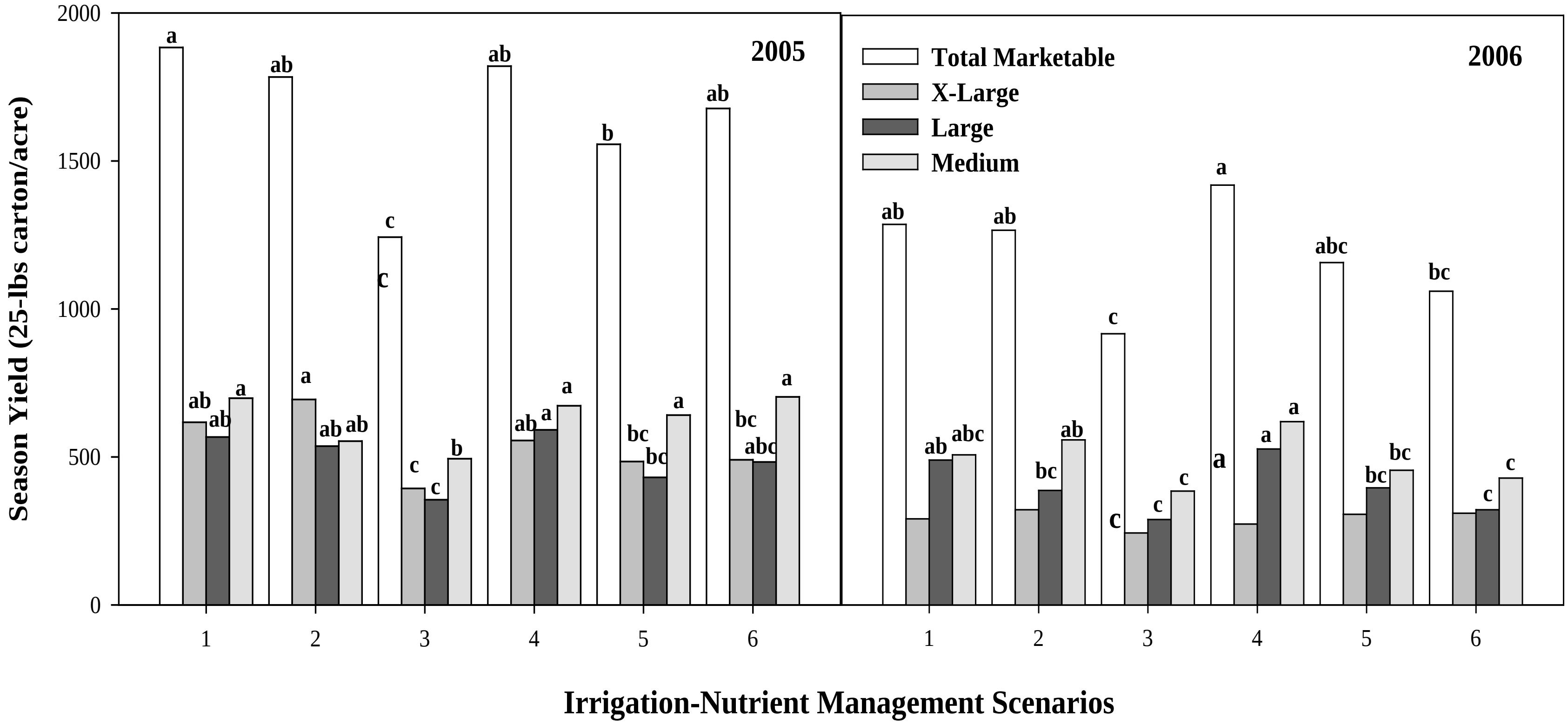


Figure 3-6. Distribution of tomato fruit grades for the total season yields during the 2005 and 2006 growing seasons. (Note: the irrigation and nutrient management programs were 1) 100% Fertigation-CL,100% Irrigation, 2) 100% Fertigation-100% Irrigation, 3) 100% Fertigation-300% Irrigation, 4) 200% Fertigation-100% Irrigation, 5) 200% Fertigation-300% Irrigation, and 6) 200% Fertigation-300% Irrigation-ML).

CHAPTER 4
NUTRIENT MANAGEMENT PROGRAMS FOR FRESH MARKET TOMATOES GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES. II. DETERMINATION OF NUTRIENT LOAD

Introduction

Quantifying nutrient load from vegetable production systems is the first step towards monitoring and understanding groundwater pollution in the field. Nutrient load is defined as the mass of a chemical entering or leaving an area, and is calculated as the product of the volume of water that the chemical is transported in and the concentration of the chemical in the water (Rice and Izuno, 2001). Fresh market tomatoes are grown with intensive fertilization and irrigation practices, and given the low water holding capacity of Florida’s sandy soils, there is an increased risk of contaminating the groundwater with plant nutrients.

In 2007, Florida accounted for 39% of the national fresh market tomato (*Solanum lycopersicum* L.) production with a value of $464 million (USDA-NASS, 2008). Fresh market tomatoes are the number one vegetable crop in Florida in total harvested acres (37,800-42,000 acres during 2005-2007) and total value ($464-805 million during 2005-2007).

Nutrient load can be determined indirectly or directly. The indirect approaches of measuring load include nutrient flow models (Kyllmar et al., 2005) and nutrient balances (Öborn et al., 2003; Parris, 1998). The direct approaches to measuring load at the field level are resin traps (Balkcom et al., 2001), leachate lysimeters, or soil sampling (Ahmed et al., 2001). The two main types of leachate lysimeters are suction cup lysimeters and drainage lysimeters (Abdou and Flury, 2004). Drainage lysimeters collect leachate from macropore flow or when the soil above the lysimeter becomes saturated or exceeds the field capacity (Zhu et al., 2002). These lysimeters consist of two main components, a collection container and a storage container. The collection container is any container filled with soil, and the storage container holds the leachate water from the collection container. Drainage lysimeters are installed below crop root zones. The storage container is installed below the collection container such that the water collected inside the collection container flows into the storage container by gravity (Migliaccio et al., 2006), and the leachate that is collected inside the storage container is retrieved with a pump. Drainage lysimeters allow the measurement of both concentration and volume of nutrients being leached and thus can be used for load calculation at the field level. For leachate samples, load is calculated by multiplying nutrient concentration in each sub-sample (mg/L) by the volume of leachate collected, by the collection container volume (feet^3, Width × Length × Depth), and by a correction factor for unit homogeneity.

Currently, there are no standard guidelines for the dimensions of the drainage lysimeter collection container, the collection container fill (which also enhance collection efficiency), and the capacity of the storage container. Hence, generally cultural practices and availability of materials have dictated the design of a drainage lysimeter. Consequently, it is often difficult to separate treatment effects (cultural practices) from lysimeter effects in many research reports.

Ideally, a drainage lysimeter should have an optimum collection area where the collection container collects leachate from the entire root zone below crop root system being tested, and should account for plant to plant and emitter to emitter variability (in the case of drip irrigation). Leachate collection efficiency may be calculated by dividing total leachate volume collected by total water applied for that time period (Zhu et al., 2002), and factors that may improve collection efficiency are the size of the collection container, and the presence of a wick. Previous work done with large plate lysimeters has shown that collection containers with collection surfaces of 162, 500 to 2005 cm^2 had increased collection efficiencies from 10%, 13%, to 26%-36%, respectively (Radulovitch and Sollins, 1987). In a study comparing zero-tension (leachate collected by free drainage) pan lysimeters and wick lysimeters installed at a depth of 4.3 feet below the soil surface, wick lysimeters collected 2.7 times more leachate than drainage lysimeters did, thereby increasing efficiency. The higher efficiency was attributed to the breaking of soil water tension by the wick (Zhu et al., 2002).

Frequency of leachate collection and storage of leachate samples are two other factors that may affect load measurement. According to David and Gertner (1987) the leachate collected in the storage container should be retrieved at frequent intervals, multiple times a week, to minimize variability in within-site nutrient concentration measurements and prevent changes in the chemical composition of the leachate. Significant increases in NH_4-N concentrations were reported at 68°F due to mineralization reactions, and significant increases in NO_3-N concentrations were seen at -4°F and acidic pH due to oxidation of NO_2^- (Clough et al., 2001). If leachate samples are being stored before analysis, the optimum storage conditions are at 39.2°F without acidification. These conditions minimize transformations of NO_2^- to NO_3^-, and minimize overestimation of NO_3^- concentrations (Clough et al., 2001).

Soil sampling is another method for direct load measurement. Typically, a soil sample used for load determination consists of a 5-foot deep soil core divided into five subsamples, each 1-foot long. A known amount of extractant is added to the sample to saturate it. After thorough mixing of the sample, chemical extraction or analysis is performed. Generally, the NH_4-N and NO_3-N concentrations in soil samples are determined using modified EPA method 350.1 and EPA method 353.2 respectively (USEPA, 1993). The chemical concentrations are then converted to original field water content basis (Ahmed et al., 2001). Nutrient load is then calculated by multiplying nutrient concentration in each sub-sample (mg/kg soil) by the wetted soil volume (feet^3, Width × Length × Depth), by soil bulk density (assumed to be homogenous), and by a correction factor for unit homogeneity. The bulk density of soils can be measured in the laboratory (USDA, 2004), or soil bulk density estimates may be found in soil survey reports published of the Natural Resources Conservation Service (USDA-NRCS, 2008).

The length (total L of mulched bed per unit area) and depth (length of the soil sub-sample) of the wetted soil volume are well known. However, width estimates of the wetted soil volume are not well known and may vary with the irrigation program and soil type. Moreover, factors which affect the volume of the wetted zone, such as soil physical properties and their spatial variability, initial moisture content, width of raised plant bed, and irrigation length (Clark and Smajstrla, 1993; Santos et al., 2003; Simonne et al., 2005; Simonne et al., 2006) also affect the width of wetted zone. Farneselli et al. (2008) reported estimates of mean (28.7, 23.6, 18.5, 13.4, and 8.3 inches for the 5.9, 18.1, 29.9, 42.1 and 53.9 inch depths, respectively), and maximum (40.9, 33.1, 25.2, 17.3, and 9.8 inches for every 1-foot depth increment) wetted widths that can be used for calculating mean and maximum nutrient loads from raised plant beds on Blanton-Foxworth-Alpin soil series (fine sand). However, their results were based on a single irrigation event without a crop, and depending on either the mean, bed or maximum wetted width, could result in nutrient load from 18.9-34.9 lb/acre. On the other hand, as there are no reported estimates of actual in-field wetted widths for different crop species, the mean and maximum wetted width estimates reported by Farneselli et al. (2008), and the bed width of the raised plant bed are currently the best estimates of wetted widths in Florida sandy soils.

A great number of similarities exist in the methods and sampling procedures used for collecting or monitoring nutrient concentrations. Also, the construction design of lysimeters, and the methodology of soil sampling procedures are explained in great detail in the literature. However, when nutrient concentrations are converted from mg/kg (for soil sampling) and mg/L (for lysimeters) to nutrient loads on a per-unit area basis, most articles do not give a detailed methodology of load calculation and there are no similarities in published literature (Abad et al., 2004; Aparicio et al., 2008; Daudèn and Quílez, 2004; Lecompte et al., 2008; Macaigne et al., 2008; Oikeh et al., 2003; Poudel et al., 2002; Ramos et al., 2002; Rajput and Patel, 2006; Sainju et al., 1999; Vázquez et al., 2006; Yaffa et al., 2000; Zotarelli et al., 2008; Zvomuya et al., 2003).

With soil sampling as a method to monitor nutrient leaching, few of the reports do not convert the NO_3-N concentration in the soil samples to NO_3-N load on per-hectare basis (Daudèn and Quílez, 2004; Macaigne et al., 2008; Poudel et al., 2002; Rajput and Patel, 2006; Yaffa et al., 2000). While some of the reports that measure NO_3-N load with soil sampling on per-hectare basis mention both the NO_3-N analytical procedure and the soil bulk density values (Halvorson et al., 2002; Zvomuya et al., 2003), some mention just the NO_3-N analytical procedure used (Abad et al., 2004; Sainju et al., 1999), and others mention neither the NO_3-N analytical procedure used nor the soil bulk density values (Oikeh et al., 2003). Syvertsen and Jifon (2001) provide the dimensions of their drainage lysimeters, however, they failed to report the NO_3-N analytical procedure and reported their results as NO_3-N concentration/lysimeter rather than NO_3-N load on per-hectare basis. For bell pepper production on plasticulture system, Romic et al. (2003) on the other hand reported NO_3-N load measured with drainage lysimeters on per-hectare basis. They, however, failed to mention whether the NO_3-N load values reported are on a cropped hectare basis or on a unit area basis.

With suction type lysimeters (SCL), where drainage cannot be estimated directly, Aparicio et al. (2008) calculated NO_3-N losses with the following equation, NL = DC/100, where NL is the NO_3-N losses at various soil depths, D is drainage water estimated using the LEACH-W model, and C is the NO_3-N concentration (analytical method not mentioned) in the soil solution extracted with the SCL. Vázquez et al. (2006), Zhu et al. (2005), and Zvomuya et al. (2003) on the other hand estimated NO_3-N losses from each sampling interval as the product of NO_3-N concentration is the soil solution and the amount of drainage. Vázquez et al. (2006) and Zvomuya et al. (2003) calculated drainage with the following equation, $D = P+I-\Delta S-E$, where D is the amount of daily drainage, P is the precipitation, I is the irrigation water applied, ΔS is the change in soil water storage between consecutive days, and E is the evapotranspiration. However, Zhu et al. (2005) measured drainage directly using modified lysimeters. The three publications also varied in their methodology for analyzing NO_3-N concentrations. While Vázquez et al. (2006) estimated NO_3-N concentration in the soil solution samples spectrophotometrically after reduction in cadmium solution (Keeney and Nelson, 1982), Zhu et al. estimated NO_3-N concentration in the soil solution samples colorimetrically with the Bran and Luebbe Model TRAACS 2000 continuous-flow analyzer. On the other hand Zvomuya et al. (2003) used the diffusion-conductivity method (Carlson et al., 1990) to estimate NO_3-N concentration in the soil solution samples.

Nutrient load or leaching is influenced by several natural and cultural factors. Some of the natural factors are climate, hydrology, soil characteristics, and topography, and some of the cultural factors are tillage, mulching, fertilization (type of fertilizer, rate, placement, and timing of application), nitrogen use efficiency of the plant (NUE) and irrigation (quantity, rate, frequency, and method of application) management. Factors that affect nutrient load or leaching (natural and cultural factors) also affect the variations in N leaching. Climatic conditions and fertilization affected variations in NO_3-N leaching by ±65%, crop rotations by ±20-25% (Krysanova and Haberlandt, 2002), fertilizer inputs alone affected variations in NO_3-N leaching by ±40% (Mertens and Huwe, 2002), and agricultural land management affected variations in N leaching by ±48% (Schmidt et al., 2008). Hengsdijk and van Ittersum (2001) showed the uncertainties associated with future modeling of NO_3-N leaching losses as functions of crop characteristics, yield levels, and crop residue-nitrogen to be -36% and +70%, -30% and +40%, and -64% and +67%, respectively. The potential for leaching might also be influenced by the NUE of the crop. Crops with low NUE could potentially result in high leaching losses. The reported NUE of crops are highly variable (Table 4-1), and for tomato depending on the soil type the NUE ranged from 27% (silt loam (Hills et al., 1983)) to 82% (sand (Scholberg et al., 2000)). A study done by David and Gertner (1987), found that the CV for volume of leachate and NO_3-N concentration measured during the study was 122% and 218% respectively. Moreover, they found that the variability in volume and NO_3-N concentration recorded within a site, soil horizon, and pit, over each period of time accounted for 18% and 15% of total variability, the variability in volume and NO_3-N concentration within a period of time re-measurement accounted for 55% and 32% of the total variability, and variation in pits within a site accounted for 50% of the total variability for NO_3-N concentration. Hansen et al. (1999) found that variability in agricultural land management resulted in CV ranging from 20% to 40%. Due to variability in N-load results with location, cropping system, and soil type site specific in-field load estimates are the best predictors of total-N load. Zotarelli et al. (2007, 2008) conducted several experiments to compare different methods of monitoring nitrate leaching in sandy soils, and for determining nitrogen and water use efficiency of zucchini squash. They reported that in sandy soils, depending on the method used to monitor nitrate leaching, nitrate-N load ranged from 1.79-33.93 lb/acre in bell pepper, 2.68-33.04 lb/acre in tomatoes, and 1.79-40.19 lb/acre in zucchini. While the CV was relatively lower than the previous studies it ranged from 26.3-35.9% for bell peppers, 15.8-31.5% for tomatoes, and 19.6-30.0 for zucchini. Moreover, with the drainage lysimeter method of estimating nitrate-N leaching, Zotarelli et al. (2007) applied a partial vacuum of 5.1-5.8 PSI which may have affected the overall nitrate-N solution flow and/or drainage.

As previously mentioned, quantifying in-field nutrient load lacks consistency in method of measurement, and there is no mention of the wetted width used in conversion of nutrient concentrations from soil and leachate samples into nutrient load on a per-unit area basis. Therefore, the goal of this project was to determine the effects of different irrigation-nutrient management programs on tomato seasonal nutrient load. The specific objectives of this study were to 1) determine the effects of a combination of irrigation-nutrient management programs on tomato seasonal total-N load as measured with drainage lysimeters, 2) determine the effects of lysimeter design on tomato seasonal total-N load measured, 3) determine the effect of depth of sampling on NO_3-N, NH_4-N and total soil-profile-N using soil samples and three different estimates of bed widths (mean wetted width, maximum wetted width, and raised bed width), 4) determine the effects of a combination of irrigation-nutrient management programs on soil-profile NO_3-N, NH_4-N and total-N using soil samples and three different estimates of bed widths (mean wetted width, maximum wetted width, and raised bed width), and 5) determine the relationship between total-N load measured with drainage lysimeters and soil-profile total-N measured with soil sampling.

Materials and Methods

Experimental Setup

The experiment was conducted at the North Florida Research and Education Center-Suwannee Valley at Live Oak, Fla. on Blanton-Foxwort-Alpin Complex soil series (20-feet deep fine sand). Field preparation and layout of treatments was done as described in Chapter 1. On April 8th, 2005 and April 5th, 2006 6-week old (Days After Transplanting (DAT) = 0) 'Florida

47’ transplants were transplanted onto the plasticulture system with a 18-inch within row spacing, on 6-foot center raised plant beds, and establishing plant a population of 4,840 plants/acre. The irrigation-nutrient management programs were a combination of preplant fertilizer source, fertilizer rate, and irrigation rate (Table 3-1). The current IFAS recommendation for N and K for commercial tomato production was used as the 100% fertigation rate and twice that amount for the 200% fertigation rate. Split application of fertilizer treatments through the drip tape was done weekly throughout the growing season and in both years (Figure 3-1).

A medium flow rate drip-tape was used for supplying the irrigation. The 100% and 300% irrigation rate was achieved by installing one drip tape three drip tapes to the respective experimental plots (24 gallons/100 ft/h flow rate at 12 PSI operating pressure, 12-inch emitter spacing; John Deere Water Technologies, San Marcos, CA). Separate drip tapes were also installed for fertigation. For the 100% and 200% fertigation rate one and two drip tapes were installed respectively. Based on the irrigation-nutrient management program, the total number of drip tapes in each program ranged from 2 to 5. Irrigation was applied as described in Chapter 1 (Figure 3-2.) respectively. As fertigation and irrigation are applied either on a weekly and daily basis, the weekly and daily amounts of fertilizer and irrigation to be applied tend to have very narrow differences between them, which then tends to result in narrow differences in fertilizer and irrigation rate treatments. Therefore, for this experiment we chose the standard IFAS rate and much higher rates of fertilizer and irrigation management as an attempt to have large treatment differences on a daily basis even with the split application of the treatments. Current recommendations for commercial tomato production for pest and disease control and all other production practices were followed (Olson et al., 2007).

Drainage Lysimeters: Installation

In March 2005, two types of drainage lysimeters designs were installed under ground at 2-feet depth to monitor different irrigation-nutrient management programs for nutrient leaching (Table 3-1). The lysimeters were installed at this depth to be below the crop root zone and to avoid damage by tillage operations. The collection containers of the lysimeters were constructed out of 55-gallon drums cut in half lengthwise. The collection containers were 3-feet long, 2-feet wide, 1-foot deep, and filled with either soil only (Soil Only Design) or soil and gravel (Soil & Gravel Design) (Figure 4-1). The Soil Only lysimeters were installed under programs 1-5 and the Soil & Gravel lysimeters were installed under program 6. The leachate storage containers, 55-gallon plastic barrels, were installed under the collection containers.

Prior to installation of the lysimeters, the field was tracked to form the outline of the raised plant bed treatment rows. Both the lysimeter designs were installed lengthwise within the treatment rows, and the collection containers were installed with 2% lengthwise slope to facilitate water movement into the storage container and to reduce the risk of a perched water table. A 2-inch diameter PVC-pipe (sample retrieval spout) running from the top of the soil and through a hole in the lid of the storage container, and connected to the bottom was installed to facilitate the retrieval of leachate water inside the storage container. The top 18-inch detachable part of the sample retrieval spout was removed for tillage purposes and reinstalled a minimum of 7 DAT.

Drainage Lysimeters: Sampling, Sample Analysis, and Load Calculation

As the sample retrieval spouts were not accessible until all tillage operations and transplant establishment were completed, the leachate was not retrieved from drainage lysimeters until 13 DAT in 2005 and 30 DAT in 2006. Afterward, the storage containers were probed once in every two weeks with a 10-foot long dipstick, and leachate was retrieved from the lysimeters with leachate inside them. Leachate was retrieved 13, 31, 48, 66, 77, and 98 DAT in 2005, and 30, 43, 57, 70, 85, 110, 148 DAT in 2006. For lysimeters without leachate inside them, the volume and nitrate (NO_3-N) concentration were recorded as “0”. Leachate was retrieved with a silicone tube attached to a pump (B/T Rapid-Load Variable Occlusion Peristaltic Pump, Cole-Parmer Instrument Co, Vernon Hills, IL) that was placed into the 2-inch diameter PVC-pipe. On each sample retrieval date leachate was pumped out and volume immediately measured and recorded. Aliquots of 0.8 oz volume were collected, treated with 2-drops of hydrochloric acid to stop nitrate loss, and rapidly frozen at -18 ºC until analysis.

The leachate samples were analyzed by the University of Florida (UF) Analytical Research Laboratory (ARL) in Gainesville, Fla. for NO_3-N concentration using EPA method 353.2. In addition to the ARL laboratory quality assurance/quality control, set standards of NO_3-N in nitric acid concentrations were randomly included in the sample set. NO_3-N concentrations in the leachate samples were converted to N-load on a cropped-acre basis (lb/acre) by multiplying the nutrient concentration in each sub-sample (mg/L) by the volume (gallons) of leachate collected, and by the length of the collection container (feet). Cumulative N-load at the end of the tomato growing season was calculated as the sum of the N-load of each collection event.

Soil Sampling: Sampling, Sample Analysis, and Load Calculation

Similar to Abad et al. (2004), soil sampling was done at the end of the tomato production season on 104 and 92 DAT in 2005 and 2006, respectively using 5-foot long, 2.5-inch internal diameter steel tubes (Forestry Supplies, Inc., Jackson, MS). One of the assumptions of the soil sampling procedure was that the rate of vertical movement of water is 0.07 inches/gallon/100ft or up to 7-inch depth for a 4-hr irrigation duration per day. A second assumption was that nutrient concentration was uniformly distributed in wetted zone (Simonne et al., 2006). Therefore, samples were taken at the center of the raised-bed from each experiment plot, and within each plot, each sample was the composite of two cores taken approximately 5-feet apart. These soil cores were subdivided into five 1-foot long sections representing 0-1, 1-2, 2-3, 3-4, 4-5 foot depths, and each section was bagged separately. The sample bags were frozen at -18 ºC until analysis. The soil samples were analyzed by the UF ARL in Gainesville, Fla. for NO_3-N and NH_4-N concentrations with Mehlich-1 extractant (0.0125 M H_2SO_4 and 0.05 M HCl). The NH_4-N was determined using modified EPA method 350.1 and NO_3-N was determined using EPA method 353.2 (USEPA, 1993).

Nitrogen (NO_3-N and NH_4-N) concentrations in the soil samples were converted to NO_3-N, NH_4-N, and total N-load (sum of NO_3-N and NH_4-N load) on a cropped-acre basis (lb/acre) by multiplying N concentration in each sub-sample (mg/kg_{soil}), by the wetted zone volume ($feet^3$, W x L x D), and by soil bulk density (90.6 $lb/feet^3$, USDA, 1961). As there are no reported estimates of actual wetted widths in the crop root zone, wetted zone width was calculated based on mean, maximum and bed width at the five sampling depth sections (Farneselli et al., 2008).

Data Analysis

The above ground irrigation-nutrient management programs were organized in a randomized complete block design with four replications. As the drainage lysimeters were buried in the ground and could not be re-installed every year, except for 200% Fertigation, 300% Irrigation-ML irrigation-nutrient management program, the remaining irrigation-nutrient management programs were randomized in both years. Soil and drainage lysimeter leachate sample responses to irrigation-nutrient management programs were determined using ANOVA and treatment means were compared using Duncan's multiple range test (SAS, 2008). The orthogonal contrasts "Nitrogen rate (100% vs 200%)", "Preplant fertilizer source (CL vs Inorganic Fertilizer)", and "Irrigation rate (100% vs 300%)" were used to test the significance of the difference between rate of fertilizer applied, source of preplant fertilizer, and irrigation rate.

Pearson’s correlation coefficient analysis was performed with PROC CORR (SAS, 2008) to correlate seasonal total-N load for the different monitoring methods.

Results and Discussion

Weather Conditions

Rainfall was relatively higher than seasonal levels during April, June, July, and was lower than normal in May 2005. During 2006 rainfall was relatively lower than normal in April, May, July, and higher than normal in June (Figure 3-3C). Rainfall events of more than 1-inch during 2005 occurred on 22, 58, 64, 65, 82, and 86 DAT recording 1.83, 1.44, 1.66, 1.04, 2.46, and 2.35 inches, respectively, and accounted for 59% of total rainfall recorded from April 8 to July 5, 2005. During 2006 rainfall events of more than 1-inch occurred on 3, 57, 68, 69, and 81 DAT recording 1.28, 1.59, 1.6, 2.25, and 1.47 inches, respectively and accounted for 67% of total rainfall recorded from April 5 to July 5, 2006 (FAWN, 2008). Based on the above weather information, 2005 was a relatively cooler and wet year, while 2006 had normal temperatures for North Florida. However, in 2006 the early part of the tomato growing season (April-May) was dry while the latter part was wet (June-July).

Seasonal Total-N Load Estimate Based on Drainage Lysimeter

For tomato seasonal total-N load calculated from drainage lysimeters, the interaction year x treatment was significant for both the volume of leachate (gallons) recorded and the total-N load (lb/acre) estimates ($p < 0.01$). Therefore, data from both years were analyzed separately. In 2005, there were no significant differences between the leachate volumes recorded for the irrigation-nutrient management programs. In 2006, there were significant differences between the leachate volumes recorded for the irrigation-nutrient management programs. Highest total leachate volume (87.2 gallons) was recorded with 200% Fertigation, 300% Irrigation-ML irrigation-nutrient management program and the lowest with 100% Fertigation-CL,100%

Irrigation, 100% Fertigation, 100% Irrigation, and 100% Fertigation, 300% Irrigation irrigation-nutrient management program (Figure 4-2A). In 2005 and 2006, irrigation-nutrient management program had a significant effect on total-N load. In 2005, the highest total-N load (8.93 lb/acre) was recorded with 200% Fertigation, 300% Irrigation-ML irrigation-nutrient management program ($p = 0.02$) and there were no significant differences between the remaining five irrigation-nutrient management programs (Figure 4-2B). The total-N load was relatively higher with the higher N nutrient management programs (200% Fertigation-100% Irrigation, 200% Fertigation-300% Irrigation, 200% Fertigation-300% Irrigation-ML) than with the lower N management programs (100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 100% Fertigation-300% Irrigation) (Figure 4-2). However, the CV was high and ranged from 87%-176%. Based on the orthogonal contrasts, the differences in the total-N load were due to the lysimeter design and were not due to the irrigation-nutrient management program. Higher total-N load ($p \leq 0.01$) was recorded with the Sand & Gravel lysimeter design (7.14 lb/acre) than with the Soil Only lysimeter design (0.79 lb/acre).

In 2006, highest total-N load (18.75 lb/acre) was recorded with 200% Fertigation, 300% Irrigation-ML irrigation-nutrient management program and the lowest total-N load was recorded with 100% Fertigation-CL,100% Irrigation, 100% Fertigation, 100% Irrigation, 100% Fertigation, 300% Irrigation, and 200% Fertigation, 100% Irrigation. Similar to the 2005 results, the CV was very high and ranged from 68%-208%. Based on the orthogonal contrasts, the differences in the total-N load were due to the irrigation management program ($p \leq 0.01$) and the lysimeter design ($p \leq 0.01$) and were not due to the nutrient management program. Higher total-N load ($p \leq 0.01$) was recorded with the Sand & Gravel lysimeter design (15.27 lb/acre) than with the Soil Only lysimeter design (7.05 lb/acre), and higher total-N load was recorded with

200% irrigation management program (8.17 lb/acre) than with 100% irrigation management program (0.31 lb/acre). Therefore, the Soil & Gravel drainage lysimeter design should be used for monitoring total-N load.

A study done by David and Gertner (1987), found that the CV for volume of leachate and NO_3-N concentration measured during the study was 122% and 218%, respectively. Moreover, they found that the variability in volume and NO_3-N concentration recorded within a site, soil horizon, and pit, over each period of time accounted for 18% and 15% of total variability, the variability in volume and NO_3-N concentration within a period of time re-measurement accounted for 55 and 32% of the total variability, and variation in pits within a site accounted for 50% of the total variability for NO_3-N concentration.

Soil-profile Total-N Load Estimate Based on Soil Sampling

For tomato soil-profile total-N calculated from soil sampling, the interaction year x treatment was significant for most of the load estimates ($p < 0.01$). Therefore the data from both years were analyzed separately. In 2005, the NH_4-N load estimate based on bed wetted width did not vary with depth ($p = 0.22$). For the remaining NH_4-N, NO_3-N, and total-N load estimates, irrespective of method of estimating the wetted width, load estimates were highest in the first 1-foot depth of soil, and did not vary for the 2-5 foot soil depth (Table 4-2). All NH_4-N, NO_3-N, and total N load estimates (based on mean, bed, and maximum wetted width, and except for bed NH_4-N) followed the pattern 1 > 2 = 3 = 4 = 5 foot depth (Table 4-2).

In 2006, all NH_4-N, NO_3-N, and total-N load estimates (based on mean, bed, and maximum wetted width) varied significantly with depth ($p \leq 0.01$). Moreover, irrespective of method of estimating the width, NH_4-N, NO_3-N, and total-N load estimates were highest in the first 30.5-cm depth of soil (Table 4-2). These results were contrary to those reported by Sainju et al. (1999) who observed an increase in NO_3-N load with an increase in soil depth. The NH_4-N load estimates based on mean and maximum wetted width estimates increased with an increase in the soil depth and followed the following pattern 1 > 2 > 3 > 4 > 5 foot depth, while the NH_4-N load estimates based on bed wetted width followed the pattern 1 = 2 > 3 = 4 = 5 foot depth. All the NO_3-N load estimates followed the pattern 1 > 2 = 3 = 4 = 5 foot depth. Total-N load based on mean and maximum wetted width followed the following pattern 1 > 2 > 3 = 4 > 5 foot depth, while the total-N load based on bed wetted width followed the following pattern 1 > 2 > 3 = 4 = 5 foot depth (Table 4-2). These results suggest that the soil samples from the top 1-foot depth may have quantified the most recent fertilizer application (high total-N load in top 1-foot soil depth), and the N-load from the previous fertilizer applications may be beyond the highest soil depth monitored (5 foot depth).

Soil sampling load was calculated based on mean, maximum and bed wetted width (Farneselli et al., 2008). Depending on the method of estimating wetted width and the irrigation-nutrient management program, the total-N load ranged from 0.13-1.54 lb/acre in 2005, and from 1.5-4.3 lb/acre in 2006. In 2005, the irrigation-nutrient management programs did not have a significant effect ($p \geq 0.054$) on NH_4-N, NO_3-N, and total-N load. Moreover, the CV was high and ranged from 83%-135% (Table 4-2). In 2006, except for NH_4-N load estimates based on mean and maximum bed width, NH_4-N load based on bed width ($p = 0.02$), NO_3^--N load (based on mean, bed and maximum wetted widths), and total-N load (based on mean, bed and maximum wetted widths) varied significantly with irrigation-nutrient management program ($p < 0.01$). Although the irrigation-nutrient management programs had a significant effect on the nutrient load estimates in 2006, the coefficients of variation were high and ranged from 38%-97% (Table 4-3). Highest and lowest NH_4-N load based on bed width were seen with 200% Fertigation, 300% Irrigation-ML and 100% Fertigation-CL,100% Irrigation irrigation-nutrient management programs respectively (1.6 and 1.07 lb/acre respectively). Significantly higher ($p < 0.01$) NO_3-N load estimates (2.09-3.1 lb/acre) were recorded with 200% Fertigation, 100% Irrigation irrigation-nutrient management program for all three methods of estimating wetted width (Table 4-3). Similarly, significantly higher ($p < 0.01$) total-N load estimates (3.18-4.32 lb/acre) were recorded with 200% Fertigation, 100% Irrigation irrigation-nutrient management program for all three methods of estimating wetted width (Table 4-3). These results suggest that based on soil sampling, increasing fertilizer rate from 100% to 200% resulted in a significant increase in NO_3-N load and total-N load in the soil. However increasing both the fertilizer and irrigation rates (200% Fertigation, 300% Irrigation, 200% Fertigation, 300% Irrigation-ML irrigation-nutrient management programs) tended to dilute nutrient concentration which reduced NO_3-N load and total-N load measured. The inorganic-N concentrations measured in the tomato field from the different treatments within 1-foot depth (0.64-8.31 mg/kg of soil) were lower than those reported in literature for soil samples (sandy loam) collected at similar depth and tomato production stage (15-45 mg/kg of soil; Yaffa et al., 1994). Also the total-N load values measured (0-18.75 lb/acre) were lower than those reported in literature for soil samples collected from similar depths (23.2-192.9 lb/acre, Sainju et al., 1999). However, the studies done by Sainju et al. (1999) and Yaffa et al. (1994) were conducted on Norfolk sandy loam soils (65% sand, 25% silt, and 10% clay) with a higher anion exchange capacity than the fine sand soils of the current study. Moreover, for plasticulture raised beds or row crops, depending on whether nutrient concentration is converted to nutrient load on per-cropped hectare or per-real estate hectare, nutrient load may be overestimated 3-fold (when raised bed or rows are on 6-foot centers). In a similar study done by Zotarelli et al. (2007) on sandy soils the N load measured with soil samples ranged from 4.6-32.51 lb/acre. The total-N load measured in the current study was much lower and ranged from

1.49-4.32 lb/acre. In the current study, soil samples were collected at the end of the tomato season, Zotarelli et al. (2007) on the other hand collected soil samples bi-weekly.

One of the assumptions of the study was that the rate of vertical movement of water is 0.07 inches/gallon/100ft or up to 7-inch depth for a 4-hr irrigation duration per day. Moreover, the maximum possible depth of the wetted zone (46.5-46.9 inches; Farnaselli et al., 2008) was well within the depth to which the soil samples were taken (60 inches). However based on the nutrient load measured, the rate of vertical movement of water was probably greater than our assumption. Another assumption of the study was that nutrient concentration is uniformly distributed in wetted zone (Simonne et al., 2006). Based on the low nutrient loads that we recorded within the wetted zone, however, the nutrient concentration distribution could possibly be non-uniform and soil sampling at the drip tape may be a zone of highest leaching rate. Moreover, Simonne et al.'s (2006) results are based on a single irrigation event and do not reflect the actual water and fertilizer movement during the cropping cycle. However, except for modeling and soil column studies (Chen et al., 1996; Mansell et al., 1988; Mansell et al., 1992; Mansell et al., 1993; Ouyang et al., 2004; Shinde et al., 1996), there are no in-field reports on water and solute movement in acidic sandy soils. In the current study soil samples were collected at the end of the growing season and sampling at the end of the cropping cycle may not give a complete estimate of N losses from the crop root zone and more frequent soil sampling might be required.

Relationship between Seasonal Total-N Load Measured with Drainage Lysimeters and Soil-Profile Total-N Measured with Soil Sampling

Although Pearson's correlation comparative analysis was performed on seasonal total-N load monitored with drainage lysimeters and soil-profile total-N measured with soil sampling, there was no significant relationship ($p > 0.70$) between the two measures ($r = 0.052$ drainage lysimeter x soil sampling$_{\text{bed width}}$, r = 0.069 drainage lysimeter x soil sampling$_{\text{mean width}}$, r = 0.07 drainage lysimeter x soil sampling$_{\text{maximum width}}$).

Conclusion

The effect of irrigation-nutrient management programs on tomato seasonal total-N load varied with year. In both 2005 and 2006, higher total-N load was recorded with Soil & Gravel lysimeter design than with Soil Only lysimeter design. With soil sampling, irrespective of treatment, tomato soil-profile total-N was highest in the first 1-foot depth of soil, and tended to decrease with an increase in depth. Tomato soil-profile total-N varied with year, depending on the method of estimating wetted width and the irrigation-nutrient management program, the soil-profile total-N load ranged from 0.39-1.54 lb/acre in 2005, and from 1.49-4.32 lb/acre in 2006. The soil-profile total-N load measured in 2005 was much lower than that measured in 2006, and the results within each year showed high variability. There were no significant differences between the irrigation-nutrient management programs in 2005. While, in 2006 the highest soil-profile total-N load was recorded with 200% Fertigation-100% Irrigation program and lowest soil-profile total-N load was recorded with the high irrigation programs (100% Fertigation-300% Irrigation, 200% Fertigation-300% Irrigation, 200% Fertigation-300% Irrigation-ML). However, based on the relatively low soil-profile total-N loads recorded, the rate of movement of the water front in this study might have been higher than expected from past research conducted under similar conditions of soil and irrigation. Moreover, within the wetted zone the nutrient concentration distribution could possibly be non-uniform, and soil sampling at the drip tape, possibly the zone of highest leaching rate, might not have been the best option. Therefore, both the drainage lysimeters and the soil samples might have underestimated the tomato seasonal total-N load and the soil-profile total-N from the different irrigation-nutrient management programs. A comparison of the seasonal total-N load monitored with drainage lysimeters and soil-profile total-N measured with soil sampling showed a lack of relationship between the two measures. Further, due to the lack of consistency in methodology of reported nutrient loads, a true comparison of total-N load across studies was not possible, and given the inherent variability associated with nutrient load measurements from site to site and within site, a comparison of total-N load across studies might not be a valid comparison.

Table 4-1. Published estimates of nitrogen use efficiency (NUE) in selected crops.

Crop	Soil Type	Location	NUE (%)	Reference
Cauliflower	Sandy Loam	Denmark	60-84	Sørensen, 1996
Canola	Loam[z]	Canada	35-42	Gan et al., 2008
Corn	Coarse-Fine Loamy	N. Dakota	50	Wienhold et al., 1995
Corn	Silt Loam	California	52-57	Hills et al., 1983
Corn	Silt Loam	Kansas	46-48	Olson, 1980
Leeks	Sandy Loam	Denmark	58-87	Sørensen, 1996
Mustard	Coarse Sandy Clay	India	53-93	Ahmad et al., 2008
Onion	Silt Loam	Utah	59-99	Drost et al., 2002
Onion	Silty Clay	Colorado	11-19	Halvorson et al., 2002
Onion	Sandy Loam	Denmark	102-182	Sørensen, 1996
Hot pepper	Sandy Loam	China	11	Zhu et al., 2005
Rice	Silt Loam	Louisiana	17-23	Patrick et al., 1974
Rice	Silt Loam	Louisiana	33-61	Reddy & Patrick, 1976
Ryegrass	Sandy Loam	Alabama	90	Terman & Brown, 1968
	Silty Clay		85	
Sugarbeet	Silt Loam	California	27-37	Hills et al., 1983
Sugarbeet	Loam	California	47	Hills et al., 1978
Tomato	Sandy	Egypt	51-68	Badr, 2007
Tomato	Clay Loam	California	40-50	Miller et al., 1981
Tomato	Silt Loam	California	27	Hills et al., 1983
Tomato	Sand	Florida	36-82	Scholberg et al., 2000
Tomato	Clay-Sandy Clay	Turkey	72-76	Topcu et al., 2007
Wheat	Silt Loam	Kansas	77-81	Olson et al., 1979
Zucchini	Sand	Florida	43-63	Zotarelli et al., 2008

[z] The experiment was conducted at four Saskatchewan locations: Melfort, Saskatoon, Scott, and Swift Current. The soil types at these locations were loam, clay loam, silt clay loam, abd silt loam respectively.

Table 4-2. Effects of depth of soil sampling in a 'Florida 47'tomato field during spring of 2005 and 2006[z] on nitrogen loads (lb/acre) based on mean, bed, and maximum wetted widths (WW).

Depth (feet)	NH_4^+-N Load (lb/acre)[y]			NO_3^--N Load (lb/acre)			Total N (lb/acre)[x]		
	Mean WW	Bed WW	Max WW	Mean WW	Bed WW	Max WW	Mean WW	Bed WW	Max WW
				2005					
0-1	0.48 a	0.41	0.69 a	2.02 a	1.79	3.00 a	2.59 a	2.21 a	1.02 a
1-2	0.25 b	0.26	0.35 b	0.45 b	0.46	0.63 b	0.70 b	0.72 b	0.97 b
2-3	0.20 b	0.26	0.27 b	0.17 b	0.22	0.23 b	0.52 b	0.48 b	0.50 b
3-4	0.16 b	0.3	0.21 b	0.35 b	0.64	0.46 b	0.37 b	0.94 b	0.67 b
4-5	0.11 b	0.31	0.13 b	0.18 b	0.54	0.21 b	0.29 b	0.84 b	0.34 b
p-values	< 0.01	0.22	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV (%)	122	83	127	133	122	135	125	104	128
				2006					
0-1	2.21 a	1.88 a	3.14 a	2.39 a	2.04 a	3.41 a	4.60 a	3.90 a	6.55 a
1-2	1.79 b	1.86 a	2.52 b	1.13 b	1.16 b	1.58 b	2.93 b	3.03 b	4.10 b
2-3	1.02 c	1.35 b	1.38 c	0.56 c	0.74 b	0.82 c	1.58 c	2.08 c	2.15 c
3-4	0.49 d	0.90 c	0.64 d	0.63 bc	1.16 b	0.76 c	1.13 cd	2.06 c	1.46 cd
4-5	0.23 e	0.68 c	0.28 e	0.45 c	1.33 ab	0.54 c	0.68 d	2.01 c	0.81 d
p-values	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV (%)	38	39	39	85	97	84	45	52	44

[z] The interaction term for year x irrigation and nutrient management program was significant for nutrient loads ($p \leq 0.05$), therefore the data from both years were analyzed separately.

[y] Means followed by different letters within each column are significantly different at the 0.05 level, according to Duncan's multiple range test.

[x] Total N load (lb/acre) based on bed, mean and maximum wetted widths was calculated by adding the NO_3^--N and the NH_4^+-N loads (lb/acre) from the respective wetted widths.

Table 4-3. Effects of irrigation-nutrient management programs in a 'Florida 47'tomato field during spring of 2005 and 2006[z] on nitrogen loads (lb/acre) based on soil sampling with three different wetted width (WW) estimates.

	NH_4^+-N Load (lb/acre)[y]			NO_3^--N Load (lb/acre)			Total N (lb/acre)		
Irrigation-Nutrient Management Programs[x]	Mean WW	Bed WW	Max WW	Mean WW	Bed WW	Max WW	Mean WW	Bed WW	Max WW
2005									
100% Fertigation-CL,100% Irrigation[w]	0.23	0.31	0.31	0.70	0.79	0.96	0.93	1.11	1.28
100% Fertigation-100% Irrigation	0.22	0.30	0.31	0.57	0.71	0.78	0.79	1.02	1.09
100% Fertigation-300% Irrigation	0.33	0.38	0.46	0.88	0.81	1.24	1.21	1.19	1.71
200% Fertigation-100% Irrigation	0.22	0.30	0.30	0.91	1.22	1.24	1.13	1.53	1.54
200% Fertigation-300% Irrigation	0.22	0.30	0.30	0.42	0.41	0.59	0.64	0.71	0.89
200% Fertigation-300% Irrigation-ML[v]	0.20	0.26	0.27	0.44	0.42	0.62	0.63	0.68	0.88
p-values	0.75	0.84	0.74	0.31	0.054	0.35	0.44	0.14	0.46
CV (%)	122	83	127	133	122	135	125	104	128
2006									
100% Fertigation-CL,100% Irrigation	1.79	1.79 c	1.31	1.52 b	1.91 b	2.09 ab	2.46 b	2.98 b	3.39 b
100% Fertigation-100% Irrigation	2.68	2.68 ab	1.74	1.16 bc	1.07 c	1.40 bc	2.26 bc	2.51 bc	3.14 bc
100% Fertigation-300% Irrigation	3.57	3.57 ab	1.68	0.56 c	0.56 c	0.79 cd	1.77 cd	2.00 c	2.46 cd
200% Fertigation-100% Irrigation	4.47	4.47 bc	1.54	2.09 a	3.10 a	2.79 a	3.18 a	4.31 a	4.32 a
200% Fertigation-300% Irrigation	5.36	5.36 bc	1.48	0.42 c	0.42 c	0.59 d	1.49 d	1.63 c	2.07 d
200% Fertigation-300% Irrigation-ML	6.25	6.25 a	1.79	0.63 c	0.64 c	0.88 cd	1.93 bcd	2.25 bc	2.68 bcd
p-values	0.11	0.02	0.13	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV (%)	38	39	39	85	97	84	45	52	44
Contrast Preplant source (CL vs 13-1.8-10.8)	.	0.95	.	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Contrast Fertigation rate (100% vs 200%)	.	0.06	.	0.02	< 0.01	0.03	0.15	0.02	0.19
Irrigation Rate (100% vs 300%)	.	0.06	.	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

[z] The interaction term for year x irrigation and nutrient management program was significant for nutrient loads ($p \leq 0.05$), therefore the data from both years were analyzed separately.

[y] Means followed by different letters within each column are significantly different at the 0.05 level, according to Duncan's multiple range test.

[x] Fertigation: Nitrogen-Potassium rate.
[w] For program 100% Fertigation-CL,100% Irrigation the source of the preplant fertilizer was chicken litter, while the rest of the programs had 13-1.8-10.8 as the source of preplant fertilizer.
[v] An additional program for estimating nitrate load using drainage lysimeters installed in the ground was carried out at the same time as the current study. The lysimeters installed under programs 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation were of the same design, and the lysimeters installed under the program 200% Fertigation-300% Irrigation-ML were modified (ML) in design and varied from the above lysimeters. To maintain the integrity of the predetermined programs data from 200% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML (which received the same above ground programs) were not combined.
[w] Total N load (lb/acre) based on bed, mean and maximum wetted widths was calculated by adding the NO_3^--N and the NH_4^+-N loads (lb/acre) from the respective wetted widths.

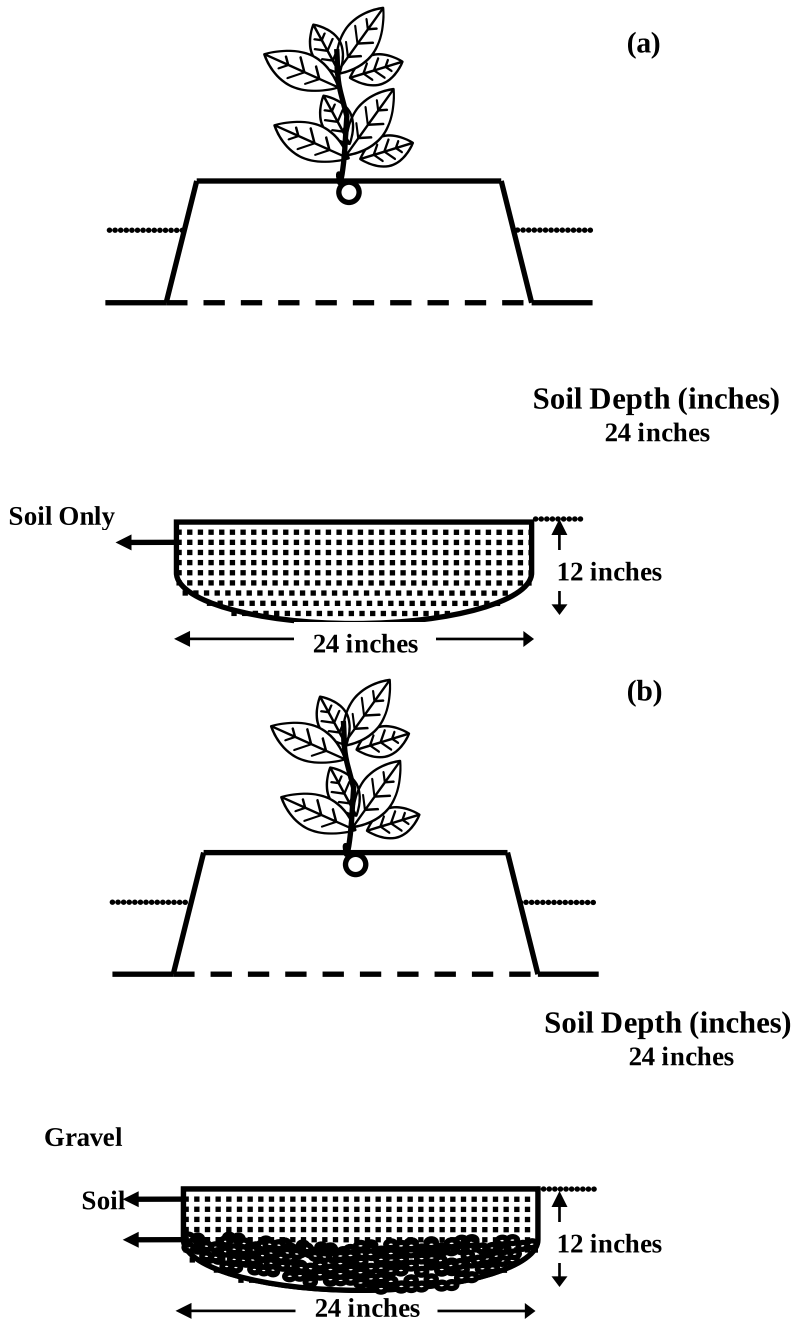


Figure 4-1. Schematics of the 3-feet long lysimeter designs used in the 2005 and 2006 fresh market tomato production experiment are as follows A) Soil Only and B) Soil & Gravel lysimeter. (Note: the dotted line in the figure represents the soil level prior to bed formation).

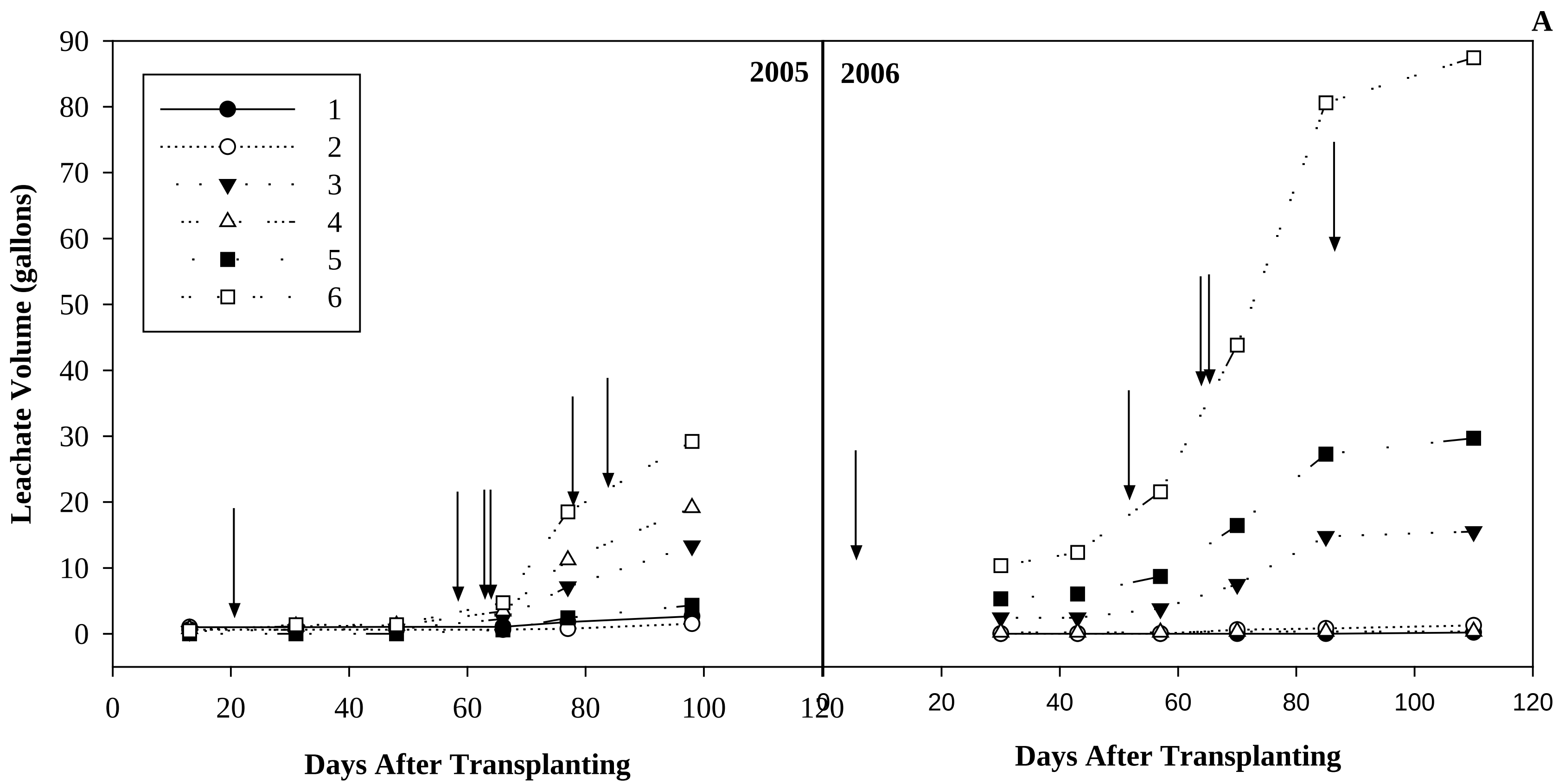


Figure 4-2. Effects of irrigation-nutrient management programs on A) mean leachate volume (L) collected, and B) mean nitrate load recorded during the 2005 and 2006 growing seasons with drainage lysimeters. (Note: the irrigation and nutrient management programs were 1) 100% Fertigation-CL,100% Irrigation, 2) 100% Fertigation-100% Irrigation, 3) 100% Fertigation-300% Irrigation, 4) 200% Fertigation-100% Irrigation, 5) 200% Fertigation-300% Irrigation and 6) 200% Fertigation-300% Irrigation-ML. The arrows indicate rainfall events greater than 1-inch. Means followed by different letters within each tomato fruit grade are significantly different at the 0.05 level, according to Duncan's multiple range test, and means within each tomato fruit grade without mean separation were not significantly affected by irrigation-nutrient management program. The mean separation was done in descending order of the means).

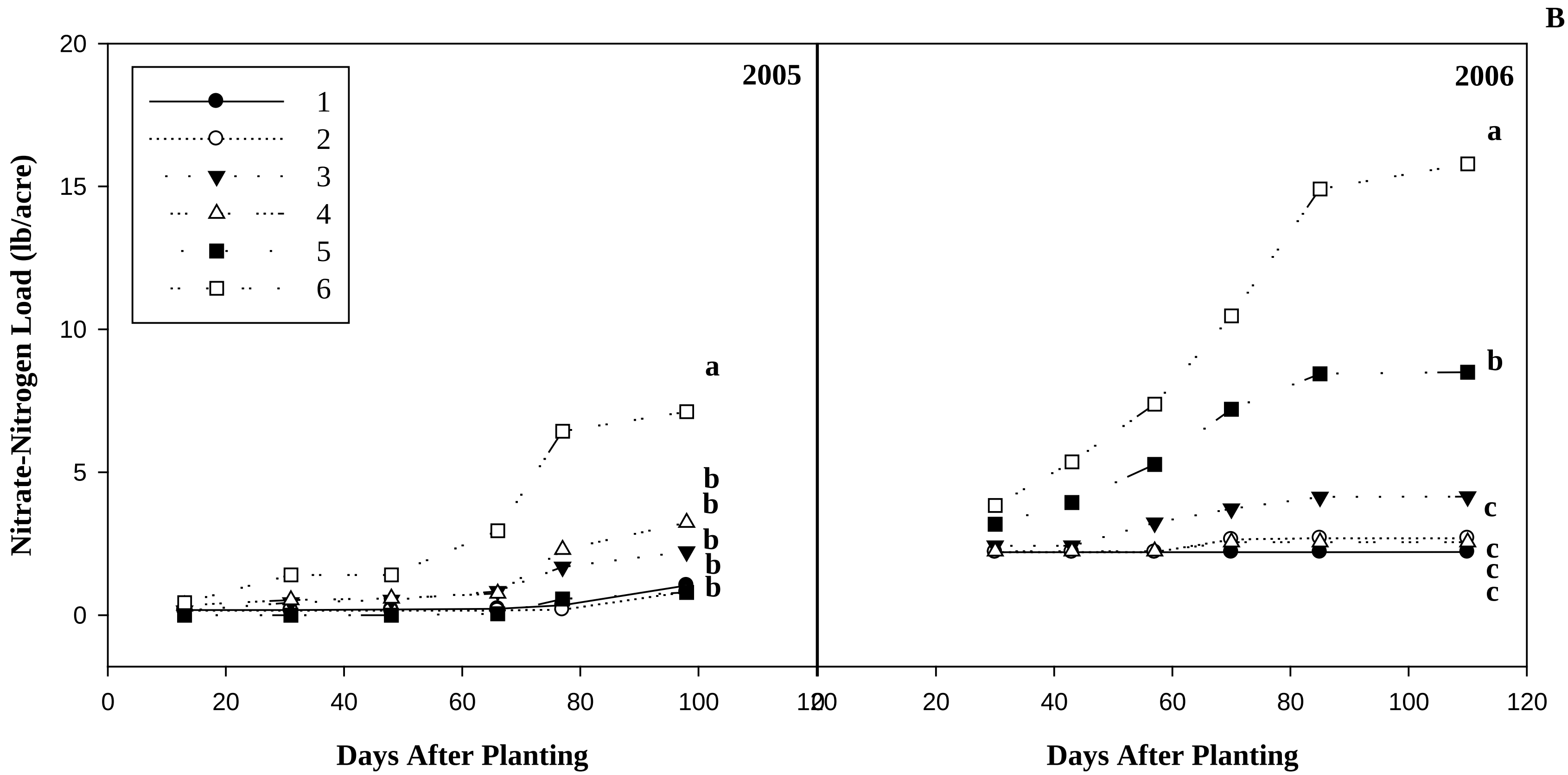


Figure 4-2. Continued

CHAPTER 5
NUTRIENT MANAGEMENT PROGRAMS FOR FRESH MARKET TOMATOES GROWN WITH PLASTICULTURE IN THE ERA OF BEST MANAGEMENT PRACTICES. III. ECONOMIC INSIGHTS

Introduction

Florida is the second largest producer of fresh market tomatoes (*Solanum lycopersicum* L.), for harvested acres and value of production, in the US. Tomato production in Florida accounts for approximately 39% of the national fresh market tomato production, and has an annual value of approximately $464 million (USDA-NASS, 2008). In North Florida, fresh market tomatoes are typically grown as a spring crop with raised beds, black plastic mulch, drip irrigation, greenhouse-grown transplants (Olson et al., 2007), and harvested 2-4 times at the mature green stage to ensure highest quality (Sargent et al., 2005). Quantity, rate, and scheduling of irrigation (Locascio, 2005), rate, sources, placement, and timing of fertilizer application are the main factors that affect fresh market tomato yield and quality (Hochmuth, 2003). Extensive research has been done to determine the fertilizer and irrigation requirements of drip-irrigated plastic mulched tomatoes. The current base fertilization recommendations for tomato production in Florida on soils testing very low in Melich-1 phosphorus (P) and potassium (K) are 66 and 187 lb/acre of P and K. For nitrogen (N) the fertilization recommendation based on research and crop nutrient requirement is 200 lb/acre N, and includes a detailed fertigation schedule (Olson et al., 2007). Production of fresh market tomatoes requires a significant financial investment in plasticulture, drip irrigation, hybrid seeds and transplants, and manual labor. Achieving high marketable crop yields has been a fundamental goal of tomato producers to assure economic viability. Growers perceive fertilizers as having a direct and positive impact on crop yields. Further, fertilizer as a crop input has been relatively cheap, representing less than 5% (University of Florida Center for Agribusiness, 2006) of the total production cost. Consequently, growers tend to apply fertilizer in excess of the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) recommended rates as a strategy to prevent nutrient shortages and maintain productivity (Cantliffe et al., 2006). Growers are also hesitant in reducing their irrigation amounts because of low water holding capacity of the sandy soils and because water movement below the root zone is a rather abstract concept to them.

With the adoption of the Federal Clean Water Act (FCWA) of 1977 (US Congress, 1977), states are required to assess the impact of non point sources of pollution on surface and ground waters, and establish programs to minimize them. Section 303(d) of the FCWA also requires states to identify impaired water bodies and establish Total Maximum Daily Loads (TMDLs) for pollutants entering these water bodies (FDACS, 2005; Gazula et al., 2007). As a result there has been an increased educational effort to encourage growers to follow the UF/IFAS recommendations for irrigation and fertilizer application. Environment friendly crop production practices may reduce farm income are very hard to sell to farmers and tend not to be adopted (Kelly et al., 1995). Comprehensive crop budget analysis and partial budget analysis help growers with their decision making process, and can be used to calculate potential profits from a change in specific farming operations (Muraro et al., 2005; Sydorovych et al., 2008). If growers are shown that under some circumstances, fertilizer/irrigation reductions are unlikely to reduce profitability, they may be more willing to follow UF/IFAS recommendations.

Partial budget analysis is a standard economic analysis tool used to determine the cost and return effects of change in a part of the production practices on production economics (Kay and Edwards. 1994; Sydorovych et al., 2008), and has in the past been used to test the economic impact of BMPs aimed at reducing N levels in river basin, or farms (Wossink and Osmond, 2002). Presently, few current research reports are available on the economic impact of the fertilizer and irrigation BMPs on fresh market tomato profitability. Therefore, to better understand the impact of irrigation and nutrient management practices on fresh market tomato production, a series of experiments were conducted simultaneously with selected irrigation-nutrient management programs. The goal of these experiments was to determine if possible BMPs (UF/IFAS recommendations) could lessen the negative impact of vegetable production (high fertilizer and irrigation rates) on the environment while maintaining or improving current yields and crop value of an economically important vegetable crop - fresh market tomatoes.

The specific objective of this study was to determine the economic impact of irrigation-nutrient management programs on fresh market tomato returns. The approach was to first assess the costs and returns associated with growing, harvesting, and marketing fresh market tomatoes grown with different irrigation-nutrient management programs and establish a fresh market tomato production model, and second through partial budget analysis assess the economic impact of changes in the irrigation-nutrient management programs on gross returns, gross returns relative to UF/IFAS recommended irrigation-nutrient management program, net returns, and net returns relative UF/IFAS recommended irrigation-nutrient management program.

Materials and Methods

Fresh Market Tomato Production System

A two-year experiment was conducted at the North Florida Research and Education Center-Suwannee Valley at Live Oak, Fla. on Blanton-Foxwort-Alpin Complex soil series (fine sand) during 2005 and 2006. Similar cultural practices were followed for both years. On April 8th, 2005 and April 5th, 2006 6-week old (Days After Transplanting (DAT) = 0) ‘Florida 47’ transplants were transplanted onto the plasticulture system with a 18-in within row spacing, and establishing plant a population of 5,808 plants/acre (1 acre = 7,260 linear bed feet). The plants were trained using the standard California/Florida stake and weave system. The irrigation-nutrient management programs were a combination of source of preplant fertilizers, fertilizer rates, and irrigation rates (Table 3-1). The current IFAS recommendation for N-K for commercial tomato production was used as the 100% fertigation rate and twice that amount for the 200% fertigation rate. Split application of fertilizer treatments through the drip tape was done weekly throughout the growing season and in both years. The standard medium flow rate used by growers in the area (24 gph/100-ft/hr at 12 psi, (12-in emitter spacing; John Deere Water Technologies, San Marcos, CA)), was used for supplying the irrigation. The 100% and 300% irrigation rate was achieved by installing one drip tape and three drip tapes to the respective experimental plots. For the 100% and 200% fertigation rate additional one and two drip tapes were installed respectively. Based on the irrigation-nutrient management program, the total number of drip tapes in each program ranged from 2 to 5.

Twenty-foot long sections located in the middle bed and representative of each experimental unit were marked for yield measurements. Mature green tomatoes were harvested at 66, 74, 81, and 88 DAT in 2005, and at 65, 85, and 91 DAT in 2006 and fruits were then graded as extra-large, large, medium, and culls (USDA, 1991). The tomato fruits in each grade were counted and then weighed. Weight of fruits from each grade were then converted to 25-lb carton/acre (A) by multiplying with the factor 17.44 (fruit weights from raised bed plots 20-feet long on 5-feet centers and with 13 plants each at 18-inch within row spacing were converted into fruit weights from 1-acre raised beds on 5-feet centers and 5808 plants at 18-inch within row spacing) in order to compare the total yields with yields reported by growers. Total marketable yield was calculated as the sum of extra-large, large, and medium grades. Total season yields were calculated as the sum of yields from all harvests and early season yields were calculated as the sum of first and second harvest yields (Locascio et al., 1985). Market prices for US #1 fresh market 25-lb tomato cartons during spring of 2005 and 2006 are presented in Table 5-1 (USDA, 2007).

Fresh Market Tomato Production Model for University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) Based Recommendations

The estimated cost to produce and harvest fresh market tomatoes with raised bed plasticulture system consist primarily of the following costs: fertilizer and irrigation costs (Table 5-2), operating costs, miscellaneous costs, fixed costs, and harvest and marketing costs (Table 5-3). The estimated costs per-acre needed to produce and harvest fresh market tomatoes in Florida using raised-bed plasticulture system were based on the tomato crop budget developed by the University of Florida Center for Agribusiness (2006). Variable costs of irrigation (Table 5-2) were based on information provided by Pitts et al. (2002) and the fertilizer input prices from 2005 and 2006 (Table 5-2) were obtained from local dealers. A harvest and marketing charge of \$3.64/25-lb carton was used to estimate the harvest and marketing costs for total marketable tomato yields in 2005 and 2006. It included cost of containers, selling cost, packing cost, harvesting cost, hauling cost, and organization fees (Table 5-3).

Methodology of Partial Budget Analysis of Irrigation-Nutrient Management Programs

Partial budget analysis was performed to determine economic effects of the irrigation-nutrient management programs on fresh market tomato production. Typically, partial budget analysis has the following components (Dalsted and Gutierrez, 2007; Eleveld, 1989):

1. Additions to income/Positive effects include
    a. Added returns due to new management program
    b. Reduced costs due to new management program
    c. Total Additions - sum of additions to income
2. Subtractions from income/Negative effects include
    a. Added costs due to new management program
    b. Reduced returns due to new management program

c. Total subtractions: sum of subtractions from income

3. Total effects/Net change in revenue: calculated as the difference between total additions/ positive effects and total subtractions/negative effects.

Added or reduced costs of the irrigation-nutrient management programs relative to the UF/IFAS recommended program were calculated by using the estimated program costs (Table 5-2) and harvest costs (Table 5-5). Added returns were incurred if the irrigation-nutrient management program resulted in higher yields and thereby higher gross returns relative to the UF/IFAS recommended program, while reduced returns were seen with lower yields and thereby lower gross returns relative to the UF/IFAS recommended program. Added costs were incurred if the irrigation-nutrient management program resulted in higher fertilizer, irrigation, or harvest costs relative to the UF/IFAS recommended program. While reduced costs were incurred if the irrigation-nutrient management program resulted in lower fertilizer, irrigation, or harvest costs relative to the UF/IFAS recommended program. Added or reduced returns relative to the UF/IFAS recommended program were based on measured yield values of the different irrigation-nutrient management programs (Table 5-6).

Results and Discussion

Fresh Market Tomato Production Costs

The market prices that the growers received for the 25-lb tomato cartons varied with year (Table 5-1). However, in 2005 and 2005, the price variations within grades and within season were minimal. Because the fresh market tomato yields varied significantly with year, results from both years were analyzed separately.

Estimated cost of irrigation-nutrient management programs varied with year and program (Table 5-2). The estimated irrigation-nutrient management costs associated with the UF/IFAS program were \$402.93/acre and \$418.37/acre in 2005 and 2006, respectively. The CL preplant irrigation-nutrient management program resulted in decreased treatment costs ($25.39/acre and $19.23/acre in 2005 and 2006, respectively) relative to the UF/IFAS recommended program. The higher irrigation and fertigation programs resulted in increased treatment costs. The cost difference between these programs and the UF/IFAS recommended irrigation-nutrient management program ranged from an additional $17.18/acre-$214.84/acre and $17.18/acre-$195.90/acre in 2005 and 2006, respectively (Table 5-2).

Total production costs, including fixed costs, harvest and marketing costs, were $13,820/acre in 2005 and $11,972/acre in 2006 (Table 5-3). The irrigation variable cost was $128.86/acre in both years, and represented 0.9%-1.1% of the total production cost. The cost of the fertilizer program ranged from $274/acre-$290/acre in 2005 and 2006, respectively. The cost of fertilizer inputs represented 1.98% to 2.42% of the total production cost. In contrast consider a crop like field corn where per acre production costs are considerably lower than fresh market tomatoes, but where fertilizer inputs represent 17.73%-19.89% of the total production costs (Duffy and Smith, 2008), with fresh market tomatoes fertilizer inputs represented a minor 1.98%-2.42% of the total production cost.

A break-even (B-E) price is defined as the market price threshold, or price needed, to recoup all production costs. Break-even price for a 25-lb tomato carton is a function of total marketable yield, and therefore varies by season. The total marketable yield in 2005 and 2006 were 1,783 and 1,271 25-lb cartons/acre, respectively. The break-even price in 2005 was $7.75 per 25-lb carton ($13,820/ 1,783 25-lb cartons). Lower total marketable yields in 2006 increased the break-even price by nearly $2 per 25-lb carton to $9.42 per 25-lb carton. Season average prices of tomato grades ($/25-lb carton) for District 4 Florida’s shipment and sales were obtained for 1998-2008 from Annual Reports of the Florida Tomato Committee (Table 5-4). Using the fresh market tomato yields recorded in 2005 and 2006, and the UF/IFAS irrigation-nutrient management program, a net profit ($/25-lb carton) analysis was conducted between 1998 and 2008 (Figure 5-1). With a break-even price of $7.75, net profits would have been realized six out of eleven years between 1998 and 2009. At a higher break-even price of $9.42, net profits would have been realized only in three. Growers generally make production decisions such as rate of fertilizer input at the beginning of the season. As commodity prices vary with season and year, current fertilizer prices, and break-even price analysis influence grower decisions on production practices.

Marginal Analysis of the Value of Extra Fertilizer and Irrigation

Marginal analysis is the process of identifying the benefits and costs of alternative farm management practices by examining the incremental or additional effects on total revenue and total cost caused by a unit change in the output or input. Marginal analysis supports decision-making based on marginal or incremental changes to resources.

A relationship (Equation 5-1) was developed to determine the break-even yield necessary to cover an increase in fertilizer (nitrogen) costs, for a range of market prices.

$$\Delta Y = \frac{\Delta F_c}{P\text{-}H} \qquad (5\text{-}1)$$

Where,
ΔY = break-even yield (25-lb cartons/acre)
ΔF_c = change in fertilizer cost ($/acre)
P = market price of 25-lb tomato carton ($/25-lb carton)
H = unit harvest cost ($/25-lb carton)

In 2005, the cost of a 32% urea-ammonium nitrate solution (32-0-0, N-P-K) was $229/2000 lbs (USDA-NASS, 2008) or $0.32/lb of N. Therefore, the cost of UF/IFAS irrigation-nutrient management program is $72/acre. Increasing the N fertilizer application by 200% increases applied N from 200 to 400 pounds per acre. Nitrogen costs increase correspondingly from $72 to

$144 per acre, or by $72. (Figure 5-2). The additional yield required to cover the increased fertilizer cost depends on the unit price of 25-lb tomato carton. With twice the UF/IFAS recommended fertilizer rate, and with market price of $5 per /25-lb tomato carton, growers would need to realize an additional 53 25-lb carton/acre to pay for the increased fertilizer costs. Alternatively, if market prices approached $20 per 25-lb carton, the additional increase in marketable yield would be 4 25-lb carton/acre.

In 2005 and 2006, the tomato yields were numerically higher with the 200% Fertigation program and yield differences among these programs ranged from 37 to 153 25-lb cartons/acre. This difference is above the additional yield required to cover the increased fertilizer costs. Therefore, the additional yield required to cover the increased fertilizer costs is minimal for a high input crop like fresh market tomato.

Growers generally make production decisions regarding rate of fertilizer input at the beginning of the season. Therefore, marginal analysis helps identify the benefits and costs of alternative farm management practices by examining the incremental or additional effects on total revenue and total cost caused by a unit change in the output or input. As mentioned earlier, because of the high capital investment in plasticulture, drip irrigation, hybrid seeds and transplants, and because fertilizer as a crop input represents only 1.98%-2.42% of the total production cost, fertilizer rates in excess of the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) recommended rates have been used by growers as a strategy to prevent nutrient shortages and maintain productivity. Based on the break-even yield analysis, these results give an insight into the growers' practice of high fertilization rates.

Effect of Irrigation-Nutrient Management Programs on Gross Returns from Fresh Market Tomato Production

As the interaction year x treatment was significant for most of the harvests and grade distributions ($p < 0.05$), data were analyzed separately by year. Total marketable tomato yields recorded in 2005 ranged from 1,242-1,883 25-lb cartons/acre, and in 2006, the total marketable tomato yields ranged from 920-1,424 25-lb cartons/acre. Overall, total marketable tomato yields recorded in 2005 were higher than those recorded in 2006. In 2005, highest total marketable yields occurred with 100% Fertigation-CL,100% Irrigation (1,883 25-lb carton/acre) and the lowest with 100% Fertigation-300% Irrigation treatment (1,242 25-lb carton/acre). In 2006, highest total marketable yields for were seen with 200% Fertigation-100% Irrigation treatment (1,424 25-lb cartons) and lowest yields were recorded with 100% Fertigation-300% Irrigation treatment (920 25-lb cartons).

Irrigation management

In both 2005 and 2006, relative to the UF/IFAS recommended irrigation-nutrient management program (100% Fertigation-100% Irrigation) the high irrigation alone program (100% Fertigation-300% Irrigation) resulted in significantly lowest total marketable tomato yields, and therefore lowest gross returns (Table 5-5).

Fertilization management

In both 2005 and 2006, there were no significant differences between the UF/IFAS recommended irrigation-nutrient management program and the high fertigation alone program (200% Fertigation-100% Irrigation) for total marketable tomato yields, and gross returns. However, in both 2005 and 2006, the 200% Fertigation-100% Irrigation irrigation-nutrient management program resulted in numerically higher total marketable tomato yields (1,820 and 1,424 25-lbs cartons/acre, in 2005 and 2006, respectively), and gross returns ($20,379/acre and

$12,035/acre, in 2005 and 2006, respectively) relative to the UF/IFAS irrigation-nutrient management program (total marketable tomato yields: 1,783 and 1,271 25-lbs cartons/acre in 2005 and 2006, respectively; gross returns: $19,972/acre and $10,736/acre in 2005 and 2006, respectively).

In 2005, with a high fertigation and irrigation management program (200% Fertigation-300% Irrigation) there were no significant differences between the UF/IFAS recommended irrigation-nutrient management program and the 200% Fertigation-300% Irrigation irrigation-nutrient management programs for total marketable tomato yields, and gross returns (Table 5-5). However, in 2006, the 200% Fertigation-300% Irrigation resulted in significantly lower total marketable tomato yields, and gross returns (Table 5-5). These results suggest in 2005, a relatively cool and wet year, the higher fertigation rate of the 200% Fertigation-300% Irrigation irrigation-nutrient management program helped offset the lower yields recorded with the high irrigation alone 100% Fertigation-300% Irrigation program. While, in 2006, a relatively warm and dry year, the higher fertigation rate of the 200% Fertigation-300% Irrigation irrigation-nutrient management program lacked a similar ameliorative effect.

Benefits from chicken litter

In both 2005 and 2006, there were no significant differences between the UF/IFAS recommended irrigation-nutrient management program (100% Fertigation-100% Irrigation) and the 100% Fertigation-CL,100% Irrigation program for total marketable tomato yields, and gross returns (Table 5-5). However, in both 2005 and 2006, the CL preplant nutrient management program resulted in numerically higher total marketable tomato yields, and gross returns (Table 5-5).

Partial Budget Analysis of Irrigation-Nutrient Management Programs

Partial budget analysis was performed on the 100% Fertigation-100% Irrigation (UF/IFAS recommended irrigation-nutrient management program), 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation irrigation-nutrient management programs. In both 2005 and 2006, there were no significant differences between the 100% Fertigation-100% Irrigation and 200% Fertigation-100% Irrigation programs. However, in both years the 200% Fertigation-100% Irrigation program resulted in numerically higher yields and the partial budget analysis was conducted to analyze the numerical differences between the different irrigation-nutrient management programs. As the UF/IFAS recommended program was used as the reference program for comparing the remaining five programs with, it did not have any added costs or reduced returns, and therefore the total effects were zero (Table 5-6). In both years, the 200% Fertigation-100% Irrigation program had higher positive effects relative to the UF/IFAS program (+$54.5/acre, and +$561.3/acre, in 2005 and 2006 respectively). In both years, relative to the UF/IFAS recommended program, the 100% Fertigation-300% Irrigation program resulted in the highest total negative effects (-$4,112.2/acre). Similarly, in both 2005 and 2006, relative to the UF/IFAS recommended irrigation-nutrient management program, the 200% Fertigation-300% Irrigation program also resulted in negative effects (-$1,932.8/acre, and -$722.9/acre, in 2005 and 2006 respectively).

Economic Returns versus Nutrient Loading

In both 2005 and 2006, relative to the UF/IFAS recommended program, the 200% Fertigation-100% Irrigation program resulted in numerically higher net returns ranging from $54.5/acre-$561.3/acre. However, relative to the UF/IFAS recommended program, the 200% Fertigation-100% Irrigation program also resulted in higher total N-load (2.42 lb/acre) (Table 5-7). Therefore, although the 200% Fertigation-100% Irrigation irrigation-nutrient management program resulted in numerically higher net returns relative to the UF/IFAS program (an advantage to growers), it also results in increased total-N load (disadvantage to environment). Currently, there are no established monetary penalties for nutrient pollution in the watershed. However, with the adoption of House Bill 547, which amends s. 403.067, F.S. (FDEP, 2008) the current law governing water quality credit trading, Florida Legislation authorizes the Florida Department of Environmental Protection (FDEP, 2008) to adopt rules to implement a water quality credit trading program, specifically in the Lower St. Johns River Basin as a pilot program. If the pilot program is a success, water quality credit trading program could potentially be expanded to other water management districts in Florida, and thus allocating a monetary value on increased total-N load or nutrient pollution.

In both 2005 and 2006, relative to the UF/IFAS recommended program, the 100% Fertigation-300% Irrigation program resulted in the highest total net negative returns (-$4,112.2/acre, and -$1,701.2/acre, in 2005 and 2006 respectively). Similarly, in both 2005 and 2006, relative to the UF/IFAS recommended irrigation-nutrient management program, the 200% Fertigation-300% Irrigation program also resulted in net negative returns (-$1,932.8/acre, and -$722.9/acre, in 2005 and 2006 respectively). When comparing the high irrigation programs (100% Fertigation-300% Irrigation, 200% Fertigation-300% Irrigation) alone, the 200% Fertigation-300% Irrigation resulted in significantly lower net negative returns than the 100% Fertigation-300% Irrigation program. These results suggest that in a high irrigation scenario higher fertilizer rates may ameliorate the negative effects of the high irrigation program. However, both high irrigation programs could also result in higher total-N load (Table 5-7).

Conclusion

Given the low water holding capacity of Florida’s coarse textured soils the drip-irrigating fresh market tomato growers oftentimes over-irrigate to maintain adequate moisture levels within the plant root zone. N-P-K fertilizers are highly water soluble, and as growers mismanage the irrigation water application, they generally tend to over-fertigate to compensate the loss of nutrients from the plant root zone. Moreover, because of the high capital investment in plasticulture, drip irrigation, hybrid seeds and transplants, and because fertilizer as a crop input in this instance represents only 0.9% to 1.1% of the total production cost, fertilizer rates in excess of the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) recommended rates have been used by growers as a strategy to prevent nutrient shortages and maintain productivity (Cantliffe et al., 2006). Based on our results the high irrigation management program (100% Fertigation-300% Irrigation) not only increased the cost of the irrigation-nutrient management program but it also resulted in lower returns relative to the UF/IFAS recommended irrigation-nutrient management program. Moreover, it could also result in higher total-N load relative to the UF/IFAS program. Therefore, we can conclude that growers should not use higher irrigation rates to ensure adequate soil moisture levels in the crop root zone as it results in net losses. Instead, they should better manage irrigation water application either by splitting irrigation application, and/or by using low-flow drip irrigation.

The high fertigation alone irrigation-nutrient management program did not differ statistically from the UF/IFAS irrigation-nutrient management program. Although, it resulted in numerically higher net returns relative to the UF/IFAS recommended irrigation-nutrient management program in both 2005 and 2006, it also resulted in higher total-N load than the UF/IFAS recommended program. Given the adoption of legislation to establish a monetary value on increased total-N load or nutrient pollution in select regions of state of Florida, there is an added negative impact to high fertilizer application. Therefore, we can conclude that with better management of irrigation water application there is no economic benefit in applying fertilizer rates in excess of the UF/IFAS recommended nutrient management program.

Table 5-1. Price of US #1 tomatoes during spring of 2005 and 2006 fresh market tomato production with raised-bed plasticulture system in North Florida[z].

Harvest Date	Price of US #1 tomatoes $/25-lb carton		
	XLarge	Large	Medium
		2005	
6/13/2005	13.20	13.20	13.20
6/21/2005	9.20	9.20	9.20
6/28/2005	11.20	11.20	11.20
7/5/2005	11.20	11.20	11.20
		2006	
6/9/2006	8.45	8.45	8.45
6/29/2006	8.45	8.45	8.45
7/5/2006	8.45	8.45	8.45

[z] Prices of US #1 tomatoes during spring of 2005 and 2006 fresh market tomato production were based on information from USDA Agriculltural Marketing Service.

Table 5-2. Estimated costs of irrigation-nutrient management programs for spring 2005 and 2006 'Florida 47' fresh market tomato production with raised-bed plasticulture system.

Irrigation-Nutrient Management Program	Irrigation-Nutrient Management Program Costs ($/acre[z])						
	Preplant Fertilizer Cost[y]	Injected Fertilizer Cost[x]	Irrigation Tubing Cost	Irrigation Pumping Cost	Irrigation System Labor Cost	Total Program Cost	Cost of Program Relative to UF/IFAS
	2005						
100% Fertigation-CL[w],100% Irrigation	40.00	208.69	107.5	8.59	12.77	377.55	-25.39
100% Fertigation, 100% Irrigation	65.39	208.69	107.5	8.59	12.77	402.93	0.00
100% Fertigation, 300% Irrigation	65.39	208.69	107.5	25.77	12.77	420.11	17.18
200% Fertigation, 100% Irrigation	65.39	417.38	107.5	8.59	12.77	611.62	208.69
200% Fertigation, 300% Irrigation	65.39	417.38	107.5	25.77	12.77	628.80	225.87
200% Fertigation, 300% Irrigation-ML[v]	65.39	417.38	107.5	25.77	12.77	628.80	225.87
	2006						
100% Fertigation-CL,100% Irrigation	50.00	220.28	107.5	8.59	12.77	399.14	-19.23
100% Fertigation-100% Irrigation	69.23	220.28	107.5	8.59	12.77	418.37	0.00
100% Fertigation-300% Irrigation	69.23	220.28	107.5	25.77	12.77	435.55	17.18
200% Fertigation-100% Irrigation	69.23	440.56	107.5	8.59	12.77	638.65	220.28
200% Fertigation-300% Irrigation	69.23	440.56	107.5	25.77	12.77	655.83	237.46
200% Fertigation-300% Irrigation-ML	69.23	440.56	107.5	25.77	12.77	655.83	237.46

[z] The raised plant beds were on 6-ft centers. Therefore, there was a total of 7,260 linear bed feet of raised plastic beds.

[y] The cost of preplant fertilizer chicken litter was $20 and $25 per 2000 lbs in 2005 and 2006, respectively. The cost of preplant fertilizer 13-1.7-10.7 was $330 and $350 per 2000 lbs in 2005 and 2006, respectively.

[x] The cost of 8-0-6.6 injected fertilizer was $180 and $190 per 2000 lbs in 2005 and 2006, respectively.

[w] For program 100%Fertigation-CL,100%Irrigation the source of the preplant fertilizer was chicken litter. The other programs had 13-1.7-10.7 as the source of preplant fertilizer.

[v] An additional program for estimating nitrate load using drainage lysimeters installed in the ground was carried out at the same time as the current study. The lysimeters installed under programs 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100% Irrigation, 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation were of the same design, and the lysimeters installed under the program 200%Fertigation-300%Irrigation-ML were modified (ML) in design and varied from the above lysimeters. To maintain the integrity of the predetermined programs data from 200% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML (which received the same above ground programs) were not combined.

Table 5-3. Estimated cost[z] to produce and harvest[y] 'Florida 47' tomatoes with raised-bed plasticulture system using University of Florida/Institute of Food and Agricultural Sciences irrigation-nutrient management program in spring of 2005 and 2006.

Category	2005	2006	2005	2006
Fertilizer and Irrigation Costs	$/acre		$/25-lb Carton	
Fertilizer	274.07	289.51		
Irrigation Tubing	107.50	107.50		
Pumping Costs	8.59	8.59		
Labor Cost	12.77	12.77		
Total Fertilizer and Irrigation Costs	402.93	418.37		
Operating Costs				
Transplants	450.00	450.00		
Fumigant	843.75	843.75		
Fungicide	243.52	243.52		
Herbicide	44.51	44.51		
Insecticide	514.75	514.75		
General Farm Labor	186.62	186.62		
Machinery Variable Cost	677.81	677.81		
Tractor Driver Labor	311.58	311.58		
Miscellaneous Costs				
Tie Plants	145.20	145.20		
Scouting	45.00	45.00		
Plastic Mulch	345.00	345.00		
Stakes	96.00	96.00		
Plastic String	110.00	110.00		
Farm Vehicles	32.00	32.00		
Stake and String Disposal	199.00	199.00		
Plastic Mulch Disposal	140.00	140.00		
Interest on Operating Capital	237.72	237.72		
Total Operating Cost	4622.46	4622.46		
Fixed Costs				
Land Rent	300.00	300.00		
Machinery Fixed Cost	235.94	235.94		
Farm Management	663.20	663.20		
Overhead	1105.33	1105.33		
Total Fixed Cost	2304.47	2304.47		
Total Pre-harvest Cost	7329.86	7345.30		
Harvest and Marketing Costs				
Containers	1337.25	953.25	0.75	0.75
Sell	267.45	190.65	0.15	0.15
Pack	3209.40	2287.80	1.8	1.8
Harvest and Haul	1515.55	1080.35	0.85	0.85
Organization Fees	160.47	114.39	0.09	0.09
Total Harvest and Marketing Cost	6490.12	4626.44	3.64	3.64
Total Cost	13819.98	11971.74	7.75[y]	9.42[y]

[z] Cost of fertilizer, irrigation, preharvest production costs for a 1-acre tomato field for the different treatments were calculated based on information provided by local fertilizer dealers, Pitts et al., (2002), and estimated production costs in the Manatee/Ruskin area, 2005-2006, University of Florida Center for Agribusiness website.
[y] Measured tomato yield of 1,783 and 1,271 25-lb cartons/acre in spring of 2005 and 2006 respectively.

Table 5-4. Season average prices of tomato grades ($/25-lb carton) for District 4 Florida's shipment and sales[z].

Year	Season Average Tomato Price ($/25-lb carton)		
	U.S. One or Better	U.S. Combination	U.S. Two
1998	10.17	8.96	8.47
1999	7.65	7.43	9.05
2000	7.33	6.46	6.69
2001	10.12	9.07	8.40
2002	8.24	7.40	6.75
2003	9.43	8.99	8.28
2004	8.51	7.37	7.04
2005	14.43	13.40	11.73
2006	10.69	10.90	10.80
2007	7.88	7.34	6.86
2008	14.76	13.33	12.44

[z] Season average prices of tomato grades for District 4 Florida's shipment and sales were based on information available in the Annual Reports of the Florida Tomato Committee, Orlando, FL.

Table 5-5. Effects of irrigation and nutrient management programs on ‘Florida 47’tomato fruit yields (25-lb carton/acre), gross returns ($/acre), and gross returns relative to the University of Florida/Institute of Food and Agricultural Sciences recommended irrigation-nutrient management program[z] during spring of 2005 and 2006[y] with raised-bed plasticulture system.

Irrigation-Nutrient Management Program[x]	Total Marketable 25-lb cartons/acre [w]	Harvest Cost ($/acre)	Harvest Cost Relative to UF/IFAS Program ($/acre)	Gross Returns ($/acre)	Gross Returns Relative to UF/IFAS Program ($/acre)
			2005		
100% Fertigation-CL[v],100% Irrigation	1,883 a	6,853	+362	21,087 a	+608
100% Fertigation-100% Irrigation	1,783 ab	6,491	0	19,972 ab	0
100% Fertigation-300% Irrigation	1,242 c	4,519	-1,972	13,905 c	-6,084
200% Fertigation-100% Irrigation	1,820 ab	6,623	+132	20,379 ab	+325
200% Fertigation-300% Irrigation	1,556 b	5,663	-828	17,426 b	-2,490
200% Fertigation-300% Irrigation-ML[u]	1,677 ab	6,103	-388	18,778 ab	-1,339
p-value	< 0.01			< 0.01	
			2006		
100% Fertigation-CL,100% Irrigation	1,291 ab	4,700	+75	10,912 ab	+176
100% Fertigation-100% Irrigation	1,271 ab	4,625	0	10,736 ab	0
100% Fertigation-300% Irrigation	920 c	3,349	-1,276	7,776 c	-2,960
200% Fertigation-100% Irrigation	1,424 a	5,184	+559	12,035 a	+1,299
200% Fertigation-300% Irrigation	1,161 abc	4,226	-399	9,810 abc	-926
200% Fertigation-300% Irrigation-ML	1,064 bc	3,875	-750	8,995 bc	-1,741
p-value	< 0.01			< 0.01	

[z] The University of Florida/Institute of Food and Agricultural Sciences recommended irrigation-nutrient management program was 100% Fertigation-100% Irrigation

[y] The interaction term for year x irrigation and nutrient management program was significant for fruit yields ($p \leq 0.05$), therefore the data from both years were analyzed separately.

[x] Fertigation: Nitrogen-Potassium rate.

[w] Means followed by different letters within each column are significantly different at the 0.05 level, according to Duncan’s multiple range test.

[v] For program 100% Fertigation-CL,100% Irrigation the source of the preplant fertilizer was chicken litter, while the rest of the programs had 13-1.8-10.8 as the source of preplant fertilizer.

[u] An additional program for estimating nitrate load using drainage lysimeters installed in the ground was carried out at the same time as the current study. The lysimeters installed under programs 100% Fertigation-CL,100% Irrigation, 100% Fertigation-100%

Irrigation, 100% Fertigation-300% Irrigation, 200% Fertigation-100% Irrigation, and 200% Fertigation-300% Irrigation were of the same design, and the lysimeters installed under the program 200% Fertigation-300% Irrigation-ML were modified (ML) in design and varied from the above lysimeters. To maintain the integrity of the predetermined programs data from 200% Fertigation-300% Irrigation and 200% Fertigation-300% Irrigation-ML (which received the same above ground programs) were not combined.

Table 5-6. Total negative effects (added costs and reduced returns), total positive effects (reduced costs and added returns), and net returns of the irrigation-nutrient management programs relative to the UF/IFAS recommended program[z] for fresh market tomato production during spring of 2005 and 2006[y] with raised-bed plasticulture system.

Irrigation-Nutrient Management Program[x]	Added Costs of Alternative Program ($/acre)	Reduced Returns of Alternative Program ($/acre)	Total Negative Effects of Alternative Program ($/acre)	Reduced Costs of Alternative Program ($/acre)	Added Returns of Alternative Program ($/acre)	Total Positive Effects of Alternative Program ($/acre)	Total Effects of Alternative Program Relative to UF/IFAS Program ($/acre)
				2005			
100% Fertigation-100% Irrigation	0	0	0	0	0	0	0.0
100% Fertigation-300% Irrigation	17	6,067	6,084	1,972	0	1,972	-4,112.2
200% Fertigation-100% Irrigation	132	221	353	0	407	407	+54.5
200% Fertigation-300% Irrigation	215	2,546	2,761	828	0	828	-1,932.8
				2006			
100% Fertigation-100% Irrigation	0	0	0	0	0	0	0.0
100% Fertigation-300% Irrigation	17	2,960	2,977	1,276	0	1,276	-1,701.2
200% Fertigation-100% Irrigation	179	559	738	0	1,299	1,299	+561.3
200% Fertigation-300% Irrigation	196	926	1,122	399	0	399	-722.9

[z] The University of Florida/Institute of Food and Agricultural Sciences recommended irrigation-nutrient management program was 100% Fertigation-100% Irrigation

[y] The interaction term for year x irrigation and nutrient management program was significant for fruit yields ($p \leq 0.05$), therefore the data from both years were analyzed separately.

[x] Fertigation: Nitrogen-Potassium rate.

Table 5-7. Net returns and changes in total-N load of irrigation-nutrient management programs relative to the University of Florida/ Institute of Food and Agricultural Sciences recommended program[z] for 'Florida 47' fresh market tomato production during spring of 2005 and 2006[y] with raised-bed plasticulture system.

Irrigation-Nutrient Management Program[x]	Net Returns Relative to UF/IFAS Program ($/acre)	Changes in Total-N Load Relative to UF/IFAS Program (lb/acre)
	2005	
100% Fertigation-100% Irrigation	0.0	0.00
100% Fertigation-300% Irrigation	-4,112.2	1.40
200% Fertigation-100% Irrigation	+54.5	2.42
200% Fertigation-300% Irrigation	-1,932.8	-0.02
	2006	
100% Fertigation-100% Irrigation	0.0	0.00
100% Fertigation-300% Irrigation	-1,701.2	1.64
200% Fertigation-100% Irrigation	+561.3	-0.16
200% Fertigation-300% Irrigation	-722.9	6.53

[z] The University of Florida/Institute of Food and Agricultural Sciences recommended irrigation-nutrient management program was 100% Fertigation-100% Irrigation.

[y] The interaction term for year x irrigation and nutrient management program was significant for fruit yields ($p \leq 0.05$), therefore the data from both years were analyzed separately.

[x] Fertigation: Nitrogen-Potassium rate.

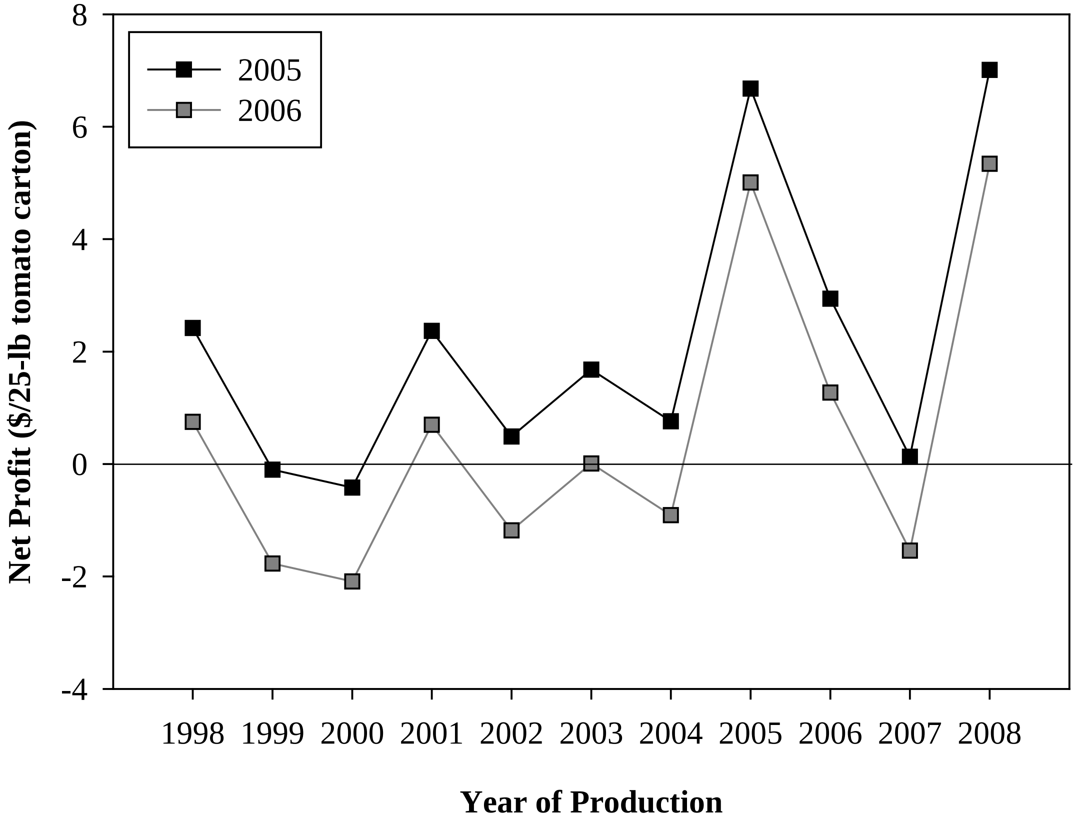


Figure 5-1. Effect of season average market prices of tomato grades ($/25-lb carton) for District 4 Florida's shipment and sales of U.S. One or Better 25-lb tomato cartons and fresh market tomato yields recorded in 2005 and 2006 with the UF/IFAS irrigation-nutrient management program (25-lb tomato cartons) on net profits ($/25-lb carton).

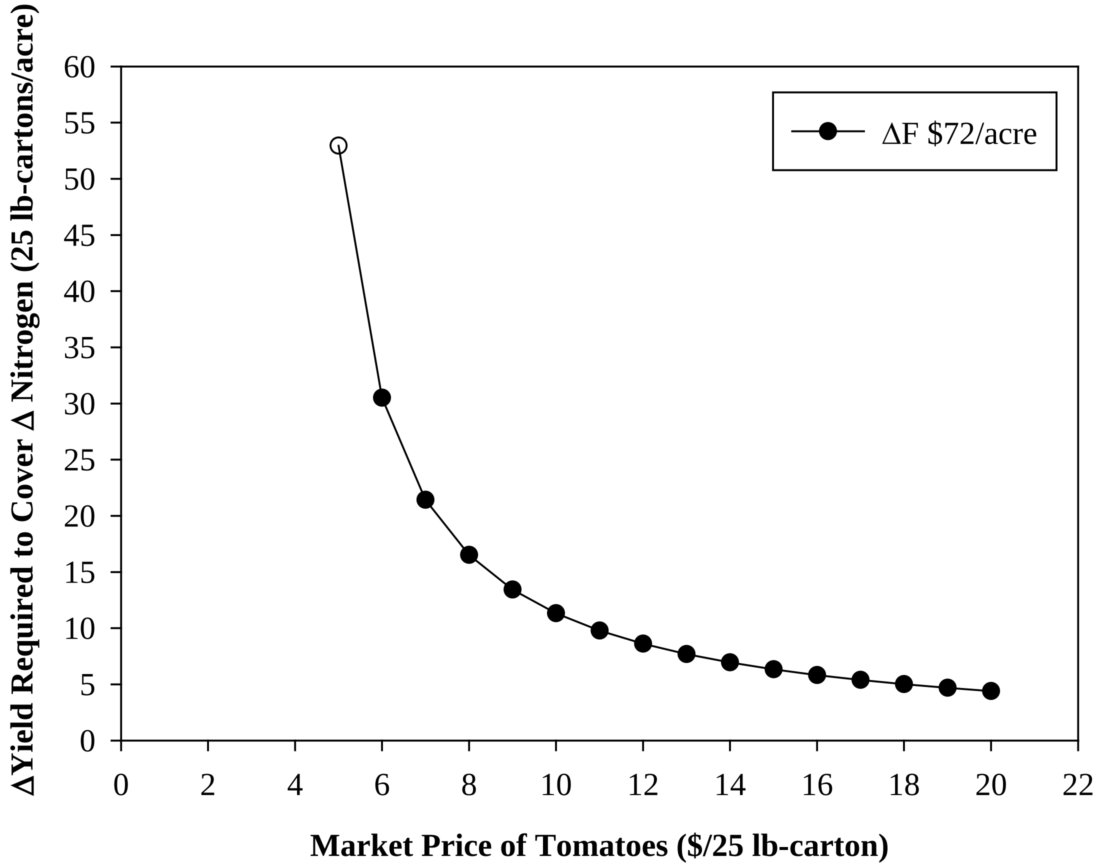


Figure 5-2. Relationship between additional break-even yield (Δ yield) and increase in nitrogen fertilizer costs (ΔF) due to increased nitrogen fertilizer application at different season average market prices of tomato grades ($/25-lb carton) for District 4 Florida's shipment and sales of U.S. One or Better 25-lb tomato cartons.

CHAPTER 6
CONCLUSION

To better understand the impact of irrigation and nutrient management practices on fresh market tomato production, by using an integrated fertilization/irrigation approach, a series of experiments were conducted simultaneously with selected irrigation-nutrient management programs. The goal of these experiments was to determine if possible BMPs (UF/IFAS recommendations) can minimize the negative impact of vegetable production (high fertilizer and irrigation rates) on the environment while maintaining or improving current yields and crop value of an economically important vegetable crop - fresh market tomatoes (*Solanum lycopersicum* L.).

The results from these experiments suggest that CL did not differ significantly from the UF/IFAS recommended irrigation-nutrient management program for total marketable yields (1,291-1,883 25-lb carton/acre, 1,271-1,291 25-lb carton/acre, respectively) and soil-profile total-N load measured with soil sampling (2.46-3.39 lb/acre, 2.26-3.14 lb/acre, respectively), and seasonal total-N load measured with drainage lysimeters (0.0040-1.04 lb/acre, 0.54-0.81 lb/acre, respectively). Based on the economic analysis, not only did CL used as a preplant fertilizer source decrease the cost of the irrigation-nutrient management program ($19.23/acre-$25.39/acre), but it also resulted in higher net returns ($1,20/acre-$777/acre) relative to the UF/IFAS recommended irrigation-nutrient management program. Therefore, CL can be used as an alternative preplant fertilizer source if transported within 164-miles from the production facility

Applying higher irrigation (100% Fertigation-300% Irrigation) reduced water stress in the plant bed for only for 1-2 days during the cropping cycle, but resulted in “insufficient” NO_3^--N and K^+ petiole concentrations, which further resulted in lowest total fruit yields in both 2005 and

2006 (920-1,242 25-lb carton/acre). The soil-profile total-N load with the 100% Fertigation-300% Irrigation did not differ significantly from the UF/IFAS recommended irrigation-nutrient management program in both 2005 and 2006 and (2.19-2.21 lb/acre, 2.26-3.14 lb/acre, respectively), and neither did the seasonal total-N load measured with drainage lysimeters (0.0040-1.04 lb/acre, 0.54-0.81 lb/acre, respectively). The partial budget economic analysis suggests that a high irrigation management program (100% Fertigation-300% Irrigation) not only increased the cost of the irrigation-nutrient management program ($17.18/acre), but it also resulted in lowest net returns (-$1,702/acre – -$4,113/acre) relative to the UF/IFAS recommended irrigation-nutrient management program. Hence, growers should not use higher irrigation rates to ensure adequate soil moisture levels in the crop root zone. Instead, they should better manage irrigation water application either by splitting irrigation application, and/or by using low-flow drip irrigation.

In the current study the high fertigation rate (200% Fertigation-100% Irrigation) was twice the UF/IFAS recommended nutrient management rate. Even with a considerably higher fertigation rate, there were no significant differences between the 200% Fertigation-100% Irrigation and the UF/IFAS recommended irrigation-nutrient management program for total marketable yield in both 2005 and 2006 (1,424-1,820 25-lb carton/acre, 1,271-1,783 25-lb carton/acre, respectively). In 2006, with soil sampling the highest soil-profile total-N load was recorded with 200% Fertigation-100% Irrigation program (3.18-4.32 lb/acre). However, with drainage lysimeters the seasonal total-N load with the 200% Fertigation-100% Irrigation did not differ significantly from the UF/IFAS recommended irrigation-nutrient management program in both 2005 and 2006 (0.38-3.24 lb/acre, 0.54-0.81 lb/acre, respectively). Although, it resulted in numerically higher net returns relative to the UF/IFAS recommended irrigation-nutrient management program in both 2005 and 2006, it also resulted in higher total-N load than the UF/IFAS recommended program. Given the adoption of legislation to establish a monetary value on increased total-N load or nutrient pollution in select regions of the state of Florida, there is an added negative impact to high fertilizer application.

The high fertigation and high irrigation nutrient management program (200% Fertigation-300% Irrigation) did not differ significantly from the UF/IFAS recommended irrigation-nutrient management program for total marketable yields (1,161-1,556 25-lb carton/acre, 1,271-1,783 25-lb carton/acre, respectively). The seasonal total-N load recorded with the 200% Fertigation-300% Irrigation varied highly with year. In 2005, the 200% Fertigation-300% Irrigation did not differ significantly from the UF/IFAS recommended irrigation-nutrient management program for total-N load (0.79 lb/acre, 3.24 lb/acre). However, in 2006 200% Fertigation-300% Irrigation had significantly higher seasonal total-N load (7.07 lb/acre) than the UF/IFAS recommended irrigation-nutrient management program (0.54 lb/acre). Moreover, based on the partial budget analysis the 200% Fertigation-300% Irrigation not only increased the cost of the irrigation-nutrient management program ($225.87/acre-$237/acre), but it also resulted negative net returns (-$722/acre - -$1,934/acre) relative to the UF/IFAS recommended irrigation-nutrient management program. Therefore, the growers should not follow a high irrigation and a high fertigation program as it results in net losses when compared to the UF/IFAS recommended irrigation-nutrient management program.

Soil-profile total-N load of selected programs was estimated using soil sampling. Irrespective of treatment, tomato soil-profile total-N load was highest in the first 30.5-cm depth of soil, and tended to decrease with an increase in depth. Tomato soil-profile total-N load varied with year, depending on the method of estimating wetted width and the irrigation-nutrient management program, the total-N load ranged from 0.13-1.54 lb/acre in 2005, and from 1.49-4.32 lb/acre in 2006. The soil-profile total-N load measured in 2005 was much lower than that measured in 2006, and the results within each year showed high variability. However, based on the relatively low soil-profile total-N loads recorded, the rate of movement of the water front in this study might have been higher than expected from past research conducted under similar conditions of soil and irrigation. Therefore, both the seasonal and soil-profile load monitoring methods might have underestimated the total-N load from the different irrigation-nutrient management programs. Further work needs to be done to improve the soil sampling and drainage lysimeter based nutrient load monitoring procedures.

Based on the results from these studies we can conclude that CL can be used as an alternative preplant fertilizer source if transported within 164-miles from the production facility. We can also conclude that growers should not use higher irrigation rates to ensure adequate soil moisture levels in the crop root zone as it results in net losses. Instead, they should better manage irrigation water application either by splitting irrigation application, and/or by using low-flow drip irrigation. We can also conclude that growers should not follow a high irrigation and high fertigation program as it results in net losses when compared to the UF/IFAS recommended irrigation-nutrient management program.

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BIOGRAPHICAL SKETCH

Aparna Gazula was born on September 1, 1977 in Visakhapatnam, India, and she is the oldest of three children. She graduated from the Acharya N.G. Ranga Agricultural University in 2000 with a BS in Agricultural Sciences. In 2004, Aparna received a Master of Science degree in horticultural and crop sciences from The Ohio State University. Aparna began her work towards a doctor of philosophy in the Horticultural Sciences department at the University of Florida under the guidance of Dr. Eric Simonne. She passed her qualifying exam and was admitted to candidacy in spring 2008, with a successful defense of the dissertation in November 2008. She was awarded the Ph.D. in horticultural sciences in May 2009.