EFFECT OF DRIP IRRIGATION AND NITROGEN APPLICATION RATES ON SOIL NITROGEN AND POTASSIUM MOVEMENT AND NITROGEN UPTAKE AND ACCUMULATION IN VEGETABLE CROPS

By

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LIST OF ABBREVIATIONS

Abbreviations	Meaning
BP	Bell Pepper
WM	Watermelon
DAT	Days After transplanting
DAFFI	Days After First Fertilizer Injection
FC	Field Capacity
PWP	Permanent Wilting Point
IV1	Irrigation Volume 1
IV2	Irrigation Volume 2
I1	Lower Irrigation rate (66% ETC)
I2	Target Irrigation rate (100% ETC)
I3	Higher Irrigation rate (133% ETC)
N1	Recommended N rate (100% IFAS rate)
N2	Higher N rate (125% IFAS rate
WAT	Weeks After Transplanting
IFAS	Institute of Food and Agricultural Sciences
US Fancy	Fancy peppers must have a minimum diameter of 3 inches and a minimum length of 3½ inches.
US#1	U.S. No. 1 peppers must have a minimum diameter and length of 2½ inches,
US#2	U.S. No. 2 grade has no size requirements.
BER	Blossom End Rot
OC	Other culls
Mark. #	Marketable Number
Mark. Wt	Marketable weight
PDW	Percent Dry Weight
DW	Dry Weight
ARL	Analytical Research Laboratory
ISA	Ionic Strength adjuster

Abstract of Dissertation Presented to the Graduate School
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Water movement is a major process that affects solute transport in the soil profile under Florida sandy soils conditions. Therefore, understanding the impact of current irrigation and N fertilization practices will have on leaching of water and nutrients below the crop root zone, and on crop yield is important for developing best management practices (BMPs). The BMPs should aim at minimizing water and nutrients leaching below the root zone while optimizing crop yield. Two field experiments were conducted in Spring 2002 in a sandy soil cropped with bell pepper and watermelon crops at North Florida Research and Education Center (NFREC) near Live Oak, Florida, to estimate the potential of leaching of N and K from the soil profile using calculated water fluxes over time, to measure biomass accumulation, N accumulation, and crop yield as affected by irrigation and N rates. The main goal of the study was to select BMPs that reduce nutrient leaching below the root zone from vegetable crops grown on plastic mulched beds under drip fertigation. The experimental design consisted of three irrigation treatments: 66, 100, and 133% of crop evapotranspiration (ET_C) and two rates of N fertilizer: 100 and 125% of IFAS recommended rate. Each treatment was replicated four times and the experiments were laid out in a completely randomized block design. At the beginning of each experiment calcium bromide was injected with the fertilizers to trace water and fertilizer movement through the soil profile. Soil samples were collected throughout the growing season, to characterize the storage and distribution of water, N-forms, and potassium in the root zone and below the root zone. Cumulative uptake and distribution of N and biomass accumulation were also monitored by taking plant samples at different stages of crop growth. Increasing irrigation rates, increased soil water content above Field Capacity (FC) and water flux was fast during crop establishment and flowering. Therefore soil water, Br, and NO_3-N, moved below root zone under both crops. The amount of soil NO_3-N leached below the root zone increased with increasing N rate. Most of the applied NH_4-N remained within the root zones for both crops and the amounts of soil NH_4-N in the root zones increased with increasing N rate. Similarly, most of soil K remained within the root zone of both crops. At harvest, soil water content was close to FC but water was still moving soil nutrients such as NO_3-N below the root-zone. Increasing N-rate increased N uptake but did not significantly increase crop yield. However, nitrate leaching below the root-zone also increased. Based on currently recommended crop factors used to calculate irrigation treatments, the BMPs for the bell pepper crop would be 66% of ET_C irrigation rate and 100% of the IFAS recommended N rate. For the watermelon crop the BMPs would be 100% ETc irrigation rate and 100% of the IFAS recommended N rate.. The above BMPs for both crops would optimize crop yield while minimizing nutrient leaching below the root zone.

CHAPTER 1
INTRODUCTION

Florida ranks second among the states in the USA for fresh market vegetable production based on area under cultivation (9.4%), production (9.0 %), and value (15.8%) of all crops (Olson, 2006). In 2005, vegetables harvested from 87.98 hectares had a farm value exceeding $1.8 billion. On a value basis for vegetables, bell pepper (*Capsicum annum* L) production in Florida in 2005 accounted for 11.5% and watermelon (*Citrullus lunatus* (Thrunb)) accounted for 6.8% of the state's total (Olson, 2006).

Water movement is one of the major processes affecting the movement of fertilizer nutrients in soils. Soil water content changes both spatially and temporarily because of water infiltration, drainage, evaporation, and plant uptake. Therefore, nutrient concentration and composition of the soil solution as well as distribution change over time. Moreover, variations in solute distribution can be due to differences in solute mobility and interactions with the soil matrix (Ryan et al., 2001; Mmolawa and Or, 2000 b).

The infiltration of rainfall and irrigation water is the most important factor affecting nutrient movement to surface and groundwater (Elmi et al., 2004). Therefore, understanding water and nutrient movement in the soil profile is important for developing efficient irrigation and nutrient management practices to minimize nutrient leaching below the root zone (Paramasivam et al., 2002).

Because nitrate nitrogen (NO_3-N) is negatively charged, it is poorly held by the soil colloids and clay minerals (Boswell et al., 1985). Thus, under excessive irrigation, NO_3-

N ions move vertically by mass flow in the soil profile and below the root zone where it becomes unavailable for plant uptake and a risk to the quality of the underlying water systems (Hatfield et al., 1999). Efficient management of mobile nutrients such as NO_3-N under shallow rooted crops is an important consideration (Patel and Rajput, 2002). Therefore, understanding water and nitrogen movement in drip fertigation systems is important for optimizing nitrogen management especially on sandy soils which are vulnerable for leaching of water and soluble nutrients. Monitoring soil water within and below the root zone is needed to improve irrigation scheduling to ensure adequate water supply for plant growth and production, without excessive leaching of water below the root zone (Li et al., 2005).

Today technologies are available to optimize nutrient management, such as fertigation through drip irrigation systems, polyethylene mulch, controlled-release fertilizers, and plant tissue testing. Drip irrigation has many benefits, some of which are becoming more important in today's environmentally concious world. One of the major benefits of drip irrigation is the capability to conserve water and fertilizers compared to overhead sprinklers and subirrigation. Drip irrigation allows for precise timing and application of fertilizer nutrients in vegetable production. In theory, fertilizers can be prescription-applied during the season in amounts that the crop needs and at a particular stage of crop growth when those nutrients are needed. This capability of drip irrigation system may help growers increase the use efficiency of applied fertilizers and should result in reduced fertilizer applications for vegetable production.

Nutrient application efficiency is generally defined as the ratio of fertilizer nutrient in the crop root zone (available for use by the crop), to the amount of fertilizer applied.

Nutrient use efficiency (NUE, defined as crop yield produced per unit of nutrient applied) is improved by small application of fertilizers applied throughout the growing season in contrast to large amounts of fertilizer at the beginning of the season (Locascio and Smajstrla, 1989; Dangler and Locascio, 1990a). Small, controlled applications not only save fertilizer but they can also reduce the potential for groundwater pollution due to fertilizer leaching from heavy rainstorms or periods of excess irrigation. Because only a portion of the field is wetted, water savings with drip irrigation can amount to as much as 80% compared to subirrigation and 50% compared to overhead sprinkler irrigation (Locascio et al., 1981b; Elmstrom et al., 1981; Locascio and Martin, 1985). Although drip irrigation has many benefits that are important in modern vegetable production, several challenges exist with this technology. Drip irrigation systems must be carefully designed and installed so that they operate with proper efficiency so that fertilizers and other chemicals can be applied in a uniform manner (Hochmuth and Smajstrla, 1991).

Most vegetable crops produced in Florida are adaptable to drip irrigation. The crops most easily adaptable are those crops that are currently produced on bedded systems using polyethylene mulch. These crops include tomatoes, peppers, eggplants, strawberries, and cucurbits including watermelons, muskmelons, squash, and cucumbers (Hochmuth and Smajstrla, 1991). Polyethylene mulch provides additional advantages to drip irrigation through reduced soil surface evaporation and exclusion of rainfall decreased nutrient leaching from the soil and therefore can provide desirable conditions for maximum yield of vegetables (Bowen and Fery, 2002). Cole crops such as cabbage, cauliflower, and broccoli also may be grown with drip irrigation.

Few studies conducted on nutrient movement, leaching, uptake and crop nutrient accumulation with drip irrigation and plastic mulched culture in sandy soils have been conducted. Dukes and Scholberg (2004a) studied scheduling irrigation using soil moisture sensors and found that scheduling irrigation using these sensors can increase water saving by 11 % and reduce leaching by up to 50 % compared to other scheduling irrigation methods. Simonne et al (2003b; 2006a) used a blue dye to determine the wetting front in plastic mulched soil beds used in vegetable production under drip irrigation and the need for spliting irrigation on sandy soil to avoid nutrient leaching.

The objectives of the studies are to: 1) determine the leaching potential of N and K using calculated water flux with increased irrigation and N rates through repeated soil moisture measurements over time; 2) quantify effects of irrigation and N rates on bell pepper and watermelon yield, and 3) measure crop N uptake and biomass accumulation as affected by irrigation and N rates.

the following hypotheses will be tested: 1) Irrigation rates greater than or equal to daily crop evapotranspiration ETc lead to nutrient leaching (crop ETc is defined as the depletion of water from the soil as a result of crop transpiration and evaporation from the soil surface upon which the crop is grown, (Izuno and Haman, 1987). 2) Increased N rates increase crop yields and 3) Increased irrigation rates reduce N-use efficiency.

CHAPTER 2
LITERATURE REVIEW

Water and nitrogen fertilizers are the two most important factors affecting NO_3-N movement to surface water and groundwater (Elmi et al., 2004). Maximization of crop yield and quality, and minimization of leaching of nutrients and water below the root zone may be achieved by managing fertilizer concentrations in measured quantities of irrigation water, according to crop requirements (Hagin and Lowengart, 1996). Frequent fertigation is common practice for vegetable crops grown with plasticulture in Florida (Hochmuth and Smajstrla, 1991). However, applying water and fertilizers in excess of crop needs may lead to leaching of water and nutrients below the crop root zone. Few studies have been conducted under Florida sandy soils on scheduling irrigation using soil moisture sensors to reduce nutrient leaching (Dukes et al., 2003; Dukes and Scholberg 2004a; 2004b) and to visualize water movement under plastic mulched soil beds used in vegetable production with drip irrigation (Simonne et al., 2003b ; 2006a). There is limited information on movement and distribution of water and nutrients in drip-fertigated plastic mulched soil beds on sandy soils. Therefore, understanding the impact of current irrigation and N fertilization practices under field conditions on the crop yield and on losses of water and nutrients from the root zone is necessary to develop best management practices to minimize leaching losses of mobile nutrients and to maximize crop yield.

2.1 Soil Water Movement

Soil water content changes spatially and temporarily because of water infiltration and evapotranspiration. As a result of changes in soil water content and other factors such as nutrient uptake by plant roots, soil solution concentration and composition as well as solute distribution change. Variations in solute distribution can be due to differences in solute mobility and interactions with the soil matrix (Mmolawa and Or 2000b). Drip irrigation is often preferred over other irrigation methods because of the high water-application efficiency, which reduces water losses from surface evaporation and results in minimal deep percolation. Also, salt concentration within the root zone can be easily managed because of the high frequency of application (Mantell et al., 1985). However, drip irrigation generates a restricted root system requiring frequent nutrient supply by applying fertilizers in irrigation water (fertigation) (Hagin and Lowengart, 1996).

Irrigation scheduling on coarse textured (sandy) soils, with their low water holding capacity, is especially critical with shallow-rooted crops because of the potential leaching of mobile nutrients such as nitrate and potassium below the crop rooting zone under excess irrigation before they can be absorbed by the crop (Schmitt et al., 1994). Nutrients leached below root zones are generally lost to future uptake by crops and often accumulate in the underlying groundwater. Because of the low water holding capacity of Florida sandy soils, proper irrigation management requires estimating crop water use, monitoring soil moisture and splitting irrigation events in order to minimize leaching risk (Simonne et al., 2002a).

Dukes and Scholberg (2004a) compared the impact of subsurface drip irrigation to sprinkler irrigation and the effects of time-based irrigation versus soil moisture-based irrigation scheduling for subsurface drip irrigation on water use. They found that approximately 11% less irrigation water was used in the 23 cm deep subsurface drip irrigation based on soil moisture sensor compared to the sprinkler irrigation treatment.

Leaching below the root zone may be reduced up to 50% using soil moisture-based subsurface drip irrigation compared to sprinkler irrigation due to more irrigation events.

The effects of fertigation strategies on wetting front movement and nitrogen distribution from ammonium nitrate in sandy and loamy soils were studied by Li et al. (2004). They found that increase in the surface wetted radius and in the vertical plane with water volume applied can be represented by a power function with power values of about 0.3 and 0.45, respectively. Increasing the water application rate allows more water to distribute in the horizontal direction, while decreasing the rate allows more water to distribute in the vertical direction for a given volume applied.

Csinos et al. (2002) conducted a field study to predict pesticide movement in micro-irrigated plastic-mulched beds using a blue dye on a loamy sand soil. The blue dye was injected first into the bed for 5 min, and then drip lines were allowed to operate from 4 to 12h. Water moves from the emitters as growing spheres which collide as the diameter increased beyond the emitter spacing. Increasing irrigation time from 4 to 24 h increased water movement directly below the emitters as indicated from the blue dye movement pattern which increased in diameter and depth as irrigation time increased.

Water movement in plastic mulched beds under drip irrigation of Florida sandy soil was studied by Simonne et al. (2003b; 2006a) using a blue dye to visualize water movement in the soil beds. Increasing irrigation volume using drip tape with 30-cm emitter spacing and 298 L/h/100m significantly increased depth, width and emitter-to-emitter coverage of the water front. The wetting front passed below the root depth of 30-cm of the shallow rooted crops such as bell pepper after irrigation volume of approximately 893 to 950L/100m, therefore the highest volume of irrigation water that can be applied on the fine sandy soil to avoid leaching is approximately 900L/100m. Highest width was 38 cm, which was only 57% of the 71-cm wide beds. Complete emitter-to-emitter coverage was reached between 2 and 3 h for drip tapes with 30-cm emitter spacing. Theses results indicated the significance of split irrigation on sandy soil to avoid nutrient leaching.

In addition to blue dye used to visualize water movement, bromide (Br^-) is widely used as a tracer to study water and solute transport because it does not adsorb to negatively charged soil minerals (Flury and Papritz, 1993). Since bromide moves as fast as water in soils and because of its low natural background concentration, this makes Br^- an ideal tracer for water movement (Flury and Papritz, 1993). Transport of Br^- in the vadose zone and its lateral movement in the surficial aquifer was studied in a field experiment by Paramasivam et al. (1999). They found that within the area of application, Br^- was detected in the surficial aquifer (approximately 2.4 m below land surface) 17 days after application, which demonstrates rapid leaching of Br^- in the vadose zone of the soil. Therefore, the leaching potential can be quite high for soil applied NO_3^- if significant rainfall occurs and before it is taken up by the citrus trees (Paramasivam et al., 1999).

Soil water movement and distribution is related to soil moisture content and it affects leaching losses of mobile nutrients. Scheduling irrigation according to crop water requirement using soil moisture sensors can save water and reduce the potential leaching of nutrients. Soil water movement can be monitored using tracers such as bromide and blue dyes to determine the wetting front movement.

2.2 Effect of Irrigation Practices on Nitrate Movement and Distribution

Fertilizer application at rates higher than crop nutrient requirements has resulted in nutrient leaching below the root zone, thereby contaminating the groundwater and surface water systems (Wierenga, 1977; Everts et al., 1989). More information on the environmental impact of current irrigation and fertilization strategies is needed to establish best management practices that will minimize the pollution of groundwater resources and decrease economic losses of nutrients. When N is used for crop production on sandy soils; N source, method, and time of application are of equal importance because of the potential for leaching losses of NO_3 through these soils during the growing season (Wolkowski et al., 1995). The amount of N available for leaching and NO_3-N leached beyond the root zone were affected by amounts of N fertilizer, the amounts of irrigation water, and amounts of annual precipitation (Ersahin and Karaman, 2001). Therefore, careful management practices are required on sandy soils. Different management practices have been proposed to control NO_3 leaching. These include, for example, irrigation and N management based on soil testing programs (Power et al., 2001), controlled release fertilizer (Paramasivam et al., 2001), groundwater table control (Drury et al., 1997), and applying fertilizers through the irrigation systems (fertigation) (Hagin and Lowengart 1996; Gardenas et al., 2005; Mmolawa and Or, 2000b). Although N enters the soil in several chemical forms, it eventually converts to the inorganic NO_3^- ion (Provin and Hossner, 2001). Because NO_3 is a negatively charged ion, which is not held by soil particles, it is readily leached as water flows through the soil with low water holding capacity (Wolkowski et al., 1995). Nitrate is very mobile, and if there is sufficient water in the soil, it can move quickly through the soil profile (Drost and Koenig, 2001). Wetting patterns and nitrogen distribution in the root zone under fertigation through drip-irrigation systems in sandy and loam soils was studied by Li et al., (2004). They found that NO_3 accumulated toward the wetting front which suggests that flushing irrigation drip irrigation system lines from the remaining fertilizer solution should be as short as possible after fertilizer application is finished to avoid the potential loss of NO_3 from the root zone and can lead to contamination of ground and surface water

Anions can be sorbed to soil. Eick et al. (1999) reported that NO_3 retention in soil was found to depend on the type and quantity of both variable and permanently charged minerals present in the soil, and that acid subsoils high in variable-charge minerals may slow NO_3 -N leaching. Anion retention may be completely reversible (Toner et al., 1989) and influenced by texture, with silt loam soils having more anion retention than sandy soils (Vogeler et al., 1997).

Nitrogen is removed from soils by four major processes: plant uptake, gaseous loss, runoff and erosion, and leaching. Leaching losses involve the movement of N with water downward through a soil below the root zone (Provin and Hossner, 2001). The low water holding capacity of sandy soils affect the degree of NO_3 leaching compared to clay soils. There are many factors that affect N management practices on sandy soils such as rate of application, timing of application, source of N, and method of application. Under sandy soil and excessive irrigation conditions, dividing crop requirements of N into several applications according to crop growth stage is a common practice to minimize leaching losses. In the early stage of growth a small amount of N can be applied and as the crop reaches the development stage where maximum uptake occurs a large amount of fertilizers can be applied (Provin and Hossner, 2001). Other factors that can affect NO_3 leaching include amount of rainfall, amount of water use by plants and how much NO_3 is present in the soil system. (Provin and Hossner, 2001).

Efficient management of mobile nutrients such as NO_3-N under shallow rooted crops is an important consideration (Sullivan et al., 2001; Patel and Rajput, 2002). Because NO_3 is negatively charged, therefore it is susceptible to movement through diffusion and mass flow in the soil water (Boswell et al., 1985). There is a direct relation between NO_3-N losses and inefficient fertigation and irrigation management. Therefore, timing and amounts of water and N fertilizer inputs should be carefully managed to avoid losses. Improved irrigation application efficiency (generally defined as the ratio of the volume of irrigation water stored in the root zone and available for plant use (evapotranspiration) to the volume delivered from the irrigation system, Clark et al., 1991) under drip irrigation, through reduced percolation and evaporation losses, provides for environmentally safer fertilizer application through the irrigation water (Mmolawa and Or, 2000b).

Patterns of nitrate distribution in the soil profile for different fertigation strategies, soil types and method of microirrigation were evaluated by Hanson et al. (2004). They concluded that short fertigation events occurring at the beginning of an irrigation event can move much of the NO_3 below the root zone and contribute to leaching. However, injecting the fertilizer near the end of the irrigation event resulted in most of the NO_3 remaining near the drip line where most of the roots are located in drip irrigation systems which reduce the potential for nitrate leaching. Therefore, duration and timing of fertigation events relative to start and the end of the irrigation events affect crop NO_3 availability and leaching.

The effects of N fertilizer and irrigation management strategies on NO_3 leaching in sandy soils were evaluated by Gehl et al. (2005). Their results indicate that applying N fertilizer and irrigation water according to crop requirements is important in reducing the NO_3 leaching from irrigated sandy soils. Also, the NO_3 leaching potential is influenced primarily by water flux and NO_3 concentrations in the soil profile. Thus, management practices that increase downward water flux, especially when soil NO_3 concentration is high, enhance the risk of NO_3 loss to below the crop root zone. Therefore, irrigation scheduling and N management are important to minimize the potential for NO_3 leaching.

Zotarelli et al., (2005) conducted a field study to evaluate the interactive effects of irrigation scheduling methods and N rates on yield, fertilizer requirements, fertilizer N uptake efficiency, and N leaching of pepper and tomato production systems. They found that scheduling drip irrigation using soil moisture sensors reduced N leaching by 33% to 67% compared to fixed daily irrigation commonly used by farmers.

Wetting patterns and nitrogen distributions under fertigation from a surface point source are affected by several irrigation variables. The effect of fertigation strategy and soil type on nitrate leaching potential for four different micro-irrigation systems was studied by Gardenas et al. (2005). Fertigation at the beginning of the irrigation cycle tends to increase seasonal nitrate leaching while fertigation events at the end of the irrigation cycle reduced the potential for nitrate leaching. Leaching potential increased as the difference between the extent of the wetted soil volume and rooting zone increased.

Li et al. (2003; 2004) investigated the influences of emitter discharge rate, input nutrient concentration, and applied volume on water movement and nitrogen distribution while nutrients were applied continuously at a constant concentration from a surface point source. They found that NO_3^- accumulated toward the front of the wetted volume for any combination of discharge rate, input concentration, and volume applied. They went on to suggest that flushing of the remaining fertilizer solution in the drip pipeline system should be as short as possible after fertilizer application is finished to avoid the potential loss of nitrate from the root zone.

The effects of application of different mulching materials and drip-fertigation on nitrate leaching in bell pepper cultivation were evaluated by Romic et al. (2003). The highest quantities of N were leached from the root zone of bell pepper in the treatment without mulch followed by the treatment with cellulose mulch and the lowest N leaching was observed in the treatment with black PE mulch. Mulching with black PE film, besides producing higher yields, reduced NO_3 leaching, and combined with fertigation can reduce a potential risk of surface and ground water pollution by NO_3.

Nitrate distribution in the soil for various fertigation strategies, soil types, and methods of microirrigation was evaluated by Blaine et al. (2004). They found that injecting NO_3 for a few hours at the beginning of an irrigation event could result in relatively nonuniform distributions of fertilizer in the root zone and may leach most of the NO_3 beyond the root zone. On the other hand, injecting for several hours at the end of the irrigation event could result in most of the NO_3 remaining near the drip line. Therefore, the timing of fertigation relative to the start and end of the irrigation event coupled with duration of fertigation event can affect crop NO_3 availability and leaching.

Numerous studies have used Br as a model for estimating NO_3-N leaching (Ingram, 1976; Onken et al., 1977; Olson and Cassel, 1999; Ottman et al., 2000). In these studies, Br^- is applied to soil and the movement of Br through soil was monitored. The difference between Br^- applied and recovered is estimated to be the amount of NO_3-N subject to leaching (Kessavalou et al., 1996; Schuh et al., 1997; Ressler et al., 1998; Ottman et al., 2000).

Advantages of using Br include: (i) it is a conservative tracer that is not subject to microbial transformations and gaseous losses; (ii) it has low concentration in most soils (Bowman, 1984); and (iii) Br^-, like NO_3 -N, is an anion and, therefore, is repulsed by negatively charged clays. Studies that use Br^- or NO_3-N as model compounds for $^{15}NO_3$ -N leaching assume that Br^-, and NO_3^-N have similar leaching kinetics.

Patra and Rego (1997) studied the potential leaching of NO_3-N beyond the root zone using Br as a tracer during wet seasons. One week after a rainfall of 64 mm, 90% of applied Br was recovered to a depth of 60 cm whereas 40% was in the top layer (0-10 cm). With continuous heavy rainfall, almost all Br had migrated beyond 50 cm depth.

Nitrate movement in the soil profile can be monitored using tracers such as bromide and blue dyes to monitor wetting front movement under different fertigation strategies. Leaching losses of nitrate can be reduced through scheduling irrigation based on using soil moisture sensors, split N application according to crop needs and applying fertilizers through irrigation system (fertigation). Therefore, fertigation timing and duration relative to irrigation event can affect nitrate leaching and availability to the crop.

2.3 Effect of Irrigation Practices on Ammonium and Potassium Movement and Distribution

Agrichemical leaching rates are generally related to water flow rate through the soil and the strength of sorption to the soil matrix by cations. Since NH_4^+ and K^+ are cations, they are subject to the process of adsorption and cation exchange to the soil components with negative charges. Therefore, leaching potential of these cations is less compared to that of ions (Ryan et al., 2001). The distributions of ammonium and nitrate concentrations in the soil were measured under different fertigation strategies that varied the order in which water and nutrient were applied (Haynes, 1990). An extremely high ammonium concentration existed in the proximity of the point source because ammonium is absorbed by soil. During a fertigation cycle (emitter rate $2Lh^{-1}$) applied ammonium was concentrated in the surface 10 cm of soil immediately below the emitter and little lateral movement occurred.

As with NH_4-N, movement of K is related to the CEC of the soil. Leaching losses of K in sandy soils is mainly due to their low cation exchange capacity (3-5 meq/100 g) (CEC) compared to clay soils with high CEC (Sparks and Huang, 1985). Leaching of K is also dependent on the concentration of other cations in the soil especially calcium (Ca^{++}) in the soil solution besides clay type and content, organic matter content and amount of applied potassium (Johnston et al., 1993).

Soil moisture affects soil K availability and diffusive flux, as well as K uptake, via its effects on root growth and activity (Seiffert et al., 1995). Zeng and Brown. (2000) studied the effects of soil moisture on soil K mobility, dynamics of soil K, soil K fixation, plant growth, and K uptake. Soil K mobility increased with soil moisture content. There was a relationship between soil moisture content and effective diffusion coefficient, suggesting that more K can diffuse to the plant roots at sufficient soil moistures.

Locascio et al. (1997) evaluated potassium sources and rates for plastic-mulched tomatoes under drip and subsurface irrigation. Marketable yields were higher with potassium nitrate (KNO_3) than potassium chloride (KCl) as sources of potassium. Tomato leaf tissue K concentration increased linearly with increased rates of K application, but was not influenced by K sources.

Cations such as NH_4^+ and K^+ are subject to the process of adsorption and cation exchange to the soil components with negative charges. Therefore, leaching potential of these cations is less compared to negatively charged ions such as NO_3^-. Since sandy soils have low cation exchange capacity, cations are subject to leaching losses under excess irrigation and/or fertilization. Leaching of soil K is dependent on the concentration of other cations in the soil solution such as Ca^{++} and on the amount of applied K. Unlike K, NH_4 ion is subject to transformation to NO_3 through nitrification process and become more subject to leaching losses.

2.4 Effect of Irrigation and Fertilizer Practices on Nitrogen Uptake and Accumulation

Fertilizers should be applied in a form that becomes available in synchrony with crop demand for maximum utilization of nitrogen from fertilizers (Boyhan et al., 2001). The method of application is important in obtaining optimal use of fertilizers. It is recommended that fertilizers be applied regularly and timely in small amounts (Neeraja et al., 1999). This will increase the amount of fertilizer used by the plant and reduce the amount lost by leaching (Shock et al., 1995).

Accurate determination of crop N needs is essential for profitable and environmentally sound N management decisions (Schmitt et al., 1994). A study was conducted by Olsen et al. (1993) to determine the efficiency of N usage by bell pepper grown with plastic mulch and trickle irrigation, and to define a rate of applied N which is equal to uptake by the crop. They found that maximum dry weight yield of fruit, leaves, roots, stems and maximum fresh weight of marketable fruit corresponded with 210 to 280 kg ha^{-1} of N for both spring and fall crops. Plant uptake of elements increased with applied N. At the application rate of 280 kg ha^{-1} of N the element uptake were ranked as follows: K > N. The fruits accumulated the greatest proportion of K, N, and P (40 to 64%, 40 to 64%, and 49 to 76%, respectively). The efficiency of fruit production from absorbed applied N declined with increasing N rate (Olsen et al., 1993).

Fertigation is an efficient means of applying crop nutrients, particularly nitrogen, so that nutrient application rates can be reduced in fertigated crops. Nutrients applied through fertigation can be applied directly to the wetted volume of soil where the majority of roots are located and therefore nutrient use efficiency by the crop can be increased and the leaching potential of mobile nutrients can be decreased (Thorburn et al., 2003). Smika and Watts (1978) studied residual NO_3-N in fine sand as influenced by nitrogen fertilizers and water management practices. They found that at lower application rates, residual NO_3-N was very because it was nearly equal to plant uptake. They also found that the injected N application method with the proper water application management can greatly reduce the potential for NO_3-N movement below the crop rooting zone on fine sand soils.

Root activity tends to be concentrated in the wetted soil volume under drip irrigation (Haynes, 1990). Therefore, knowledge of nutrient uptake by plant roots is required for optimizing nutrient application for satisfying plant requirements and minimizing losses to the environment (Hagin and Lowengart, 1996). Under trickle irrigation only a portion of the soil volume directly below the emitter is usually wetted and therefore crop root growth is essentially restricted to this volume of soil. Nutrient available within that volume can become depleted by crop uptake and/or leaching below the root zone (Haynes, 1985)

Nutrient uptake by plant roots affects the concentration, movement and distribution of these nutrients within the root zone. Since water content and availability and root distribution are changing continuously, root uptake patterns of water and nutrients are highly dynamic (Mmolawa and Or, 2000a)

Carballo et al. (1994) studied the effects of various timing and rates of N and K applied through drip irrigation to bell pepper grown on plastic mulched soil beds on fruit quality and susceptibility to bacterial soft rot. Fruits of plants fertilized with high N and K rates had greater N and dry matter content.

Nutrient uptake by the crop can be maximized through fertigation where they can be applied directly to the wetted volume of soil where the majority of roots are located and therefore nutrient use efficiency by the crop can be increased and the leaching potential of mobile nutrients can be decreased. Timing of application, nutrient source, application rate, growth stage and available soil water can affect uptake of nutrients.

2.5 Effect of Irrigation and Fertilizer Practices on Biomass Accumulation and Yield

Drip irrigation at a rate close to plant water uptake affect soil water regime and plant response (Assouline, 2002). A recent study conducted by Zotarelli et al. (2005) to evaluate the interactive effects of irrigation practices and N rates on yield, fertilizer requirements, fertilizer N uptake efficiency, and N leaching of pepper and tomato production systems, showed that pepper plant growth during the first six weeks was not significantly affected by either irrigation or N rate. Likewise, tomato yields with daily fertigation were not increased over weekly fertigation events on a fine sand soil (Locascio and Smajstrla, 1995). Another study by Neary et al. (1995) showed that yield of drip-irrigated bell peppers (*Capsicum annum* L.) was not affected by fertigation interval (11 or 22 days) on a loamy sand soil. Conversely, Cook and Sanders (1991) examined the effect of fertigation frequency on tomato yield in a loamy sand soil and found that daily or weekly fertigation increased yield compared to less frequent fertigation. However, there was no advantage of daily over weekly fertigation.

Goreta et al. (2005) conducted a study to evaluate the effects of N rate and planting density on growth, yield and quality of watermelons grown on black polyethylene mulch. Average fruit weight and fruit size distribution were generally unaffected by N rate. Leaf N concentration increased as N rate increased. Total and marketable yields linearly decreased with an increase in plant spacing from 0.5 to 1.5 m, and the same was noticed with the total and marketable number of fruit per ha. With increased plant spacing average fruit weight increased and fruit size distribution shifted to larger categories.

Carballo et al. (1994) studied the effects of various rates and timings of N and potassium applied to plastic-mulched bell pepper under drip irrigation on fruit quality and susceptibility to post harvest bacterial soft rot (Ervinia carotovora Snubs. carotovora). They found that neither N rate nor application timing affected total yield in either year. However, the high fertilizer rate (266 and 309 kg ha^{-1} of N and K, respectively) increased class 1 yield in the first harvest and reduced total culls. Mid or late-season fertigation produced more second harvest yield and less discards than the first harvest under the higher fertilizer rate. However, fruit quality of tomatoes may be improved when N and K are applied by drip irrigation as compared to applying all fertilizer as preplant (Dangler and Locascio, 1990b).

Plant growth and crop yield are related to nutrient availability in the crop root zone. Fertilizer and irrigation rates affect nutrient availability and consequently crop growth and yield. Under irrigation and/or fertilization can limit crop yield while excessive irrigation and/or irrigation can reduce fertilizer use by the crop and increase leaching losses. Therefore, managing both fertilizer and irrigation can maximize crop growth and yield and reduce the potential for leaching losses.

2.6 Fertigation for Minimizing Nutrient Leaching and Maximizing Uptake

The use of fertigation has increased in Florida covering a variety of agricultural fields and crops. Fertigation offers the potential for increasing efficiency of application of mobile nutrients such as NO_3-N (Locascio and Martin, 1985). Although drip irrigation can improve irrigation efficiency, care must be exercised to operate the system properly that optimum amounts of water are applied. Inadequate irrigation can reduce yields and over irrigation in a sandy soil can leach mobile nutrients such as NO_3-N and K below the root-zone. Since nutrients are easily added during fertigation, it is most beneficial in sandy soils with a low cation exchange capacity (CEC) (Hagin and Lowengart, 1996). These soils need frequent irrigation and nutrient replenishment. Drip irrigation systems are used on a commercial scale and the expansion is mostly in horticultural and high value crops (Hagin and Lowengart, 1996).

Under trickle irrigation only a portion of the soil volume directly below the emitter is usually wetted and therefore crop root growth is restricted to this volume of soil. Nutrient available within that volume can become depleted by crop uptake and/or leaching below the root zone. Fertigation gives a flexibility of fertilization which enables the specific nutritional requirements of the crop to be met at different stages of its growth. Therefore, fertilizer use efficiency for most crops can be improved when they are applied by fertigation (Haynes, 1985)

Applying fertilizers through irrigation systems has several benefits. Fertilizer application can be targeted to specific areas, so that plant nutrients can be applied directly in the root-zone and can be more efficiently utilized by the plants. Since the majority of roots in drip-irrigated crops are located within the wetted zone, drip applied nutrients will be placed in the soil region containing the highest root density. Therefore, the nutrients applied in this manner are generally used more efficiently by plants than if the same amounts were surface applied. This should result in maximization of crop yield and quality and the reduction in the potential of nutrients leaching below the rooting zone (Hagin and Lowengart, 1996).

Efficient fertigation scheduling requires attention to three factors: crop and site specific nutrient requirements, timing nutrient delivery to meet crop needs, and controlling irrigation to minimize leaching of soluble nutrients below the effective root zone. Seasonal total N, P and K requirements vary considerably by area and soil type (Hochmuth and Hanlon, 1995). In many situations a small percentage of N and K (20 -30 %), and most or all P, is applied in a preplant broadcast or banded application. Preplant application of N (and K, if needed) is particularly important where initial soil levels are low (Locascio et al., 1982; 1985b) or in conditions where early season irrigation is not required. It is commonly accepted that the efficiency of fertilizer use can be improved when it is applied by fertigation to most crops (Haynes, 1985).

With fertigation it is possible to maintain levels of nutrient in the soil solution and to reduce nutrient leaching. Fertigation also provides greater flexibility in the timing and sources of nutrient application (Lately et al., 1983). Although fertigation is practiced under all irrigation methods (surface irrigation, sprinkler irrigation, and drip irrigation), it is more easily and precisely controlled and flexible under drip irrigation (Bar-Yosef , 1999).

Fertigation enables the application of soluble fertilizers and other chemicals uniformly and more efficiently along with irrigation water, (Patel and Rajput, 2000 ; Narda and Chawla, 2002). However, the increasing use of nitrogenous fertilizers has caused environmental problems, generally evident in groundwater contamination.

There is a direct relation between large NO_3-N losses and inefficient fertigation and irrigation management. Therefore, water and N fertilizer inputs should be precisely managed to avoid these losses. Improved water efficiency under drip irrigation, by reducing percolation and evaporation losses, provides for environmentally safer fertilizer application through the irrigation water (Rolston et al., 1979 ; Mmolawa and Or, 2000 b)

Fertilizers should be applied in a form that becomes available according to crop demand for maximum utilization of nitrogen from fertilizers (Boyhan et al., 2001). The method of fertilizer application is very important for optimal use of the fertilizer, therefore the fertilizer should be applied regularly and timely in small amounts (Neeraja et al., 1999). This will increase the amount of fertilizer used by the plant and reduce the amount lost by leaching (Shock et al., 1995).

Fertilizer use efficiency (the ratio of amount taken up by the crop to the amount of fertilizer applied) can be improved when it is applied by fertigation to most crops (Haynes, 1985). Increased fertilizer use efficiency would be particularly useful for nitrogen (N) in production systems, as significant losses of N from volatilization (Freney et al., 1991) and denitrification (Weier et al., 1996) can occur with conventional means of application. Over-application of N can substantially increase leaching of N from the root zone (Verburg et al., 1998). Maximization of crop yield and quality and minimization of leaching of nutrients and water below the root zone may be achieved by managing fertilizer concentrations in measured quantities of irrigation water, according to crop requirements (Hagin and Lowengart, 1996).

The method of fertilizer application is very important in optimizing fertilizer use efficiency by the crop and therefore reducing nutrient losses and potential contamination of water resources. Applying fertilizers through irrigation systems especially drip irrigation can increase nutrient use efficiency by the crop since the majority of plant roots are located in the wetted soil volume of the soil. Timing and duration of fertigation event relative to the irrigation event affect movement and distribution of the nutrient in the crop root zone and therefore the potential for leaching losses. Therefore, it is recommended to split fertilizer application regularly and timely in small amounts to maximize crop yield and minimize the potential for leaching losses. .

2.7 Conclusion

Water movement is one of the major processes affecting solute transport in soils. Since soil water content changes both spatially and temporarily due to water infiltration, evapotranspiration and, concentration and composition of the soil solution change over time. Moreover, variations in solute distribution can be due to differences in solute mobility and interactions with the soil matrix. Water and nitrogen fertilizers are the two most important factors affecting NO_3-N movement to surface and groundwater. Therefore, understanding water and nutrient movement in the soil profile is important for developing efficient irrigation and nutrient management practices to minimize nutrient leaching below the root zone.

Drip irrigation is often preferred over other irrigation methods because of the high water-application efficiency (85%), which reduces losses from surface evaporation and minimizes deep percolation. Also, salt concentration within the root zone can be easily managed because of the high frequency of fertilizer application. This will depend on the method used to schedule irrigation. Time based irrigation scheduling where irrigation can be twice a day or can be as many times a day when soil moisture sensors are used to schedule irrigation is preferred (Dukes and Scholberg, 2004a; 2004b)

Drip irrigation generates a restricted root system requiring frequent nutrient supply by applying fertilizers in irrigation water (fertigation).Therefore, most vegetable crops produced on plastic mulched soil beds in Florida are adaptable to drip irrigation including tomato, pepper, eggplant, strawberry, and cucurbits including watermelon, muskmelon and cucumber. Efficient management of mobile nutrients such as NO_3-N under shallow rooted crops is an important consideration. Because NO_3 is negatively charged, it is susceptible to movement through diffusion and mass flow in the soil water. Therefore, understanding of the impact of current irrigation and N fertilization practices under field conditions on the crop yield and on losses of water and nutrients from the root zone is necessary to develop best management practices for both fertilizer and irrigation to maximize crop yield and minimize nutrient leaching below the root zone.

CHAPTER 3
MATERIALS AND METHODS

3.1 Field experiment

This research consisted of two side-by-side field experiments conducted in the Spring of 2002 at the North Florida Research and Education Center, Suwannee Valley near Live Oak, Florida, on a Lakeland fine sand (thermic, coated, Typic Quartzipsamment) (USDA, 1961). For each crop, the experimental design was a randomized complete block design with four replications. Treatments were irrigation (66%, 100%, 133% of IFAS target rate; Simonne et al., 2006c) and N fertilization (100% and 125% of IFAS N recommended rate) rates (Olson et al. , 2006a, b) for bell pepper and watermelon crops, respectively.

3.1.1 Cropping System

Unless otherwise specified, similar procedures were used for the bell pepper and watermelon trials. Results from a soil sample taken in the fall of 2001 indicated that Mehlich 1 P was ‘very high” and Mehlich 1 K was “very low” (Mylavarapu and Kennelly, 2002). In mid February, the rye cover crop (Secale cereale L.) was disked. In late February, the field was overhead irrigated with approximately 1 cm of water, false beds were formed and the preplant fertilizer was applied at a rate of 34 kg N ha^{-1} using 13-4-13. The N-form ratio in the preplant fertilizer was 50:50 NO_3-N: NH_4-N. After rototilling the preplant fertilizer, beds were formed, 66:33 (W:W), methyl bromide:chloripicrin was injected at a rate of 448 kg ha^{-1}, a single drip irrigation tape

(Roberts Ro Drip; 279 L $100m^{-1}hr^{-1}$ flow rate at 69 kPa, 30-cm emitter spacing; San Marcos, CA) was laid and a low-density polyethylene mulch (38.1 micro-m thick) was laid. Seventy one (71) cm wide beds were formed on 1.52 m and 2.28 m centers for the bell pepper and watermelon crops, respectively.

On March 29 (Days After Transplanting, DAT =0), six-week-old 'Brigadier' bell pepper and 'Mardi Gras' watermelon transplants were established in double staggered and single rows, respectively. Plots were 7.3 and 16.5 m long for the bell pepper and watermelon crops, respectively, which created plant stands of 34,800 and 4,800 plants ha^{-1}, respectively. Pest control followed the recommendations of IFAS for bell pepper and watermelon crop production in Florida (Olson et al, 2006a, b).

3.1.2 Irrigation Treatments

The design of the drip-irrigation system allowed for independent delivery of water and fertilizers, and randomization of the treatments (Simonne et al., 2002 a). Irrigation treatments were (66%, 100%, 133% of ET_C (IFAS target rate; Simonne et al., 2006a). Irrigation treatments were calculated based on the crop growth stage and with pan adjustment factors (Simonne et al., 2006c). The 66% ET_C and 133% ET_C irrigation rates were adjusted with the number of drip tapes installed in the bed. For example, 100% ET_C irrigation rate included three drip tapes for irrigation; whereas, 66% ET_C irrigation rate included two drip tapes.

In mid March, the single drip tape already under the plastic was replaced by 3, 4 or 5 similar drip tapes based on irrigation and fertigation treatments. Emitters from different irrigation tapes were not aligned. Hence, the maximum distances between two consecutive emitters were 15 to 30 cm for 66%, 10 to 30 cm for 100% and 8 to 30 cm for the 133% irrigation treatment. For each plot, one drip tape was used to deliver N. The remaining drip tapes (2, 3 or 4) were used to create irrigation rates of 66%, 100% and 133% of ET_C (IFAS target rate) based on Class A pan evaporation (Simonne et al., 2006b).

There was one irrigation line equipped with a water meter which irrigated the whole field and total amounts of irrigation water were recorded daily. Different irrigation treatments with different numbers of drip tapes were connected to the main irrigation line. Amount of irrigation water applied for each irrigation treatment was calculated by knowing the total linear meters of drip tapes for each irrigation treatment relative to the total linear meters of drip tape for the whole field and the amount of irrigation water recorded from the water meter for the whole field. For each factorial combination of irrigation and N rates, seasonal water application rates were calculated by adding the amount of water applied by the irrigation line and that applied by the fertilizer line (including water applied from Br injection) (Appendices D-3 and D-7).

3.1.2.1 Irrigation Scheduling

Because only part of the field is actually under plastic mulch, and therefore irrigated, E_{pan} values were converted to irrigation volumes using 10 mm E_{pan} = 835 L / 100 m of plastic. This conversion factor is based on the percentage of the field under plastic. Crop factor values were tested in 2001 and 2002 (Simonne et al., 2006c) at the North Florida Research and Education Center-Suwannee Valley (NFREC-SV) at this site.

Irrigation treatments were scheduled daily to both crops based on Class A pan evaporation (Epan) from the previous day. The 100% ET_C (IFAS target rate) was determined using the conversion factor of 10 mm of Ep corresponding to 835L/100 m of irrigated bed. Irrigation events were initiated manually twice each day, one event in the morning and one at mid afternoon to ensure uniform transplant establishment. Plants were irrigated by drip irrigation to maintain a tensiometer reading of approximately -10 kPa at 15 cm deep in the bed between two plants in a row. Crop ET was estimated from daily class A pan evaporation (E_{pan}) and crop factor CF as follows:

$$I = ET_C = E_{pan} * CF \quad [3\text{-}1]$$

The value of CF varied during crop growth, from a minimum of 0.2 shortly after planting, then increasing with the development of the leaf canopy to attain a maximum value of 1. Crop factor (CF) values were selected as half of Kc values. During crop establishment (from March, 29 to April 17, 2002), irrigation water was applied through N fertilization lines. Actual irrigation treatments started on April 18, 2002 and continued until the end of the growing season. Although the total linear bed meters for the two N treatments of the bell pepper experiment were the same (87.8 m), total amount of irrigation water applied through N1 line (100% N rate) for the whole field was 6675 liters while for N2 line (125% N rate) the total amount of irrigation water was 6422 liters. Calculated weekly and seasonal amount of irrigation water applied to each treatment for both crops are given in Appendices D-1 and D-5.

3.1.2.2 Calculation of irrigation water amounts

Based on the surface under plastic mulch (0.71 m wide) then a 10 mm E_{pan} corresponds to 835 L/100 m of irrigated bed**.** Irrigation treatments were calculated based on the crop growth stage and with pan adjustment factors (Simonne et al., 2001). The 100% ET_C (I2) treatment (3 drip tapes) was selected as the target irrigation treatment (1.0 I2); hence, I1 (2 drip tapes) was 0.66 I2, and I3 (4 drip tapes) was 1.33 I2. However, from the data in Appendices (D-4, and D-8), these ratios varied with time and were also different for the bell pepper and watermelon crops. This observation is important when calculating percent recovery of nutrients in the soil during the dates of soil sampling (Appendices B-1 to B-4).

3.1.3 Fertilizer Application

Current recommendation for bell pepper production in Florida based on 1.80 m standard bed spacing includes application of 224 kg N ha^{-1} (blanket), 0 kg P ha^{-1}, and 186 kg K ha^{-1}per season when Mehlich 1 P is high and Mehlich 1 K is low. For watermelon, current recommendation based on 2.40 m standard bed spacing includes application of 168 kg N ha^{-1}, 0 kgP ha^{-1}, and 140 kg K ha^{-1}, per season. Fertilizers were applied as 20% of the 75% IFAS recommended rate for N and K as prelant application and the remaining 80 % of the fertilization rate was applied through the drip irrigation system in weekly injections following IFAS recommendation for both bell pepper and watermelon crops (Appendices C-1 and C-2)

Preplant fertilizers were applied during bed preparation using 258 and 194 kg ha^{-1} of 13-4-13 commercial fertilizer (N rate = 34 and 25 kg ha^{-1}) for bell pepper and watermelon, respectively. Nitrogen and K were applied from ammonium nitrate (NH_4NO_3) and potassium nitrate (KNO_3) fertilizers. Fertilization rate for bell pepper was adjusted to 269 kg N ha^{-1} for N and 223 kg $ha^{-1}$for K_2O, respectively, based on actual bed spacing of 1.50 m. For watermelon the fertilization rate was adjusted to 180 kg ha^{-1} for N and 150 kg ha^{-1} for K_2O based on actual bed spacing of 2.25 m.

After transplants were established, irrigation rates were tested under 100% and 125% of the recommended N rate (N1 and N2, respectively). Combinations of potassium nitrate and ammonium nitrate were injected weekly to supply the required injected rate for both bell pepper and watermelon crops based on crop stage of growth (Appendix C -3). Weekly and cumulative amounts of NO_3-N, NH_4-N, applied N (NO_3-N+NH_4-N) and

K_2O were calculated using combination of NH_4NO_3 and KNO_3 fertilizers (Appendices B-1 to B-4) and were used to calculate percent of NO_3-N, NH_4-N, and K retained in the soil profile and percent N removed by the crop.

There were two fertigation lines one for each crop and each of them equipped with water meters. Nitrogen treatments were applied weekly through N lines to give the fertilizer application rates that meet the crop requirement at each stage of crop growth (Appendix A). Calculated weekly and seasonal amounts of water (L/100m) used to inject the fertilizes (including water from Br injection) for both crops are given in Appendices D-2 and D-6. The fertilizer injection schedule was based on crop growth stage.

Fertilizer application rates were calculated based on standard bed spacing of 1.83 and 2.44 meter for bell pepper and watermelon, respectively, which give a total of 5468 m per hectare for bell pepper and 4100 m per hectare for watermelon. The actual bed spacing was 1.52 and 2.27 m for both crops which gave a total of 6562 and 4374 m per hectare for both crops, respectively. The fertilizer application rates were adjusted based on the actual bed spacing for both crops by applying more fertilizer to meet the increase in linear bed meters. For example, if N application rate of 224 kg N ha^{-1} for bell pepper was applied based on 1.83 m-bed spacing then each 100 m-of plastic mulched beds (total linear meters /100) contain 4.10 kg N 100 m^{-1} (224 kg N/54.68). To keep the same amount of N per 100 m based on the actual bed spacing of 1.52 m (269 kg N/65.62 m) which gives 4.10 kg N100m^{-1}. For both crops, the fertilizer injection schedule followed the recommendations of vegetable production for Florida (Olson and Simonne, 2006). Nitrogen rates (N1 and N2) were made by adding increasing amounts of fertilizer in the same volume of solution, so that differences in water applications due to N-treatments will be minimal.

3.1.3.1 Example of fertilizer calculation

Amounts of KNO_3 and NH_4NO_3 needed to accomplish injections for the bell pepper experiment were calculated as follows. Each nitrogen treatment line feeds a total of 87.78 m (3I x 4 replicates x 7.32 m/plot = 87.78 m; plots are 6.10 m long but the tube runs through the 1.52 m alley and 0.30 extra meters of tube was left at the end of each plot for flushing the lines. Since all the drip tubes had emitters even in the alleys the practical plot length was 6.10 + 1.52/2 + 0.3 = 7.16 m). On 1.52 m centers, 87.78 m of plastic corresponds to 0.0134 hectare.

When KNO_3 is used, 1kg K_2O ha^{-1} is applied with 2.59 kg of KNO_3 (K=39 and KNO_3 = 101 g/mole). For each nitrogen treatment (0.0134 ha), 0.0347 kg of KNO_3 will provide a rate equivalent to1 kg K_2O ha^{-1} (2.59 x 0.0134 = 0.0347 kg). When 0.0347 kg of KNO_3 are applied to 0.0134 ha, 0.0048 kg N are also applied to the plot (0.0134x 14/101 = 0.0048), which corresponds to 0.359 kg N ha^{-1} (0.0048/0.0134 = 0.359). So, when 0.0347 kg of KNO_3 is applied to 87.78 m of line, 0.359 kg N ha^{-1} and 1.0 kg K_2O ha^{-1} are applied.

When NH_4NO_3 is used 1 kg N ha^{-1}corresponds to 2.86 kg NH_4NO_3 (80/28 = 2.86). So, for each treatment (0.0134 ha) 0.0383 kg NH_4NO_3 (2.86 x 0.0134 = 0.0383) is needed. For each nitrogen treatment, 0.0383 kg NH_4NO_3 provides a rate equivalent to 1 kg N ha^{-1}**.** A rate of 1 kg K_2O per treatment as KNO_3 also supplies 0.0485 kg NO_3-N ha^{-1} (14/101 x 0.0134/ 0.0383).

3.1.3.2 Bromide injection

Bromide was applied with the first fertilizer injection on April 11 (14 days after transplanting =14 DAT; Days after First Fertilization Injection DAFFI = 0) as a tracer for water and fertilizer movement using calcium bromide at rate of 22 and 15 kg Br ha^{-1} for the bell pepper and watermelon experiments, respectively. Application rates of Br were calculated as kg Br ha^{-1} since the bed spacing for watermelon was 1.5 times greater (2.28 m vs. 1.52 m for watermelon and bell pepper respectively) than the bed spacing for bell pepper; therefore 1.5 times more Br was applied to bell pepper than watermelon. However, these rates are numerically different on a per hectare basis, but are the same (1.01kg Br/100 m) on a linear meter of bed or row basis.

3.2 Soil and Plant sampling

3.2.1 Soil Sampling

The soil was sampled using 30 mm internal diameter steel tube. Soil cores were taken under a randomly chosen N application emitter from the fertilizer line in each plot. Emitter was located by cutting the plastic mulch and the core was divided into four depth increments. After taking the soil samples, the sampling hole was refilled with soil and samples were stored at 4° C in plastic bags until analyses.

Soil samples were taken from each plot under random emitters at 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm soil depth increments at transplanting (first sampling, March 29, 0 DAT), one day after first fertilizer injection (second sampling; April 12, 14 DAT), at full flower (third sampling, May 2, 36 DAT), and at first harvest (fourth sampling, June 10, 75DAT).

Since the main goal of the study was to characterize water and nutrient movement within and below the crop root zone, the contents (kg ha^{-1}) of NO_3-N, NH_4-N and K within the root-zone (0-30 cm) of bell pepper were calculated by combing the contents for 0-15 and 15-30 cm. The contents of NO_3-N, NH_4-N and K below the root zone were calculated by combining the 30-60 cm and 60-90 cm depth together. For watermelon, the contents (kg ha^{-1}) of NO_3-N, NH_4-N and K were combined for 0-15 and 15-30 cm and 30-60 to give the contents within the root zone (0-60cm) and 60-90 cm below the root zone. Soil samples were taken after preplant fertilizer application and before transplanting; after first fertilizer injection; during flowering and at harvest. These stages of plant growth correspond to 0, 1, 22, and 60, days after first fertilizer injection (DAFFI) for bell pepper and watermelon which correspond to 0, 14, 36 and 75 days after transplanting (DAT).

Soil moisture content, Br, NO_3-N, NH_4-N, and K, concentration (mg kg^{-1}) in soil samples were measured after soil extraction (see laboratory analyses, below). Patterns of water, NH_4-N, NO_3-N, K, and Br distribution within the soil profile were determined.

3.3.2 Plant Sampling

Plant samples were taken from leaves, stems and fruits of the plant during fruit development and at harvest which correspond to 53 and 75 DAT, respectively for both crops. Fresh weight was determined and was dried to constant weight at 70° C and biomass accumulation was determined. Percent dry weight (PDW) was calculated as dry weight (DW) in grams per plant divided by fresh weight (g) times 100. Dried samples were ground-to pass a 20-mesh screen. Total Kjeldhal Nitrogen was determined using EPA method 351.2 (USEPA, 1993) at the Analytical Research Laboratory (ARL), Soil and Water science department, University of Florida,

3.3.3 Harvest, Grading and Yield Estimation

Bell peppers were harvested once on 75 DAT, and graded as US fancy, US #1, US #2, and cull. Total yield was calculated by adding US fancy, US #1, US #2, and cull weights (USDA, 1989). Marketable yield was calculated by adding US fancy, US #1, and US #2 weights. Watermelon was also harvested at 75 DAT, weight and number of fruits for each plot was recoded to calculate the marketable yield.

Table 3-1. Summary of major field events at the experimental site

Date	DAT	DAFFI	Events
2/15/2002			Cover crop was disked
3/8/2002			Preplant fertilizer was applied and beds were formed
3/15/2002			Drip tapes were connected to irrigation and N lines
3/29/2002	0		Transplanting and first soil sampling
4/11/2002	14	0	First fertilizer and bromide injection
4/12/2002	15	1	Second soil sampling
4/18/2002	21	7	Start of irrigation treatments
5/2/2002	35	22	Third soil sampling
5/21/2002	53	44	First plant sampling
6/10/2002	73	59	Forth soil sampling and second plant sampling
6/11/2002	74	60	Harvest

3.3 Laboratory Analyses

3.3.1 Soil Analysis

Soil moisture content, Br, NO_3-N, NH_4-N,and K were measured in soil samples taken up to the 90 cm depth in different increments (0-15, 15-30, 30-60 and 60-90 cm) from all treatments. About 10 grams of moist soil were extracted with 20 mL of 0.5 M KCl. Then, the samples were shaken for 30 minutes using a reciprocating shaker and then filtered through Whatman No.1 filter paper and finally 10 ml of clear supernatant was taken and frozen until analysis. Using 0.5M KCL for soil extraction was based on personal communication. A second sub sample of soil was dried at 105° C for 24 hours to determine the oven-dry weight of extracted soil. All results were expressed on an oven-dry soil weight basis.

Ammonium-N was determined using EPA method 350.1 (USEPA, 1993) in which the sample is buffered at a pH of 9.5 with a borate buffer in order to decrease hydrolysis of cyanates and organic nitrogen compounds, and is distilled into a solution of boric acid. Alkaline phenol and hypochlorite react with ammonia to form indophenol blue that is proportional to the ammonia concentration. The blue color formed is intensified with sodium nitroprusside and measured calorimetrically. The analysis was done at (ARL)

Nitrate-N was determined using EPA method 353.2 (USEPA, 1993) in which a filtered sample is passed through a column containing granulated copper- cadmium to reduce nitrate to nitrite. The nitrite (that was originally present plus reduced nitrate) is determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye which is measured colorimetrically. Separate, rather than combined nitrate-nitrite, values are readily obtained by carrying out the procedure first with, and then without, the Cu-Cd reduction step. As with ammonium-N, laboratory analysis was performed at ARL.

Soil K was extracted using double acid 0.05N HCl and 0.025N H_2SO_4 (Mehlich-1) method of extraction for K (Mehlich, 1953). This extraction procedure was developed for use with acid, sandy soils found in the southeastern U.S., having less that 5% organic matter. The analysis was done using Atomic Absorption (AA) equipment at Soil and Water Science Department, IFAS, University of Florida.

Soil bromide was extracted from soil samples using 20 ml of deionized water for every 10 g of soil samples, shaking for 30 minutes using a reciprocating shaker and finally taking 10 ml of clear supernatant, which was analyzed for Br using Orion ion selective Model 9635 ion plus series Bromide electrode (Orion research, Inc. 500 Cummings center, Beverly, MA USA). Soil Br concentration was calculated based on established calibration curve of known bromide concentrations and plotting the log concentration of bromide and the corresponding mV reading. The concentration used to established the calibration curve was in decades (1, 10, 100, and 1000 mg/L Br). To prepare 1000 mg/L Br using sodium bromide (NaBr), 1.287 g of NaBr was dissolved in one liter of deionized water. A series of dilutions were made to prepare the remaining concentrations of 1, 10, and 100 mg/L Br from the original 1000 ppm Br solution. Measurement of Br concentration in the samples requires the use of ionic strength adjuster (ISA) which can be prepared using 5 M $NaNO_3$. The total ionic strength of a sample affects the activity coefficient and it is important that the ionic strength stays constant. In order to accomplish this, the addition of an ionic strength adjuster was used and the variation between samples becomes small and the potential for error was reduced.

Prepared standard solutions of known concentrations were then measured with the pH meter set to read mV. The mV reading of each solution was recorded and a graph of concentration vs. mV reading was plotted. The Br concentrations of the unknown solution were then calculated using the measured mV value.

3.3.2 Soil Characteristics

Soil bulk density (ρ_b) was calculated from core samples (58.88 cm^3) collected at 0-15, 15-30, 30-60 and 60-90 cm depth from the experimental site using Eq 3.2

$$\rho_b = M_s / V_t \qquad (3\text{-}2)$$

where M_s is the mass of oven dried soil and V_t is total volume of the soil. Soil bulk density was used to convert NH_4-N, NO_3 –N, K and Br data from mg kg^{-1}soil to kg ha^{-1}.

Soil moisture content was determined gravimetrically by placing 20 grams of wet soil in an aluminum can and was dried in the oven at 105 C for 24 h. The soil moisture content, θ_w, as a mass fraction of soil is:

$$\theta_w = (M_w / M_s) \tag{3-3}$$

where M_w is the water mass in grams and M_s is the mass of oven dry soil in grams. To convert the gravimetric water content to volumetric (θ_v) water content the following formula was used,

$$\theta_v = \theta_w * \rho_b \tag{3-4}$$

(see Appendices E-1 to E-3)

The water flux (q) was calculated using Darcy's law (Eq. 3-5) by taking the Reference Level at the 90 cm depth (Appendices F-1 to F-6) using volumetric water content at different soil depths for different irrigation rates (Appendices E-1 to E-3). The effective conductivity (K_{eff}) was calculated from Eq. 3-6 and was used to calculate the effective flux. (Appendices F-1 to F-6)

$$q = -K(h)[H1-H2)/(X1-X2) \tag{3-5}$$

$$Keff = \sum bi/(\sum bi/Ki) \tag{3-6}$$

where K (h) = conductivity of the soil layer at suction (h, cm), (Appendices G-1 and G-2); (X_1-X_2) = the thickness of the soil layer (cm); K_{eff} = the effective conductivity of all soils layers, $\sum b_i$ = thickness of all soil layers (cm); b_i = thickness (cm) of layer (i) considered; K_i = conductivity of layer (i).

Volumetric water content was converted to depth of water (cm) by multiplying the volumetric water content as a fraction by the sampling depth. Particle size analysis was performed using the pipetee method (Grossman and Reinsch, 2002) The pipette method measures the actual percent by weight of each particle size class (sand, silt and clay) in the soil sample based on Stokes's Law which states that large particles settle faster than smaller particles when suspended in a liquid.

Soil water retention curves were determined in the laboratory according to the process described by Klute (1986) using Tempee Cells and was adapted from (Sanchez, 2004). Undisturbed soil samples were obtained in March 2002 with a soil core sampler for different soil depths (0-15, 15-30, 30-60 and 60-90 cm). The soil sampler held two brass cylinders of 3 cm in height each. The brass cylinders were 5.4 cm in diameter and the total volume of the cylinder was 68.64 cm^3. A total of 24 soil cores were obtained (4 depth*3 locations*2 cores per depth).The brass cylinders were removed carefully from the soil core sampler. Each sample was covered with a plastic bag and wrapped with a rubber band to avoid any soil loss. The samples were stored in the refrigerator to maintain the original soil water content until processing in the laboratory at the Soil and Water Science Department, University of Florida.

In the laboratory, soil at both ends of each cylinder was trimmed carefully. To determine the water retention curves between 0 and 33.8 kPa, the soil cores were placed in the base cap of a Tempee cell containing a 0.5 bar porous ceramic plate. The soil sample was covered with the top cap of the Tempee cell. The Tempee cell was placed in a container with appropriate water level to saturate the soil sample. After the samples reached saturation, the Tempee cells were removed from the water container and excess water was allowed to drain from the saturated samples under gravity. The Tempee cells were then weighed and the initial weights were recorded.

After the first point of equilibrium, the pressure line was connected to the top inlet of the Tempee cell. The weights were recorded, each time the Tempee cell reached equilibrium with the corresponding pressure applied, The Tempee cells were subjected to 10 levels of pressure: 0.3, 2.0, 2.9, 4.4, 5.9, 7.8, 9.8, 14.7, 19.6 and 33.8 kPa. After applying the last level of pressure and reaching equilibrium, the Tempee cell was opened and the soil core was carefully removed. Then, the weight of the core was recorded.

Saturated hydraulic conductivity was determined by constant head method where the bottom of the soil core was covered with cheesecloth. To determine saturated hydraulic conductivity, another brass ring of 3-cm in height was attached and sealed with a duct tape on top of the soil core. The surface of the soil sample in the cylinder was covered with a filter paper to avoid any disturbance during water application. The soil sample in the core-assembly was rewetted in a water container. The core-assembly was then transferred to the hydraulic conductivity apparatus where water was applied to the top cylinder and the water level was maintained constant. Once a steady flow was established, the drainage water under the soil sample was collected for a known period of time for each sample. The volume of drained water and time were recorded and the saturated hydraulic conductivity was calculated.

The soil moisture release data were fit with the van Genuchten (1980) model (Eq. 3-7) and the hydraulic conductivity as function of water potential suction (Eq. 3-8) was also calculated with the van Genuchten model (1980). See Appendices (G-1 and G-2)

$$\theta(h) = (\theta_s - \theta_r) (1/[1+(\alpha h)^n]^{(1-1/n)} + \theta_r \qquad (3\text{-}7)$$

$K(h) = K_s [1+(\alpha h)^n]*SQRT [(1-[\alpha h]^{n-1})* (1+(\alpha h)^m)]$ (3-8)

where θ_s = saturated water content; θ_r = residual water content; α = fitted parameter; n = fitted parameter; h = suction; K = hydraulic conductivity; m = (1-1/n)

3.3.3 Soil Content and Recovery Calculations

Soil sample contents of NO_3-N, NH_4-N and K were calculated as kg ha^{-1} using the measured concentration of mg N or K kg^{-1} of soil then the concentration was converted to contents using the calculated mass of soil. The calculated mass of soil using the measured bulk density for each sampling depth was based on maximum wetting width of 38 cm (Simonne et al., 2006a) and the total linear bed meter which in turn depends on the bed spacing from the following:

Soil mass (kg ha^{-1}) for a given depth = (soil volume * bulk density)

Soil mass (kg ha^{-1}) for a given depth = (soil depth*soil width * soil length)* bulk density

Detailed information about soil mass calculation for both crops is given in (Appendices H-1 and H-2). Calculation of percent remaining of applied NO_3-N, NH_4-N and K were based on cumulative amounts of applied NO_3-N, NH_4-N and K (Appendices B-1 to B-4).With regard to Br, calculated percent remaining was based on the total amount of Br that was applied at the first fertilizer injection since Br was only applied once.

Percent remaining = Soil content (kg ha^{-1})/ amount applied (kg ha^{-1}) *100

3.3.4 Crop Measurements and Tissue Analysis

Fresh weight was recorded and biomass accumulation was calculated for different plant parts and growth stages of bell pepper and watermelon crops after drying the samples at 70 C for 72 h to constant weight. Total Kjeldahl Nitrogen (TKN) of different parts of the plant was determined by using $CuSO_4$ (Mylavarapu and Kennelly, 2002) instead of $HgSO_4$ as a catalyst (modified EPA Method 351.2; USEPA, 1993) in which the sample is heated in the presence of sulfuric acid, K_2SO_4 and $HgSO_4$ for two and one half hours. The residue is cooled, diluted to 25 mL and placed on the auto analyzer for ammonia determination.

Total Kjeldahl nitrogen content for watermelon fruits was not determined; values at harvest from the literature for crops fertilized with the recommended 168 kg N ha^{-1} were used to estimate N accumulation. The values used was the average of 25.6 (Segura, 2006) and 24.1 (S. Shkula, personal communication) g N kg^{-1} of dry fruits.

3.3.5 Crop Uptake and Accumulation Calculation

Total Kjeldahl nitrogen (TKN) was measured at different stages during the growing season and was expressed as kg N kg^{-1} of dry tissue. Nitrogen uptake and accumulation by different parts of the plant was calculated by multiplying the total nitrogen content and biomass at each growth stage. Percent uptake of applied N by the crop was calculated by dividing the amount of accumulated N by the crop by the amount of N applied at each growth stage.

3.4 Statistical Analyses

Data (yield and grade distribution, nutrient amount in soil samples at different depths, biomass, and N accumulation in plant samples) were analyzed using analysis of variance and Duncan Multiple Range Test at the 5% level (SAS, 1999). Analyses of variance were done for each depth increment (within the root-zone and below the root-zone) and also for the whole soil profile for both crops. The resulting ANOVA tables were used to determine treatment differences for various sampling dates and depths. Grubbs's test was used to identify outliers using Statgraphics (2007).

CHAPTER 4
WATER AND NUTRIENT MANAGEMENT OF DRIP IRRIGATED BELL PEPPER AND WATERMELON CROPS

The effect of different irrigation rates (66, 100, and 125% of crop ET) was assessed under two N rates (100 and 125 % of IFAS recommended rate) on soil water, Br, NO_3-N, NH_4-N and K concentrations and distributions at different soil depths and times during the growing season of bell pepper and watermelon crops. The data will be presented in three sections. The first section will cover a period of 5 weeks from preplant fertilizer application to one day after the first fertilizer injection (1DAFFI). The second section will cover the period between 1DAFFI and 22DAFFI (flowering). The third section will cover the period between 22DAFFI and 60DAFFI (harvesting). In each section, results of calculated soil water fluxes, Br, NO_3-N, NH_4-N and K soil concentrations, and percent of solute remaining in the soil profile relative to the total amount (soil profile + applied) under both bell pepper and watermelon crops will be presented and discussed.

The soil type at the experimental site was Lakeland fine sand from the surface to 90 cm with a high saturated hydraulic conductivity in each soil layer (Table 4-1). The soil moisture release curve data (Appendix G, Table G-1) of soil cores taken in depth increments were simulated with the van Genuchten model (1980), using Eq. 3-7. The data and results of model simulations are presented in Fig. 4-1. The hydraulic functions for each soil layer were also calculated using the van Genuchten model (Eq. 3-8) and the data are presented in Appendix G, Table G-2. Model input parameters (K_{sat}, θ_s, θ_r, and n) that were used to simulate the soil moisture release curves and to calculate the hydraulic functions are presented in Table 4-1.

The volumetric water content at field capacity (FC) is 0.10 cm^3 cm^{-3} at 0-30 cm depth and slightly decreases to 0.08 cm^3 cm^{-3} at 60-90 cm depth (Fig. 4-1). Available water depth (cm) is reported in Table 4-1 because that is how rainfall, evapotranspiration, or irrigation water is generally reported in the literature (Hillel, 1998). Therefore, the effect of irrigation rates on water content in this chapter will be analyzed and discussed in terms of soil water depth. Available water is 2.70 cm in the shallow root-zone (0-30 cm) for the bell pepper crop and 5.10 cm in the deeper root-zone for the watermelon crop (0-60 cm). For the entire sampled soil profile (0-90 cm), the available water is 7.20 cm (Table 4-1).

The content of NO_3-N, NH_4-N, and K in the soil profile, three weeks after preplant fertilizers application (at transplanting, DAT), are presented in Table 4-2. Most of the nutrients are within the root-zone for both crops. The root-zone for the bell pepper crop is 0-30 cm and for the watermelon crop 0-60 cm. The depth of soil moisture is very close to available water depth, therefore there was insignificant movement of nutrients below the root-zone at this time.

The data presented in Table 4-3 compare the ratios of volumes of water applied to both crops at each week from transplanting to harvest. The initial weekly applied water volume after 2 weeks from transplanting was used to divide the weekly applied water volume for the following weeks, from week 3 to week 5, for each irrigation rate (I1, I2, and I3). Then the applied water volume at week 5 is used to divide the water volume for the following weeks up to week 11. Soil moisture was measured at three soil sampling dates (beginning of week 3, week 6, and week 11). The root-zone water content depth at each sampling date and the available water depths are also presented in Table 4-3. Since the ratios of applied water volumes are equal to or greater than 1, we can assume that the soil moisture content for the following weeks after each soil sampling date (week 3 to week 6, and week 6 to week 11) should also be equal or greater than what is reported in Table 4-3. One observation is that more water was applied to the watermelon crop than the bell pepper crop from transplanting to harvest. On the average, the watermelon crop received 1.3 times more water than the bell pepper crop (Appendix D, Tables D-3, and D-7).

4.1.1 Soil Water Content as Affected by Irrigation Volume One Day after First Fertilizer Injection (1DAFFI)

At this time (1DAFFI) irrigation treatments had not been applied. However, from transplanting to one day after the first fertilizer injection (1DAFFI), for the bell pepper crop, 1730 L/ 100 m (termed IV1) had been applied through the 100% fertilizer rate (N1) and Br tapes. For the 125% fertilizer rate (N2), 2380 L/ 100 m (termed IV2) was applied through fertilizer and Br tapes (Table 4-4 and Appendix D, Table D-4). Therefore more water was applied to N2 plots than N1 plots. For the watermelon crop, 3660 L/ 100 m of water (IV1) were applied through the 100% fertilizer rate (N1) and Br lines. However, 3930 L/ 100 m of water (IV2) were applied through the 125% IFAS recommended rate (N2) and Br lines (Table 4-4 and Appendix D, Table D-6). Therefore there was a small difference in water that was applied to NI and N2 watermelon plots. During Br injection, 319 L/ 100 m (IV1) were applied to N1 plots and 430 L/ 100 m (IV2) were applied to N2 plots for the bell pepper crop and for the watermelon crop, 354 L/ 100 m (IV1) were applied to N1 plots and 373 L/ 100 m were applied to N2 plots (Table 4-4). Therefore, the total water applied was different when considering NO_3-N, NH_4-N, and K movement for the bell pepper and watermelon crops. Similarly the applied water was different for the bell pepper and watermelon crops when considering Br movement and also when considering the movement of NO_3-N, NH_4-N, and K in relation to the movement of Br (Table 4-4).

Average volumetric soil moisture content under bell pepper and watermelon crops (1DAFFI) was above FC (Table 4-5) and greater than the depth of available water (Tables 4-1 and 4-6) at all soil depths regardless of irrigation volume applied. The applied irrigation volumes did not increase the depth of water in the soil between IV1 and IV2 plots (Table 4-6). However, all plots at all soil depths had water content above FC (Table 4-5) implying that water was most likely moving through the soil profile.

The downward movement of water can be demonstrated by calculating water fluxes at the time the soil was sampled using soil moisture data in Table 4-5 and hydraulic functions from the van Genuchten model in Appendix G, Table G-2. The calculated fluxes are presented in Appendix F, Table F-1 for the bell pepper crop. One day after the first fertilizer injection (1DAFFI), water applied at the soil surface of bell pepper plots will move out of the root-zone (0 -30 cm) in 1.2 day and 1.5 day for IV1 and IV2 plots, respectively. Similarly water will leach below the 90 cm depth in less than 4 days, regardless of irrigation volume that was applied.

For IV1 and IV2 plots for the watermelon crop water will leach below the root-zone in less than 2 days and would exit the 90 cm depth in less than 3 days, regardless of irrigation volume applied (Appendix F, Table F-4). Note that for the two irrigation volumes applied the calculated gradient is negative (Appendix F, Tables F-1 and F-4) under both crops indicating that water flow is from top to bottom of the soil profile (0-90 cm). In the root-zone the calculated water fluxes for watermelon plots are twice the water fluxes for the bell pepper plots.

For both crops, the calculated water fluxes in Appendix F, Tables F-1 and F-4 demonstrate that even if irrigation volume caused no significant difference on soil water content in the profile (due to IV1 and IV2 irrigation volumes), the water in the soil was moving downward and will not be available for crop uptake. The rapid downward water movement should be reflected in leaching of Br that was applied in the water at the first fertilizer injection.

Note that when the irrigation treatments were imposed (7DAFFI) more water was applied to all plots than what was applied during the week of the first fertilizer injection (1DAFFI). Therefore, unless ET_C reduced soil water content from week 3 to week 11, we would expect water content and fluxes to be similar to those at the soil sampling dates (1DAFFI, 22DAFFI, and 60DAFFI).

4.1.2 Soil Bromide Content as Affected by Irrigation Volume One Day after First Fertilizer Injection (1DAFFI)

Bromide was used as a tracer for water and nitrate movement. Bromide, water and nitrate were simultaneously applied to the soil through drip irrigation lines. Soil samples were collected from the field 1DAFFI and bromide injection. Since bromide was applied once and initially sampled at 1DAFFI, soil Br content should reflect the pattern of water movement discussed earlier.

At 1DAFFI, soil Br concentration decreased ($P<0.01$) in the bell pepper root-zone due to increase in irrigation volume between IV1 and IV2 (Table 4-7 and Fig. 4-2). Irrigation volume IV2 was equal to 1.3 IV1 (Table 4-4). Therefore, more leaching is expected to occur for bromide, for the plots treated with IV2 applied through the N2 line (125% N IFAS fertilization rate).

Unlike bell pepper plots, soil Br concentration in the watermelon root-zone (0-60cm) was not affected by irrigation volume (Table 4-7). It should be noted that less Br (15 kg ha^{-1}) was applied to the watermelon crop compared to the bell pepper crop (22 kg ha^{-1}); thus differences in Br concentration in the soil profile (Table 4-7). There was no difference in soil Br concentration due irrigation water volumes IV1 and IV2 because of small differences in amounts of water applied. The irrigation volume IV2 was equal to 1.1 IV1 (Table 4-4). Due to a small difference in water applied, leaching was similar for bromide for all watermelon plots as demonstrated by the percent of Br remaining in the profile (Fig. 4-2).

The applied water as volumes IV1 and IV2 used to inject Br during the first fertilizer injection were about 10 times less than water volumes that were applied to the plots of both crops since transplanting. Therefore, IVs for bromide data are 0.1 IVs that will be considered while discussing NO_3-N, NH_4-N and K data at 1DAFFI.

Since Br in the soil moves with the water, this implies that there was less leaching of water and Br due to IV1 compared to IV2 for the bell pepper crop. This is illustrated by the higher recovery in the root-zone (0-30cm) for IV1 plots (Fig.4-2). However, for the watermelon crop there was no difference in the amount of Br recovered between IV1 and IV2 plots since IV1 was essentially equal to IV2 and water fluxes were similar (Appendix F, Table F-4 and Fig. 4-2).

The percent of bromide remaining in the soil profile for soil samples taken one day after bromide injection was 49% on average in all plots for the bell pepper and watermelon crops (Table 4-11, Appendix I, Table I-1, and Fig. 4-2). This implies that NO_3-N applied with bromide would be subject to similar leaching since the crops were too small to take up large amounts of NO_3-N.

The pattern of bromide concentration and recovery corresponds to water fluxes that were calculated at this sampling date for both crops (Appendix F, Tables, F-1 and F-4). Regardless of water volumes applied, soil moisture content was above FC in all plots for both crops, therefore water was moving rapidly downward, causing leaching of water and mobile nutrients below the root-zone.

4.1.3 Soil NO_3–N Content as Affected by Irrigation Volume One Day after First Fertilizer Injection (1DAFFI)

One day after the first fertilizer injection, about 11 kg ha^{-1} of NO_3-N had been stored in the soil from preplant and fertilizer injection for N1 and N2 bell pepper plots in addition to about 14 kg ha^{-1} in the soil as NH_4-N (Appendix B, Tables B-1 and B-2). For the watermelon crop about 16 kg ha^{-1} of NO_3-N was stored in N1 and N2 watermelon plots in addition to about 12 kg ha^{-1} in the soil as NH_4-N (Appendix B, Tables B-3 and B-4). During the first fertilizer injection, the amount of NO_3-N that was applied for both crops was about 3 kg ha^{-1} and the injected NH_4-N was about 1 kg ha^{-1} (Appendix B, Tables B1 to B-4). Therefore, the bulk of the NO_3-N found in the profile is from the applied preplant NO_3-N and also from nitrification of applied NH_4-N, since 50% NH_4-N has been reported to be converted to NO_3-N in sandy soils in Florida in one day (Sato and Morgan ., 2006). The discussion of NO_3-N concentration and movement in the soil is further complicated by the contribution to NO_3-N from NH_4-N due to nitrification. It is not possible to separate the contribution to NO_3-N concentration in the soil from KNO_3 and NH_4NO_3.

There was no effect of irrigation volume (IV) on soil NO_3-N content at any soil depth for bell pepper and watermelon crops (Table 4-8). However, there is more NO_3-N remaining in the soil profile (0-90 cm) for the bell pepper crop compared to the watermelon crop because the amount of water applied to the watermelon plots was about twice the amount that was applied to the bell pepper plots (see IVs under Table 4-8).

The data for NO_3-N seem to contradict water and Br data discussed earlier at this soil sampling date where more water was applied for IV2 plots and reduced the amount of Br remaining in the soil profile compared to IV1 plots for the bell pepper crop. The data could be explained by considering the small amount of NO_3-N applied with the first fertilizer injection (about 3 kg ha^{-1}) compared to the total amount of NO3-N (about 8 kg ha^{-1}) that was found in the soil profile at 1DAFFI. The NO_3-N was part of preplant fertilizers applied in granular form and also the contribution from NH_4^+ due to nitrification. Whereas, there was no Br in the profile and Br was applied in liquid form. Therefore, the data show that regardless of irrigation volume applied, most of the NO_3-N remained in the root-zone for both crops (Table 4-8 and Fig. 4-3).

The amount of NO_3-N remaining in the entire profile for bell pepper plots was about 78 % (Table 4-11, Appendix I, Table I-1, and Fig. 4-3). The amount of NO_3-N remaining in the entire profile for the watermelon crop was about 10% (Table 4-11 and Fig. 4-3) due to more water that was applied to the watermelon crop compared to the bell pepper crop (Table 4-4).

The differences between the percent of NO_3-N remaining in the soil profile under bell pepper and watermelon crops can be explained by comparing the calculated values for effective water flux (Appendix F, Tables F-1 and F-4) for bell pepper and watermelon crops. These values indicate that under bell pepper calculated effective water flux values within the root-zone were 25 and 20 cm d^{-1} for IV1 and IV2, respectively, while below the root-zone the calculated effective flux values were 17 and 16 cm d^{-1}. For watermelon, the calculated effective flux values within the root-zone (0-60 cm) were 84 cm d^{-1} for both IV1 and IV2, while the calculated values for effective flux below the root-zone were 21cm d^{-1}. Also note that the amount of irrigation water that was applied to the watermelon crop was about twice that applied to the bell pepper crop, causing the average water flux for the watermelon plots to be more that 3 times that of the bell pepper crop. This explains the difference in the percent of NO_3-N remaining in the profile between the two crops (Appendix D, Tables D-4 and D-8, Table 4-11 and Fig. 4-3).

In this study Br was used as a tracer for nitrate leaching as such the Br data are in agreement with data reported by Gehl et al. (2005) that indicated that applying N fertilizer and irrigation water according to crop requirements is important in reducing NO_3 leaching from irrigated sandy soils, since NO_3 leaching potential is influenced primarily by water flux in the soil profile. Therefore, management practices that increase downward water flux increases the risk of loss of NO_3-N below the crop root-zone.

Calculated water fluxes imply that increasing irrigation volume increased the vertical wetted depth which depends primarily on the hydraulic conductivity of the soil and the application rate. These data are supported by Li et al. (2003), who observed that both the surface wetted radius and the vertical wetted depth increased with time and water application rate. In general, applying higher irrigation rates increased soil moisture content within the root-zone and the entire soil profile, and also increased water movement and NO_3-N below the root-zone and out of the 90 cm depth. The soil cannot store moisture above FC water content (Tables 4-1 and 4-2) without moving down due to the effect of gravity (Veihmeyer and Hendrickson, 1950). This implies that a solute like bromide will also move out of the root-zone in less than one day for both irrigation volumes used in this study. Since irrigation water was applied twice a day, the downward water movement demonstrated in Appendix F, Tables F-1 and F-4 should even be more immediately after irrigation during the experiment as long as water content in the soil is greater than FC water content in a given soil layer.

In this study, water that was applied to both crops at this stage of crop development (from transplanting to the first fertilizer injection) was intended to sustain crop water requirement. However, the amount of water that was applied was much more than required for crop use since the crops were small and could not effectively take up water and nutrients. Therefore, the amount and frequency of the NO_3-N fertigation scheme employed at this stage of crop development should be considerably revised.

4.1.4 Soil NH_4–N Content as Affected by Irrigation Volume One Day after First Fertilizer Injection (1DAFFI)

By 1DAFFI about 15 kg ha^{-1} of NH_4-N had been stored in the soil from preplant and amount initially in the soil profile for the bell pepper crop and 11 kg ha^{-1} for the watermelon crop. The amount of NH_4-N that was applied through fertilizer lines was about 2 kg ha^{-1} and 0.5 kg ha^{-1} for the bell pepper crop and watermelon crop, respectively (Appendix B, Tables B-1 to B-4).

There was no effect of irrigation volume (IV) on soil NH_4-N content at any soil depth for bell pepper and watermelon crops (Table 4-9). Higher values of NH_4-N were observed in bell pepper root-zone (0-30 cm) compared to below the root-zone (30-90cm). The same trend was also observed under the watermelon crop (Table 4-9). Although water flux was high (Appendix F, Tables F-1 and F-4), the data could be explained by the fact that NH_4^+ undergoes cation exchange which reduces its flux through the soil. Therefore, NH_4^+ leaching potential is less from the root-zone compared to negatively charged ions such as bromide (Ryan et al., 2001).

The amount of NH_4-N remaining in the profile for bell pepper plots was 27% and for watermelon plots 34% (Table 4-11, Appendix I, Table I-1, and Fig. 4-4). The fact that less NH_4^+ remained in the soil profile than Br implies that most of the NH_4^+ was nitrified rather than being leached out of the soil profile.

4.1.5 Soil K Content as Affected by Irrigation Volume One Day after First Fertilizer Injection (1DAFFI)

By 1DAFFI, about 57 kg ha^{-1} and 47 kg ha^{-1} of K had been stored in the soil for the bell pepper and watermelon plots, respectively. The K was from preplant fertilization and K initially in the soil profile. The amount of K that was injected to both crops was less than 3 kg ha^{-1} (Appendix B, Tables B-1 and B-2). Therefore, most of the K concentration in Table 4-10 was not from fertilizer injection.

After the first fertilizer injection, there was no effect of irrigation volume (IV) on soil K concentrations at any soil depth for bell pepper and watermelon crops (Table 4-10). The amount of K remaining in the soil profile was 91% for the bell pepper plots compared to 64% for the watermelon plots (Table 4-11, Appendix I, Table I-1, and Fig. 4-5). The difference in percent of K remaining in the soil profile between bell pepper and watermelon plots is attributed to differences in water fluxes discussed earlier. The data for K^+ also demonstrate the reduced K^+ flux due to cation exchange compared to Br that is not adsorbed by the soil.

Since the crops were small and could not take up much of the nutrients, the higher %K retained in the soil compared to %NH_4-N also implies that nitrification of NH_4^+ played a big role in reducing NH_4-N in the soil profile. Potassium and NH_4^+ are both cations and are almost equally retained in the soil due to cation exchange.

4.1.6 Conclusions

At the beginning of the study about two weeks after transplanting the two crops, the amount of water that was applied to establish the crops was much more than the crops needed. Therefore, most of the water applied leached below the root-zone in less than 2 days and out of the entire profile in less than 4 days. At this stage of crop growth less water should be applied since the crops are too small and are not effectively taking up water. The applied water will merely move the nutrients below the root-zone which is not the intent of fertigation.

The soil Br data obtained one day after injection confirmed the effect of calculated water fluxes can have on solute transport. The amount of Br that remained in the soil profile was 49%. On the same day only 10% of NO_3-N remained in the soil profile in the watermelon plots because much more water had been applied to the watermelon plots. Due to transformation of NH_4^+, much less NH_4-N was retained in the soil profile compared to K^+. In general, too much water was applied to both crops during two weeks after transplanting. The faster the water fluxes due to applied water, the more Br, and NO_3-N were leached below the crop root-zone. Therefore, Br movement traced water and NO_3-N movement.

4.2.1 Soil Water Content as Affected by Irrigation Rates between 1DAFFI and 22DAFFI (flowering)

Irrigation treatments (I1, I2, and I3) were initiated 7 days after the first fertilizer injection during the beginning of week 4 and soil samples were taken 22 days after the first fertilizer injection (22DAFFI) which was the flowering stage for both crops. The soil samples were also taken one day after the first fertilizer injection. The assumption is made that the soil sample data obtained at 22DAFFI are representative of each cycle of fertilizer injection during this period. During bell pepper flowering, the depth of water for I1 plots was lower ($P<0.05$) than I2 and I3 plots (Table 4-12). However, the depth of water in each layer was greater than available water and therefore water was moving from the root-zone (0-30 cm) and below the 90 cm depth (Appendix F, Table F-2). The calculated water fluxes show that water was moving fast out of the root-zone in the order of I3 ≈ I2 > I1 irrigation treatments.

Regardless of irrigation rate, the applied water on the soil surface would move out of the root-zone (>30 cm depth) in less than a day. However, water would take between 2 to 3 days to move out of the 90 cm depth. A major factor for differences in calculated water fluxes is the different hydraulic conductivity among irrigation rates in the root-zone and below the root-zone. In general, water moved slower from 30 to 90 cm soil depth due to lower hydraulic conductivity (Appendix F, Table F-2). The calculated water fluxes show that the applied irrigation rates increased soil moisture content in the root-zone and the entire soil profile which enhanced water movement below the root-zone and out of the 90 cm depth. The soil cannot store moisture above FC water content (Appendix E, Table E2) without water moving down (Veihmeyer and Hendrickson, 1950).

At the flowering stage for the watermelon crop (22DAFFI) soil moisture contents were close to FC at all soil depths (Appendix E, Table E-3). Soil water content was not affected by irrigation rates at any soil depth at this time (Table 4-12). At this sampling date there was slower downward water movement compared to 1DAFFI (Appendix F, Tables F-4 and F-5) because the hydraulic conductivity was smaller (Appendix G, Table G-2). However, even if only the flux data for the 22DAFFI are considered for the discussion, water applied would move out of the root-zone in less than 20 days, regardless of irrigation application rate (Appendix F, Table F-5). Therefore, leaching of water and nutrients below the root-zone is still happening. It appears, however, that most of the supplemental irrigation water applied close to 22DAFFI was taken up by the watermelon crop. Note that from week 1 to week 5 of the experiments much less irrigation water was applied to the bell pepper crop compared to the watermelon crop (Appendix D, Tables D-4 and D-8). Therefore, for both crops application of I1 rate should be close to optimum.

4.2.2 Soil Br Content as Affected by Irrigation Rates between 1DAFFI and Flowering (22DAFFI)

By the flowering stage of bell pepper and watermelon crops (22DAFFI) most of the soil bromide had been leached below the soil sampling zone (0-90 cm). The bromide concentration in the soil was so low that any statistical analysis due to the effect of irrigation rates is not appropriate (Table 4-13). The recovery of Br was less than 1% for both crops. Any bromide detected in the soil profile is possibly due to hydrodynamic dispersive flux that was not considered while calculating water fluxes presented in Appendix F. Therefore, by week 5 the three irrigation rates leached Br essentially equally out of the soil profile (0-90 cm) from both crops.

The Br data obtained in this study agree with the study of Paramasivam et al. (1999) who demonstrated a rapid leaching of Br 17 days after application. A similar trend of Br reduction over time in the top soil was observed in an earlier study. Recovery of Br applied to a sandy soil under citrus production was 25% in the top 15 cm depth 7 d after application, and then decreased to 2.5% in the same layer by 28 d after application (Paramasivam et al., 2002). Also, increase of Br leaching with increasing water applied was observed in a soil column study with clay loam from South Dakota (Clay et al., 2004). Cumulative percentage of Br leached through column increased from 18% with 1000 ml of water collected to 58% with 3000 ml of leachate. In a field study conducted by Ottman et al. (2000) the total recovery of applied Br in the soil was 19% of applied Br. Soil bromide movement and distribution as affected by irrigation volume is in agreement with the data of Patra and Rego (1997) who used bromide as a tracer for the potential leaching of NO_3-N beyond the root-zone during wet seasons. One week after a rainfall of 64 mm, 90% of applied Br was recovered to a depth of 60 cm, 40% of Br was in the top layer (0-10 cm). With continuous heavy rainfall, almost all Br had leached below the 50 cm depth. The Br recovery data in this study indicate that the leaching potential for mobile solutes such as NO_3-N was high when soil moisture content was above FC.

The implication of Br recovery in this study is that 21 days after the first fertilizer injection, nitrate that was in the soil at 1DAFFI and was not taken up by the crops would have also been leached out of the soil profile (0-90 cm) regardless of irrigation rate.

4.2.3 Soil NO_3-N Content as Affected by N and Irrigation Rates between 1DAFFI and Flowering (22DAFFI)

At this soil sampling date (22 DAFFI) irrigation treatments had been imposed for 14 days. The water content in the root-zone for the bell pepper crop was much higher than FC (Appendix E, Table E-2) and high water fluxes were calculated for all bell pepper plots (Appendix F, Tables F-2). The water content at all soil depths for the watermelon crop was equal or below FC (Appendix E, Table E-3) and the calculated water fluxes in all watermelon plots was slow (Appendix F, Table F-5). This observation is remarkable since almost twice as much water had been applied to the watermelon crop compared to the bell pepper crop (Appendix D, Tables D-4 and D-8). One explanation is that the watermelon crop took up more water than the bell pepper crop, from 1DAFFI to flowering (22DAFFI).

There was no interaction between irrigation and N rates on soil NO_3-N contents during bell pepper flowering (Table 4-14). Irrigation rates had no effect on soil NO_3-N concentration while an increase in N rate increased NO_3-N within the root-zone (Table 4-14). From the first fertilizer injection to soil sampling at 22DAFFI a total of 44 kg ha^{-1} had been injected into to the bell pepper crop plots. One day before soil sampling, 20 kg ha^{-1} of NO_3-N were injected to the bell pepper crop. In addition 31 kg ha^{-1} of NH_4-N were injected to the bell pepper plots during the same period (Appendix B, Table B-2). However, data in Table 4-14 show that a maximum of 30 kg ha^{-1} remained in the entire soil profile. This implies that most of the NO_3-N must have leached below the soil profile by 22DAFFI, similar to Br data discussed earlier.

Examining data in Table 4-14 for the bell pepper crop revealed that there was a large amount of NO_3-N below the root-zone (30-90 cm) compared to within the root-zone (0-30 cm) regardless of irrigation treatment indicating nitrate movement below the bell pepper crop root-zone and the potential for leaching. However, there was no difference in the percent of NO_3-N remaining in the entire soil profile due to irrigation treatment implying that all irrigation treatments leached NO_3-N essentially equally (Fig. 4-6). The % of NO_3-N remaining in the soil profile (0-90cm) ranged between 46 and 52 % for N1 plots (Appendix I, Table I-2). The same trend was observed for the percent of NO_3-N remaining in the soil profile for the N2 plots in which higher values of soil NO_3-N were found in the 30-90cm soil depth. The percent of NO_3-N remaining in the soil profile (0-90cm) for N2 plots ranged between 48% and 79 % across irrigation treatment and was not different between irrigation treatments (Fig. 4-6B).

At this stage of crop development part of the applied NO_3-N was taken up by the crop other than being leached out of the soil profile. Since essentially equal amounts of N were taken up by the crop in N1 and N2 plots (See chapter 5, Figs. 5-3 and 5-4), the difference in the percentage of NO_3-N remaining in the profile between N1 and N2 plots is due to differences in N rates, considering that more NH_4-N was applied to N2 plots. Note that about 20% of N was taken up by the bell pepper crop at 35 DAFFI (Fig. 5-3). Assuming that 10% was from NO_3-N, leaching accounted for about 40%.

Similar to the bell pepper crop, there was no interaction between irrigation and N rates on soil NO_3-N content at any soil depth during the flowering stage of the watermelon crop (Table 4-14). Soil NO_3-N concentration was not affected by either irrigation or N rates (Table 4-14) except for the % remaining in the entire soil profile where increased irrigation rates ($P<0.05$) reduced % NO_3-N remaining in the soil (Fig. 4-7). Note that by 22DAFFI, 23 kg ha^{-1} of NO_3-N had been injected to the watermelon crop plus 14 kg ha^{-1} as NH_4-N. Out of that total amount of NO_3-N applied 10 kg ha^{-1} of NO_3-N were injected to the watermelon plots a day before soil sampling. Since less than 10 kg

ha^{-1} were found in the soil profile (Table 4-14), this implies that the previously applied NO_3-N must have been leached out of the soil profile by 22DAFFI.

Unlike bell pepper crop, under the watermelon crop much higher percentage of soil NO_3-N remains within the crop root-zone (0-60 cm) under both N rates compared to below the root-zone (60-90 cm). The highest values of % NO_3-N remaining was observed under the lowest irrigation rate (I1) for both N rates (Fig. 4-7). The % NO_3-N remaining in the soil profile decreased with increasing irrigation rates under both N rates. The % of NO_3-N remaining in the entire profile was much less for the watermelon crop compared to the bell pepper crop because water applied to the watermelon crop was 1.3 times that applied to the bell pepper crop (Appendix D, Tables D-3 and D-5). The calculated effective fluxes for the watermelon crop are still large enough to leach NO_3-N out of the soil profile from 1DAFFI to 22DAFFI (Appendix F, Table F-5). Since N taken up by both crops is about 20% (Figs. 5-3 and 5-4), this implies that there was much more leaching of NO_3-N in the watermelon crop compared to the bell pepper crop (Figs. 4-6 and 4-7 and Appendix G, Table G-4).

The data of NO_3-N movement and distribution as affected by N rate showed that there was an increase in nitrate concentration with a higher N rate. The data agree with the study of Li et al. (2003) who found that there was an increase in nitrate concentration with a higher input concentration. Similar to this study, Ershain and Karaman (2001) found that the amount of NO_3 leached below the root- zone was affected by the amounts of N fertilizer and irrigation water. This observation was also supported by Paramasivam et al. (2000) who found that soluble nutrients are subject to potential leaching through sandy soils. Data from this study are also in agreement with the data of Cote et al. (2003)

who showed that water and nutrients move quickly vertically downwards from the emitter in highly permeable coarse textured soils, therefore they become susceptible to leaching losses.

4.2.4 Soil NH_4^+ Content as Affected by N and Irrigation Rates between 1DAFFI and Flowering (22DAFFI)

By the time the soil samples were taken, 22DAFFI, 32 kg ha^{-1} had been injected to the bell pepper plots, and 13 kg ha^{-1} of that were injected a day before soil sampling. For the watermelon plots, 14 kg ha^{-1} had been injected since 1DAFFI, and 7 kg ha^{-1} were injected a day before soil sampling (Appendix B, Tables B-2 and B-4). Since the total amount of NH_4-N in the entire soil profile (0-90 cm) for both crops is very close to what was applied just a day before soil sampling (Table 4-15), this implies that the previously applied NH_4-N was either nitrified or leached below the root-zone, regardless of irrigation rate.

During bell pepper flowering (22 DAFFI), there was no interaction between irrigation and N rates on soil NH_4-N content under both bell pepper and watermelon crops (Tables 4-15). For the bell pepper crop increasing N rates ($P<0.01$) increased NH_4-N contents within the root-zone (0-30cm) while increasing irrigation rates had no effect on soil NH_4-N (Table 4-15). For the watermelon crop, NH_4-N content was not affected by either irrigation or N rates (Table 4-15).

Comparing NH_4-N percentage remaining in the soil profile under the bell pepper crop as affected by N rates indicated that between 9 and 20 % with the majority of NH_4-N remaining in the root-zone was found under N1 rate across irrigation rates (Appendix I, Table I-2). However, more NH_4-N remained in the root-zone for N2 plots (about 60%) across irrigation rates (Fig. 4-8, Appendix I, Table I-2). The most probable explanation is that increasing NH_4-N application to N2 plots enhances NH_4^+ competition for exchange sites with applied K^+. Although the water flux was high for all irrigation treatments (Appendix F, Table F-2), the difference between N1 and N2 plots for the percentage of NH_4-N retained is due to several processes including plant uptake, leaching, transformation, and amount of NH_4-N applied (Fig. 4-8). Because of the many processes that attenuate NH_4-N in the soil profile, identifying the predominant process is difficult for the current study.

The NH_4-N percentage remaining in the soil profile under the watermelon crop was not affected by irrigation or N rates. The data indicated that between 26 and 46 % of NH_4-N (Fig. 4-9, Appendix I, Table I-2) remained in the soil profile with the majority of NH_4-N remaining in the root-zone (0-60cm). As was observed for NO_3-N leaching potential, more water was applied to the watermelon crop than the bell pepper crop (from 1DAFFI to 22DAFFI), thus more leaching of NH_4-N from watermelon plots than bell pepper plots is expected. As such all irrigation rates leached NH_4-N essentially equally. It is worth mentioning again that interpretation of NH_4-N data is complicated by the many processes that tend to attenuate it in the soil profile (cation exchange, plant uptake, nitrification, and leaching).

4.2.5 Soil K Content as Affected by Irrigation and N Rates between 1DAFFI and Flowering (22DAFFI)

During bell pepper and watermelon flowering (22 DAFFI), there was no interaction between irrigation and N rates on soil K content in plots of both crops (Tables 4-16). Increasing irrigation or N rates had no effect on K contents within the root-zones and below the root-zones for both bell pepper and watermelon crops. However, most of the K was within the root-zone of both crops because of reduced velocity of K due to sorption on soil particles. On the average about 85% of K remained in the bell pepper plots compared to about 65% remaining in the watermelon plots (Figs. 4-10 and 4-11; Appendix I, Table I-2). This can be explained by the higher amount of irrigation water that was applied to the watermelon plots compared to the bell pepper plots since transplanting (Appendix D).

4.2.6 Conclusions

During this period, Br data indicated that leaching of water and mobile nutrients below the root-zone for both crops was occurring. About 1% of Br was left in the soil profile mainly because Br was applied once. However, even for NO_3-N that was continuously applied, 50% of NO_3-N remained in the soil profile with a larger proportion below the root-zone for the bell pepper crop. Increasing N rate increased the percentage of NO_3-N remaining in the profile to about 60%. All three irrigation treatments leached NO_3-N almost equally in the bell pepper plots. For the watermelon plots the NO_3-N was mainly in the root-zone essentially due to the amount that was applied a day before soil sampling. The percentage of NO_3-N remaining in the soil profile significantly increased with decrease in irrigation rate. However, due to large amounts of water applied to the watermelon crop compared to the bell pepper crop less than 20% of NO_3-N remained in the soil profile.

Due to several processes that attenuate NH_4^+ (transformation, crop uptake, sorption, and leaching), the interpretation of NH_4^+ data is complicated. For both crops the percent of NH_4^+ remaining in the soil was larger in the root-zone than below the root-zone due to sorption. Increasing N rate increased percentage of NH_4^+ in the root-zone but not for the watermelon crop due to differences in leaching potential. Increasing irrigation rates had no significant effect on percentage of NH_4^+ remaining in the soil profile for a given N rate for both crops. For both crops lower percentage of NH_4^+ remained in the soil profile than NO_3-N due to nitrification of NH_4^+. Much less percent of NH_4 remained in the soil profile for the watermelon crop compared to the bell pepper crop due to more leaching in the watermelon plots caused by more amount of irrigation water applied.

Most of the K remained in the root-zone for both crops possibly due to sorption of K in the soil. Nitrogen and irrigation rates did not affect the percentage of % K remaining in the soil profile. Higher percentage of K remained in the soil profile than NO_3-N and NH_4-N. However, due to more water that was applied to the watermelon plots less percentage of K was found in the watermelon plots compared to the bell pepper plots.

During this stage of crop development, less water should be applied to both crops, because all irrigation treatment leached mobile solutes such as Br and NO_3-N out of the root-zone. Since K is more retained in the soil than NH_4-N or NO_3-N, less K should be applied to both crops.

4.3.1 Soil Water Content as Affected by Irrigation Rates between Flowering (22DAFFI) and Harvesting (60DAFFI)

At bell pepper and watermelon harvest (60 DAFFI), depth of soil moisture was not affected by irrigation rates within the root-zone and below the root-zone (Table 4-17). Regardless of irrigation rate the water content was close to or less than FC at all soil depths (Appendix E, Tables E-2 and E-3). This is also reflected in the depth of water (Table 4-18) that is close to available water (Table 4-1). At this stage of crop growth it appears that most of the water applied was taken up by the crops maintaining water content close to FC. Data in Appendix F, Tables F-3 and F-6 clearly show that there was very slow water movement from the root-zone and below the root-zone. Note that regardless of irrigation rate the effective hydraulic conductivity values are very small compared to the values of the other two sampling dates (Appendix G, Table G-2). In terms of effective flux, the order was I3 ≈ I2 ≈ I1 = 1 cm d^{-1} in the root-zone. It therefore appears that I1 irrigation treatment would supply enough water needed to sustain the crop water requirements while minimizing water leaching below the root-zone and the rest of the soil profile.

4.3.2 Soil Br Content as Affected by Irrigation Rates between Flowering (22DAFFI) and Harvesting (60DAFFI)

By harvest (60DAFFI) most of the soil Br had been leached below the soil sampling zone (0-90 cm) for both bell pepper and watermelon crops. The Br recovery in the soil was less than 1% for both crops and thus, similar to the concentration that was observed at 22DAFFI (Tables 4-13 and 4-18). The recovery of Br was less than 1% for both crops. The Br data agree with the calculated water fluxes that indicate there was slow downward movement of water and mobile nutrients from 22DAFFI to 60DAFFI (harvest).

4.3.3 Soil NO_3-N Content as Affected by N and Irrigation Rates between Flowering (22DAFFI) and Harvesting (60DAFFI)

At harvest both bell pepper and watermelon plots had soil moisture content (Appendix E, Tables E-2 and E-3) close to or below FC in the soil profile (0-90 cm). The calculated water fluxes in plots for both crops regardless of irrigation rate were about 1 cm d^{-1} in the root-zone (Appendix F, Tables F-3 and F-6). From flowering to harvest there are 38 days. At an average flux of 1 cm d^{-1}, NO_3-N and water applied at 22DAFFI would move out of the bell pepper crop root-zone (0- 30 cm) and would move into the watermelon root-zone to a depth of about 38 cm below the soil surface.

There was no interaction between irrigation and N rates on soil NO_3-N content for both crops at harvest (Tables 4-19). Irrigation rates had no effect on soil NO_3-N content while increasing N rates increased NO_3-N within the root-zone (0-30 cm) for the bell pepper crop but not for the watermelon crop (Tables 4-19). Note that 20 kg ha^{-1} and 7 kg ha^{-1} were injected in the bell pepper plots and watermelon plots, respectively, 4 days before soil sampling at harvest. Thus, most of the NO_3-N is in the root-zone is from the last injection (Table 4-19 and Appendix I, Tables I-2 and I-3) for both crops. For the bell pepper crop the soil NO_3-N concentration and the percentage of NO_3-N remaining were not affected by irrigation rates. However, a higher percentage of NO_3-N in the bell pepper root-zone at harvest (15% to 26%) was observed under the 125% of IFAS (N2) recommended rate (Fig. 4-12 and Appendix I, Tables I-2 and I-3). Below the bell pepper root-zone, NO_3-N remaining ranged between 3% and 9%. Since leaching was slow it appears that most of the NO_3-N applied from flowering to harvest was taken up by the bell pepper crop.

For the watermelon crop the NO_3-N concentration in the soil profile was very low and the effect of irrigation rates and N rates could not be determined at harvest (Table 4-19). Note that 4 days before harvest much less NO_3-N was applied to the watermelon crop compared to the bell pepper crop (Appendix B, Tables B-1 to B-4). The percentage of NO_3-N remaining in the watermelon crop root-zone was about 2% regardless of N rate (Fig. 4-13 and Appendix I, Tables I-2 and I-3). Most of the applied NO_3-N must have been taken up by the crop since leaching was negligible.

4.3.4 Soil NH_4-N Content as Affected by N and Irrigation Rates between Flowering (22DAFFI) and Harvesting (60DAFFI)

Four days before soil sampling more NH_4-N was applied to the bell pepper plots compared to the watermelon plots. The amount applied to the bell pepper plots was (N1 = 17 kg ha^{-1} and N2 = 20 kg ha^{-1}) and for the watermelon plots (N1= 4 kg ha^{-1} and N2 = 5 kg ha^{-1}). Essentially twice as much NH_4-N was applied to the bell pepper plots compared to the watermelon plots (Appendix B, Tables B-1 to B-4). The amount of NH_4-N found in the root-zone reflects the last application. Since there was little water movement and NH_4^+ undergoes cation exchange, most of the NH_4-N is found in the root-zone for both crops (Table 4-20, Appendix G, Tables G-5 and G-6).

There was no interaction between irrigation and N rates on soil NH_4-N content under both crops (Table 4-20). Increasing irrigation rates decreased ($P<0.05$) NH_4-N contents within the root-zone (0-30cm) for the bell pepper plots. This might be due to cation exchange that slows down NH_4^+ movement and tends to concentrate it in the root-zone at the lowest irrigation rate (I1). Increasing N rates increased ($P<0.01$) NH_4-N content in the root-zone and below the root-zone ($P<0.001$). For the watermelon plots increasing irrigation rates decreased ($P<0.01$) NH_4-N content within the root-zone. However, increasing N rates had no effect on soil NH_4-N, possibly due to the lower application rate of NH_4-N to the watermelon crop compared to the bell pepper crop.

For the bell pepper crop N2 rate increase percentage of NH_4-N remaining in the soil. The percentage of NH_4-N remaining in the soil profile ranged between 11 and 55% in the root-zone and was due to N2 fertilizer application rate. For the watermelon plots very low concentrations were measured in the soil and the percentage of NH_4-N remaining in the root-zone was less than 4% and below the root-zone close to zero regardless of N and irrigation rates (Appendix I, Table I-2 and I-3, and Figure 4-15). Due to the complex processes attenuating NH_4-N in the soil profile (crop uptake, leaching, and nitrification) the dominant process reducing NH_4-N in the soil is difficult to isolate in this study.

4.3.5 Soil K Content as Affected by Irrigation and N Rates between Flowering (22DAFFI) and Harvesting (60DAFFI)

There was no interaction between irrigation and N rates on soil K content for both bell pepper and watermelon crops (Table 4-21). Increasing irrigation rates decreased ($P<0.05$) K contents within the root-zone (0-30cm) and below the root-zone (30-90cm) for the bell pepper crop (Table 4-21, Appendix I, Tables I-2 and I-3). Increasing irrigation rates decreased ($P<0.05$) soil K content within watermelon root-zone. Increasing N rates seems to have increased soil K contents within the root-zone ($P<0.01$), but it is doubtful since the same amount of K was applied to N1 and N2 plots. The K data show a delayed effect of irrigation rates due to reduced flux of K caused by sorption on soil particles. As such the effect of irrigation rates is observed at harvest for both K and NH_4-N but not for NO_3-N.

Since K in the soil profile is attenuated by two processes (leaching and crop uptake) and there was slow water movement, the K not found in the soil profile must have been taken up by the crops. Note that a high percentage of K remaining in the soil profile is also observed for I1N2 treatment for the bell pepper plots as was observed for NH4-N (Figs.4-14 and 4-16). There must have been an error in applying these fertilizers. If we omit data for I1N2 plots, soil K remaining in the bell pepper soil profile at harvest ranged between 24 to 71% depending on irrigation rate. For the bell pepper crop, percentage of K remaining in the soil profile ranged between 17 and 28% (Appendix I, Table I-2 and I-3). K data was most demonstrative of the effect of irrigation treatments.

4.3.6 Conclusions

From flowering to harvest, the irrigation treatments essentially met crop water use. However, for mobile nutrients water still moved the nutrients such as NO_3-N below the root-zone at slow flux. For cations such as NH_4^+ and K^+ the irrigation treatments concentrated the solutes in the root-zone. Increasing N rates increased NH_4-N in the root-zone. At harvest high amounts of K were in the root-zone for both crops compared to NO_3-N and NH_4-N. Using the currently recommended crop factors (CF) to calculate irrigation rates, 66% ET_C irrigation rate is adequate to supply water for crop requirement However, if 66% ET is adequate to supply water requirement for the crops, then crop factors should be reduced

4.4 General Conclusions

At the beginning of the study about two weeks after transplanting of the two crops, the amount of water that was applied to support the crops was much more than the crop requirements. Therefore, most of the water applied leached below the root-zone in less than 2 days and out of the entire profile in less than 4 days. The calculated water fluxes were very high and caused about 77% of the applied Br to leach out of the root-zone (0-30 cm) in one day for the bell pepper crop. For the watermelon crop 69% of the applied Br had leached out of the root-zone (0-60 cm). For NO_3-N about 40% leached out of the root-zone in two weeks for the bell pepper crop and 90% NO_3-N had leached out of the root-zone for the watermelon crop, because twice as much water was applied to the watermelon crop compared to the bell pepper crop. Note that part of the NO_3-N that remained in the root-zone is due to nitrification of NH_4-N. About 70% to 85% NH_4-N was removed from the root-zone of both crops partly due to leaching and nitrification. For K about 50% had been leached out of the root-zone for both crops. Since fertigation is intended to keep nutrients in the root-zone, less water and nutrients should be applied to both crops at this stage of crop development when the crops cannot take up much water and nutrients. These data demonstrate that the nature of the nutrient (anion or cation), the total amount of water that has been applied to the crop since transplanting, the amount and frequency of supplemental irrigation, and transformation processes affect the leaching potential and the amount of the nutrient remaining in the root-zone.

From the time irrigation treatments were initiated (3 weeks after transplanting) to the flowering stage (22DAFFI), increasing irrigation rates increased soil water content and applied water was moving out of bell pepper root-zone in less than one day. It appears that I1 would suffice to meet water crop needs. However, for the watermelon crop a slow downward water movement was calculated because soil water content was less or close to FC, most likely due to higher water use by the watermelon crop.

During flowering 50% of soil NO_3-N remained in the soil profile and about 20% of N was theen up by the bell pepper crop. Thus, about 30% of NO_3-N was leached out of the soil profile. A slight increase in NO_3-N remaining in the soil profile was attributed to an increase in N rate. However, for the watermelon crop about 20% of NO_3-N remained in the soil profile and about 20% of applied N was taken up by the watermelon crop. The rest of NO_3-N not accounted for was attributed to leaching. Nitrogen rates had no effect on NO_3-N remaining in the soil profile. At this stage of crop growth it appears that irrigation rates equally caused leaching of NO_3-N below the crop root-zone. Therefore, I1 (66% of crop ET) would be adequate to meet water crop requirements.

Due to several processes that attenuate NH_4^+ (transformation, crop uptake, sorption, and leaching), the interpretation of NH_4^+ data is complicated. For both crops the percent of NH_4^+ remaining in the soil was larger in the root-zone than below the root-zone due to sorption on soil particles. Increasing N rate increased % NH_4^+ in the bell pepper crop root-zone but not for the watermelon crop due to much more NH_4-N that was applied to the bell pepper crop. Increasing irrigation rates had no effect on % NH_4^+ remaining in the soil profile for a given N rate for both crops. For both crops less % NH_4^+ remained in the soil profile than NO_3-N due to nitrification of NH_4^+. Much less % NH_4 remained in the soil profile for the watermelon crop compared to the bell pepper crop due to more leaching in the watermelon plots. Most of K remained in the root-zone (about 50%) for both crops due to sorption of K in soils. Irrigation and N rates did not affect % K remaining in the soil profile. A high percentage of K (about 70%) remained in the soil profile than NO_3-N, and NH_4-N. During this stage of crop development, less water should be applied to both crops, because all irrigation treatment leached mobile nutrients such as NO_3-N and Br out of the root-zone. Since K is more retained in the soil than NH_4-N or NO_3-N, less K should be applied to both crops.

From flowering to harvest, the irrigation treatments essentially met crop water use. However, for mobile nutrients water still moved the nutrients such as NO_3-N below the root-zone. The % of NO_3-N remaining in the bell pepper root-zone at harvest (15% to 26%) was observed under the 125% of IFAS (N2) recommended rate. Below bell pepper root-zone, NO_3-N remaining ranged between 3% and 9%. Since leaching was negligible it appears that most of NO_3-N was taken up by the bell pepper crop from flowering to harvest. For the watermelon crop the amount of NO_3-N concentrations in the soil profile were very low. The % of NO_3-N remaining in the watermelon crop root-zone was about 3% regardless of N rate. Most of the applied NO_3-N must have been taken up by the crop since leaching was negligible. Less NO_3-N should be applied to the bell pepper crop between flowering and harvest.

For cations such as NH_4^+ and K^+ the lowest irrigation treatment tended to concentrate the solutes in the root-zone. There is a delayed effect of irrigation rates on solutes such as K^+ and NH_4^+ due to cation exchange that reduce their flux in the soil. The % NH_4-N remaining in the soil profile for the bell pepper crop was between 11% and 26% mainly in the root-zone and due to N2. For the watermelon plots very low concentrations were measured in the soil and the % NH_4-N remaining in the root-zone was less than 4% and below the root-zone close to zero regardless of N and irrigation rates. Similar to NO_3-N, less NH_4-N should be applied to the bell pepper crop between flowering and harvest. At harvest high amounts of K were in the root-zone and below the root-zone for both crops compared to NO_3-N and NH_4-N. Soil K remaining in the bell pepper root-zone at harvest was about 50% and for the watermelon crop about 20%. Similar to NO_3-N and NH_4-N, less K should be applied to the bell pepper crop between flowering and harvest. At these two stages of crop development it appears that I1 is adequate to supply crop water requirement as long as crop yield is not significantly reduced.

These data strongly suggest that the irrigation at all stages of crop growth should be revised, since all three irrigation rates leached mobile nutrients such as NO_3-N almost equally out of the root-zone. However, for K the data have demonstrated that the lowest irrigation rate retained highest K content in the root-zone at harvest. Therefore, I1 would be most appropriate. The amount of irrigation water and the frequency of irrigation should be revised for these two crops. The current application rates of NO_3-N, NH_4-N and K to the bell pepper crop should be reduced when applied to a sandy soil like Lakeland fine sand.

Table 4-1. Selected properties of Lakeland fine sandy soil at North Florida Research and Education Center-Suwannee Valley, FL

Soil depth	$^{Z}K_{sat}$	θ_s	θ_r	α	n	Bulk density (ρ_b)	Water content (θ_v) at 0.1 bar (FC)	Water content (θ_v) at 15 bar (PWP)	Available water depth
cm	cmh^{-1}					gcm^{-3}	…….. cm^3cm^{-3}……….		cm
0-15	165	0.42	0	0.034	2.148	1.46	0.10	0.01	1.35
15-30	110	0.37	0	0.028	2.117	1.55	0.10	0.01	1.35
30-60	210	0.41	0	0.031	2.234	1.42	0.09	0.01	2.40
60-90	225	0.42	0	0.034	2.361	1.48	0.08	0.01	2.10
0-30	Total depth of water in shallow root-zone (cm)								2.70
30-90	Total depth of water (cm)								4.50
0-60	Total depth of water in deep root-zone (cm)								5.10
60-90	Total depth of water (cm)								2.10
0-90	Total profile depth of water (cm)								7.20

$^{Z}K_{sat}$ = Saturated hydraulic conductivity; θ_s = saturated water content; θ_r = residual water content; α and n coefficients; EC= Electrical Conductivity; FC = Field capacity; PWP = Permanent wilting point.

Table 4-2. Soil content of NO_3-N, NH_4-N and K in different depths of soil beds cropped with bell pepper and watermelon crops three weeks after preplant fertilizer application

Crop	Soil Depth (cm)	NH_4-N	NO_3-N	K	Depth of soil moisture
		……………	kg ha^{-1}	……………	cm
Bell pepper	0-30	8.50	3.95	32.06	2.50
	30-90	3.13	3.99	25.39	5.31
	0-90	11.63	7.94	57.45	7.81
Watermelon	0-60	9.86	12.36	41.87	5.17
	60-90	1.21	2.76	6.01	2.20
	0-90	11.07	15.12	47.88	7.37

Table 4-3. Ratios of irrigation volumes of water applied to crops, using week 2 as reference volumes for each irrigation rate from weeks 2 to 5, (5A) and then using weeks 5 (5B) as reference volume from week 5 to week 11.

Crop	Week	Soil Sampling date	N1-plots stored water ratios			N2-plots stored water ratios			Root-zone water content depth (cm)			Root-zone available water depth (cm)
			I1	I2	I3	I1	I2	I3	I1	I2	I3	I1, I2, and I3
Bell pepper	2	1DAFFI	1	1	1	1	1	1	4.73	4.73	4.73	2.70
	3		1	1	1	1	1	1				
	4		2	3	4	2	2	3				
	5A	22DAFFI	2	3	4	2	2	3	4.87	5.34	5.23	2.70
	5B	22DAFFI	1	1	1	1	1	1	4.87	5.34	5.23	2.70
	6		2	2	2	2	2	2				
	7		3	3	3	3	3	3				
	8		3	3	3	3	3	3				
	9		1	3	3	1	1	3				
	10		2	2	2	2	2	2				
	11	60 DAFFI	1	2	2	1	1	2	2.80	2.90	2.80	2.70
Watermelon	2	1DAFFI	1	1	1	1	1	1	10.5	10.5	10.5	5.10
	3		1	1	1	1	1	1				
	4		2	2	3	2	2	3				
	5A	22DAFFI	2	2	5	2	2	3	4.67	4.78	5.41	5.10
	5B	22DAFFI	1	1	1	1	1	1	4.67	4.78	5.41	5.10
	6		1	1	1	1	1	1				
	7		2	2	1	2	2	2				
	8		2	2	1	2	2	2				
	9		2	2	1	2	2	2				
	10		1	1	1	1	1	1				
	11	60DAFFI	1	1	1	1	1	1	4.70	4.60	6.20	5.10

Table 4-4. Applied volumes of water (IV1 and IV2) to bell pepper and watermelon crops at one day after first fertilizer injection (1DAFFI).

Irrigation volume[Z] (L/100m)	Bell pepper Br	Bell pepper NO_3-N, NH_4-N, K	Watermelon Br	Watermelon NO_3-N, NH_4-N, K
IV1	319	1730	354	3660
IV2	430	2380	373	3930
		Flux (cm/d)		
0-30 cm (IV1, IV2)	(25, 20)	(25, 20)		
60-90 cm (IV1, IV2)	(17, 16)	(17, 16)		
0-60 cm (IV1, IV2)			(84, 84)	(84, 84)
60-90 cm (IV1, IV2)			(21, 21)	(21, 21)

[Z]IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
IV2 = 1.4 IV1 for bell pepper and IV2 = 1.1 IV2 for watermelon, for NO3-N, NH4-N, K
IV2 = 1.3 IV1 for bell pepper and IV2 = 1.1 IV2 for watermelon, for Br
IV-watermelon= 2*IV-bell pepper for NO3-N, NH4-N, and K
IV-watermelon ≈ IV-bell pepper for Br

Table 4-5. Average volumetric water content (θ_v) as a function of irrigation volume (IV[Z]) at different soil depths one day after first fertilizer injection under drip irrigated bell pepper and watermelon crops. No irrigation treatments were applied.

Crop	Irrigation volume[Z]	Soil depth (cm) 0-15	15-30	30-60	60-90
		……………………cm^3cm^{-3}……………………			
	IV1 (N1-plots)	0.16	0.16	0.13	0.11
Bell Pepper[¶]	IV2 (N2-plots)	0.15	0.16	0.13	0.12
	IV1 (N1-plots)	0.20	0.21	0.15	0.13
Watermelon[¶]	IV2 (N2-plots)	0.20	0.21	0.15	0.13

[Z]IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
IV2 = 1.4 IV1 for bell pepper; IV2 = 1.1IV1 for watermelon
[IV-watermelon]/[IV-bell pepper] ≈ 2.

Table.4-6. Effect of irrigation volume on soil water depth (cm) one day after first fertilizer injection (1DAFFI) at different soil depths under drip irrigated bell pepper and watermelon crops.

Crop	Soil Depth (cm)	Irrigation volume^{Z} IV1^{Y} (N1-plots)	IV2 (N2-plots)	Significance
		…………cm…………		
Bell Pepper^{X}	0-30	4.73	4.73	NS
	30-90	7.16	7.22	NS
	0-90	11.89	11.95	NS
Watermelon	0-60	10.50	10.42	NS
	60-90	3.88	3.83	NS
	0-90	14.38	14.25	NS

^{Z}IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
^{Y}IV2 = 1.4 IV1 for bell pepper; IV2 = 1.1IV1 for watermelon
^{X} [IV-watermelon]/[IV-bell pepper] ≈ 2.

Table 4-7. Soil Br content one day after first fertilizer injection (1DAFFI) at different soil depths under bell pepper and watermelon crops as affected by volume of water applied from fertilizer injection and bromide lines.

Crop	Soil Depth (cm)	Irrigation volume^{Z} IV1^{Y} (N1-plots)	IV2 (N2-plots)	Significance
		……………kg ha^{-1}……….		
Bell Pepper^{X}	0-30	9.78	5.13	**
	30-90	3.73	3.04	NS
	0-90	13.51	8.18	**
Watermelon	0-60	4.60	4.64	NS
	60-90	2.91	2.67	NS
	0-90	7.51	7.31	NS

^{Z}IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
^{Y}IV2 = 1.4 IV1 for bell pepper; IV2 = 1.1IV1 for watermelon
^{X} [IV-watermelon]/ [IV-bell pepper] ≈ 2.

Table 4-8. Effect of irrigation volume on soil NO_3-N content as a function of soil depth at one day after first fertilizer injection (1DAFFI) under drip-irrigated bell pepper and watermelon crops.

Crop	Soil Depth (cm)	Irrigation volume[Z]		
		IV1[Y] (N1-plots)	IV2 (N2-plots)	Significance
		…………kg ha^{-1}………		
Bell Pepper[X]	0-30	7.04	6.79	NS
	30-90	1.22	2.03	NS
	0-90	8.27	8.83	NS
Watermelon	0-60	1.04	1.55	NS
	60-90	0.29	0.46	NS
	0-90	1.33	2.01	NS

[Z]IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
[Y]IV2 = 1.4 IV1 for bell pepper; IV2 = 1.1IV1 for watermelon
[X][IV-watermelon]/[IV-bell pepper] ≈ 2.

Table 4-9. Effect of irrigation volume on soil NH_4-N content as a function of soil depth at one day after first fertilizer injection (1DAFFI) under drip-irrigated bell pepper and watermelon crops.

Crop	Soil Depth (cm)	Irrigation volume[Z]		
		IV1[Y] (N1-plots)	IV2 (N2-plots)	Significance
		………...kg ha^{-1}……….		
Bell Pepper[X]	0-30	2.04	1.87	NS
	30-90	1.69	1.89	NS
	0-90	3.74	3.75	NS
Watermelon	0-60	3.16	3.79	NS
	60-90	0.43	0.40	NS
	0-90	3.59	4.20	NS

[Z]IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
[Y]IV2 = 1.4 IV1 for bell pepper; IV2 = 1.1IV1 for watermelon
[X] [IV-watermelon]/[IV-bell pepper] ≈ 2.

Table 4-10. Effect of irrigation volume on soil K content as a function of soil depth at one day after first fertilizer injection (1DAFFI) under drip-irrigated bell pepper and watermelon crops.

Crop	Soil Depth (cm)	Irrigation Volume[Z]		
		IV1[Y]	IV2	Significance
		…………kg ha^{-1}………..		
Bell Pepper[X]	0-30	24.66	26.35	NS
	30-90	28.32	29.14	NS
	0-90	52.99	55.49	NS
Watermelon	0-60	24.79	27.30	NS
	60-90	6.52	6.44	NS
	0-90	31.31	33.74	NS

[Z]IV = Irrigation volumes were applied through fertilizer (N1 and N2) and bromide lines
[Y]IV2 = 1.4 IV1 for bell pepper; IV2 = 1.1IV1 for watermelon
[X] [IV-watermelon]/[IV-bell pepper] ≈ 2.

Table 4-11. Percent of solutes remaining in the root-zone, below root-zone and the entire soil profile at 1DAFFI.

Crop	Soil depth (cm)	Br	NO_3-N	NH_4-N	K
		…………………………%...			
Bell pepper	0-30	34	63	14	43
	30-90	15	15	13	48
	0-90	49	78	27	91
Watermelon	0-60	31	8	29	51
	60-90	18	2	4	13
	0-90	49	10	34	64

Table 4-12. Main effect of irrigation rates on soil water depth (cm) as a function of soil depth at 22DAFF under drip-irrigated bell pepper and watermelon crops.

Treatment	Bell pepper			Watermelons		
	Soil Depth (cm)			Soil Depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
Irrigation (I)	……………………………cm……………………………..					
I_1[Z]	4.87	5.81	10.67	4.67	2.08	6.75
I_2	5.34	6.12	11.46	4.78	2.15	6.93
I_3	5.23	6.49	11.73	5.41	2.24	7.65
Significance	NS	***	**	NS [Y]	NS	NS
I_1 vs. $I_2$and I_3	* [Y]	***	**	NS	NS	NS
I_2 vs. I_3	NS	**	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.
[Y] NS, *, **, *** Main effects were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

Table 4-13. Main effects of irrigation rates on soil Br content as a function of soil depth at 22DAFFI under drip irrigated bell pepper and watermelon crops.

	Bell pepper			Watermelons		
	Soil Depth (cm)			Soil Depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	……………………….kg ha^{-1}…………………………					
Irrigation (I)						
I_1[Z]	0.26	0.47	0.73	0.47	0.25	0.72
I_2	0.27	0.45	0.73	0.44	0.21	0.64
I_3	0.25	0.41	0.67	0.49	0.22	0.72

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively.

Table 4-14. Main effect of irrigation and N rates on soil NO_3-N content as a function of soil depth at 22DAFFI under drip-irrigated bell pepper and watermelon crops

	Bell pepper			Watermelons		
	Soil Depth (cm)			Soil Depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	……………………………. kg ha^{-1} ………………………………….					
Irrigation (I)						
I_1 [Z]	11.60	11.58	23.19	8.85	0.40	9.25
I_2	10.94	18.98	29.92	4.88	0.24	5.05
I_3	9.94	18.44	28.42	5.32	0.51	5.82
Significance	NS [Y]	NS	NS	NS	NS	NS
I_1 vs. $I_2$and I_3	NS	NS	NS	NS	NS	NS
I_2 vs. I_3	NS	NS	NS	NS	NS	NS
N [X]						
N1	7.67	13.33	21.00	7.02	0.36	7.37
N2	13.98	19.36	33.35	5.68	0.40	7.45
Significance	*	NS	*	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.

[X] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

[Y] NS, *, **, *** Main effects and interactions were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

Table 4-15. Main effect of irrigation and N rates on soil NH_4-N content as a function of soil depth at 22DAFFI under drip-irrigated bell pepper and watermelon crops

	Bell pepper			Watermelon		
	Soil Depth (cm)			Soil Depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	……………………………….. kg ha^{-1} …………………………..					
Irrigation (I)						
I_1 [Z]	12.02	1.81	13.83	8.65	0.58	9.23
I_2	12.98	1.30	14.28	4.20	0.65	6.39
I_3	15.57	1.58	17.15	6.20	0.31	6.51
Significance	NS [Y]	NS	NS	NS	NS	NS
I_1 vs. I_2 and I_3	NS	NS	NS	NS	NS	NS
I_2 vs. I_3	NS	NS	NS	NS	NS	NS
N [X]						
N1	4.69	0.99	5.68	4.57	0.61	6.12
N2	22.36	2.13	24.48	8.22	0.42	8.64
Significance	**	*	**	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.

[X] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

[Y] NS, *, **, *** Main effects and interactions were not significant or significant at P ≤ 0.05, 0.01, or 0.001 respectively, according to F tests.

Table 4-16. Main effect of irrigation and N rates on soil K content as a function of soil depth at 22DAFFI under drip-irrigated bell pepper and watermelon crops

	Bell pepper			Watermelon		
	Soil Depth (cm)			Soil Depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	…………………………………. kg ha^{-1} …………………………………					
Irrigation (I)						
I_1[Z]	43.37	24.53	67.90	50.52	6.31	56.83
I_2	52.41	29.17	81.58	36.96	7.60	44.57
I_3	56.07	28.86	84.94	40.24	5.61	47.56
Significance	NS	NS	NS	NS	NS	NS
I_1 vs. $I_2$and I_3	NS	NS	NS	NS	NS	NS
I_2 vs. I_3	NS	NS	NS	NS	NS	NS
N						
N1	44.97	25.81	70.78	41.57	6.64	49.36
N2	56.26	29.24	85.50	43.58	6.37	49.95
Significance	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.

[X] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

[Y] NS, *, **, *** Main effects and interactions were not significant or significant at P ≤ 0.05, 0.01, or 0.001 respectively, according to F tests.

Table 4-17. Effect of irrigation rates on soil water depth (cm) as a function of soil depth at 60DAFFI under drip-irrigated bell pepper and watermelon crops.

	Bell pepper			Watermelon		
	Soil depth (cm)			Soil depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	……………………….. cm…………………………..					
Irrigation (I)						
I_1 [Z]	2.79	6.25	9.06	4.65	1.83	6.47
I_2	2.88	6.18	9.06	4.57	2.32	6.89
I_3	2.74	5.79	8.53	6.22	2.47	6.68
Significance	NS	NS	NS	NS	NS	NS
I_1 vs. $I_2$and I_3	NS	NS	NS	NS	NS	NS
I_2 vs. I_3	NS	NS	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.

[Y] NS, *, **, *** Main effects were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

Table 4-18. Main effects of irrigation rates on soil Br content as a function of soil depth at 60DAFFI under drip irrigated bell pepper and watermelon crops.

	Bell pepper			Watermelon		
	Soil depth (cm)			Soil depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	…………………….………kg ha^{-1} …………………..					
Irrigation (I)						
I_1 [Z]	0.34	0.38	0.72	0.60	0.55	1.15
I_2	0.19	0.37	0.56	0.67	0.27	0.95
I_3	0.21	0.39	0.61	0.47	0.20	0.67

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of, crop evapotranspiration (ET_c) respectively.

Table 4-19. Main effect of irrigation and N rates on soil NO_3-N content as a function of soil depth at 60DAFFI under drip-irrigated bell pepper and watermelon crops

	Bell pepper			Watermelon		
	Soil depth (cm)			Soil depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	……………………………….. kg ha^{-1}			…………………………………..		
Irrigation (I)						
I_1 Z	20.96	8.21	29.18	2.14	0.06	2.19
I_2	19.81	4.59	26.68	1.62	0	1.62
I_3	12.20	2.56	14.77	0.63	0.15	0.78
Significance	NS	NS	NS	NS	NS	NS
I_1 vs. $I_2$and I_3	NS	NS	NS	NS	NS	NS
I_2 vs. I_3	NS	NS	NS	NS	NS	NS
N X						
N1	1.91	2.248	4.16	1.45	0.03	1.48
N2	33.41	9.48	42.90	1.47	0.11	1.58
Significance	***	**	***	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

Z Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.

X Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

Y NS, *, **, *** Main effects and interactions were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

Table 4-20. Main effect of irrigation and N rates on soil NH_4-N content as a function of soil depth at 60DAFFI under drip-irrigated bell pepper and watermelon crops

	Bell pepper			Watermelon		
	Soil Depth (cm)			Soil Depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	………………………………….. kg ha^{-1}………………					
Irrigation (I)						
I_1[Z]	31.33	3.53	34.86	1.83	0.22	2.06
I_2	16.49	2.14	18.63	1.32	0.17	1.49
I_3	6.65	1.68	8.33	2.37	0.19	2.56
Significance	NS	NS	NS	**	NS	**
I_1 vs. $I_2$and I_3	*	NS	*	NS	*	NS
I_2 vs. I_3	NS	NS	NS	**	NS	**
N[X]						
N1	2.79	0.87	3.67	1.74	0.18	1.92
N2	33.51	4.029	37.54	1.94	0.21	2.15
Significance	**	***	**	NS	NS	NS
Interaction	NS	NS	NS	NS	*	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts.

[X] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

[Y] NS, *, **, *** Main effects and interactions were not significant or significant at P ≤ 0.05, 0.01, or 0.001 respectively, according to F tests.

Table 4-21. Main effect of irrigation and N rates on soil K content as a function of soil depth at 60DAFFI under drip-irrigated bell pepper and watermelon crops

	Bell pepper			Watermelon		
	Soil depth (cm)			Soil depth (cm)		
	0-30	30-90	0-90	0-60	60-90	0-90
	……………………. kg ha^{-1} ……………………………………					
Irrigation (I)						
I_1[Z]	89.22	83.02	172.23	32.26	5.78	38.04
I_2	51.37	43.82	95.19	24.91	5.42	35.24
I_3	31.26	35.35	66.61	21.24	4.96	26.20
Significance	*	***	**	*	NS	NS
I_1 vs. $I_2$and I_3	**	***	***	*	NS	NS
I_2 vs. I_3	NS	NS	NS	NS	NS	NS
N						
N1	34.43	51.48	85.91	27.06	5.43	35.77
N2	80.13	56.64	136.77	25.21	5.34	30.56
Significance	**	NS	*	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 were 66%, 100% and 133% of crop evapotranspiration (ET_c), respectively. Irrigation levels effects were compared to each other with contrasts

[X] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

[Y] NS, *, **, *** Main effects and interactions were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

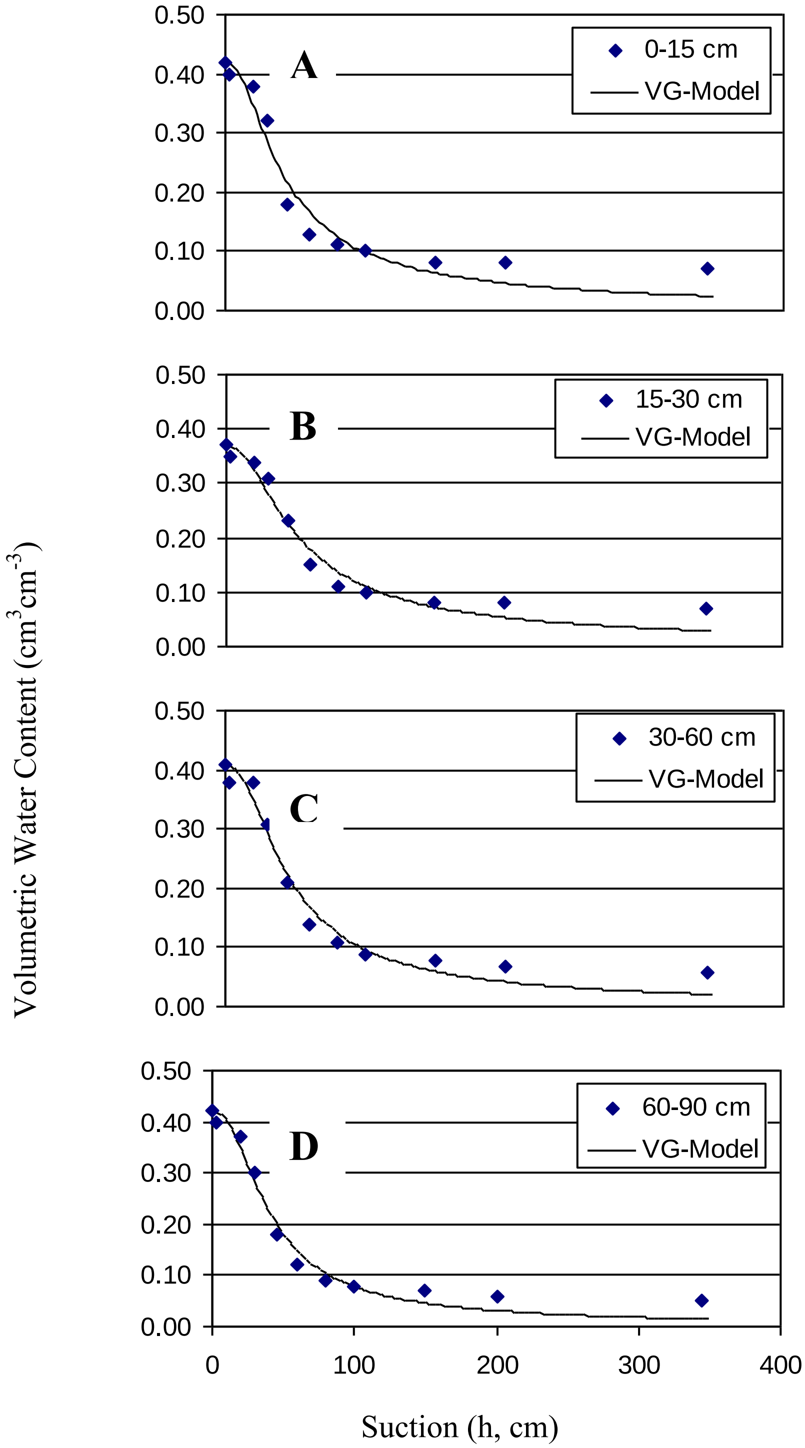

Figure 4-1. Soil moisture release curves for sampling depth 0-15 cm (A), 15-30 cm (B), 30-60 cm (C), and 60-90cm (D) of Lakeland fine sand soil at North Florida Research and Education Center-Suwannee Valley near Live Oak, FL, simulated with van Genuchten (VG) model (1980)

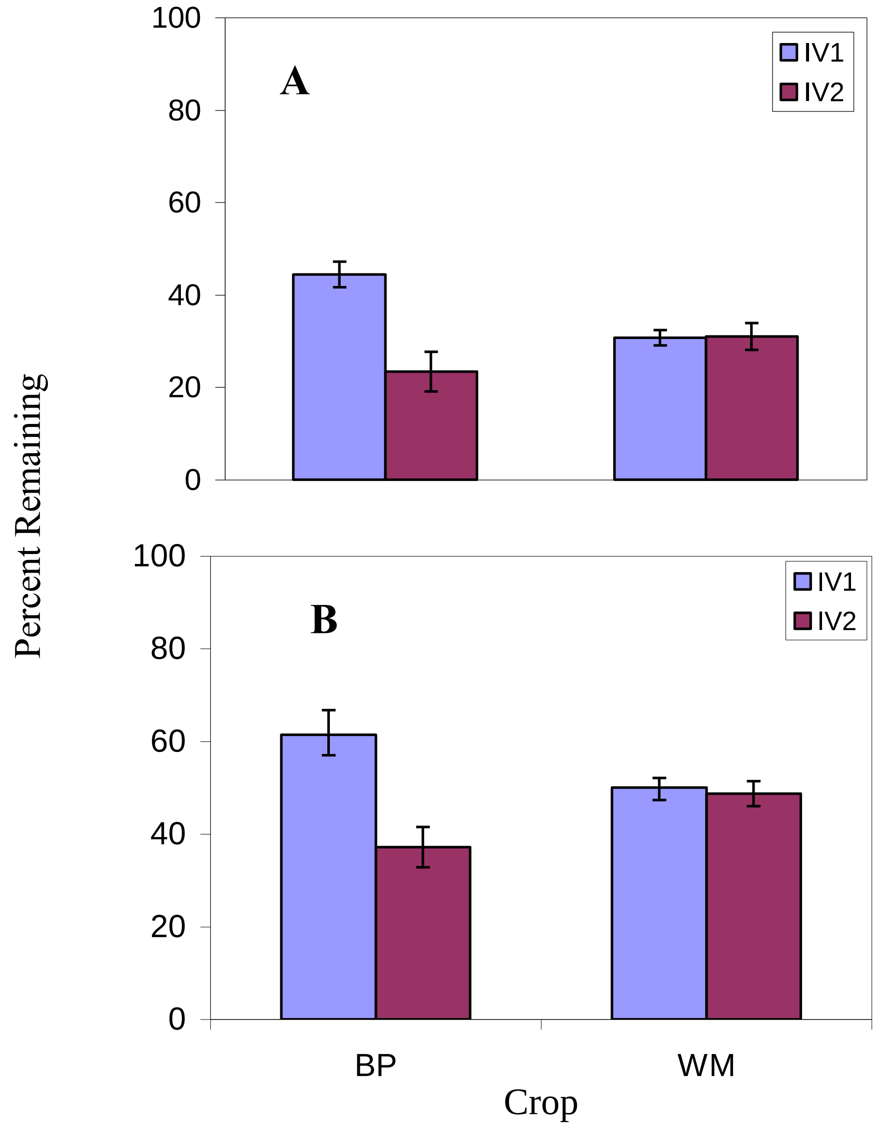

Figure 4-2. Percent of Br remaining in the root-zone (A) and in the entire soil profile (B) as affected by irrigation volumes (IV1 and IV2) for bell pepper (BP) and watermelon (WM) crops at 1DAFFI.

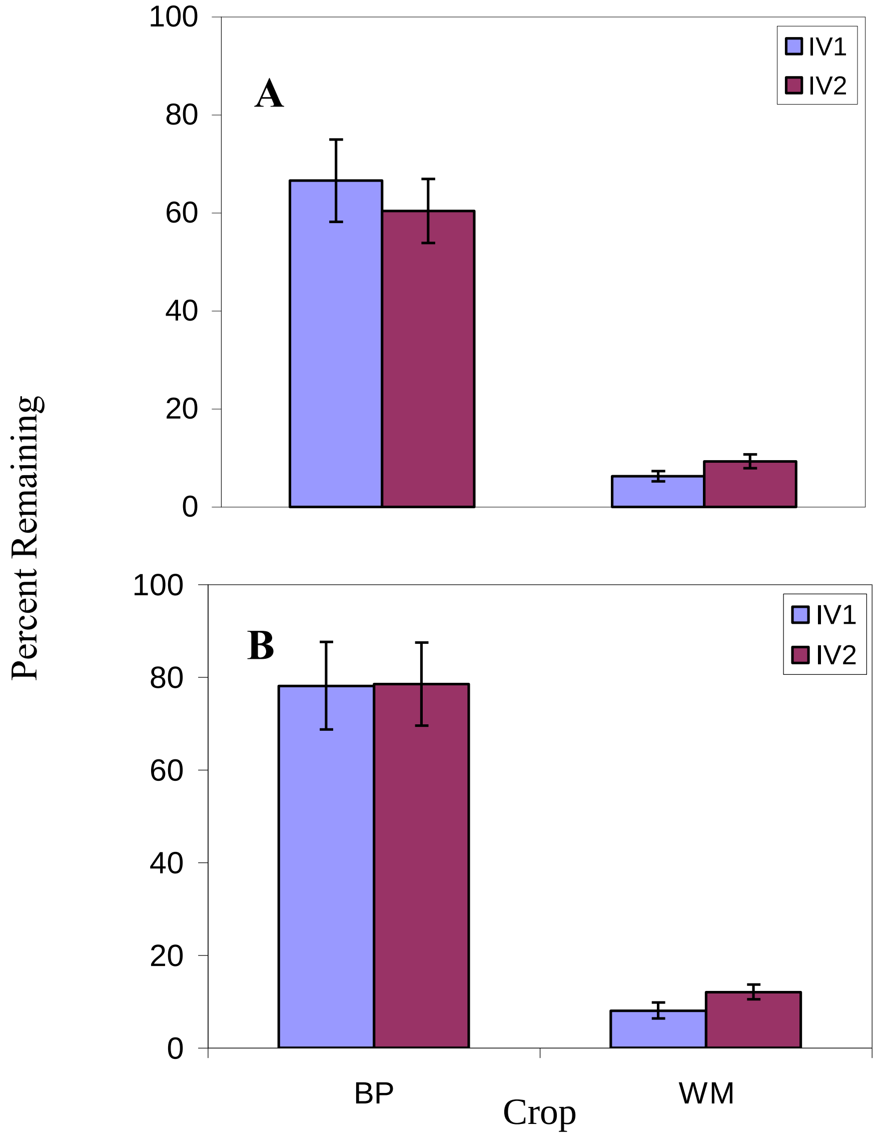

Figure 4-3. Percent of NO_3-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by irrigation volumes (IV1 and IV2) for bell pepper (BP) and watermelon (WM) crops at 1DAFFI.

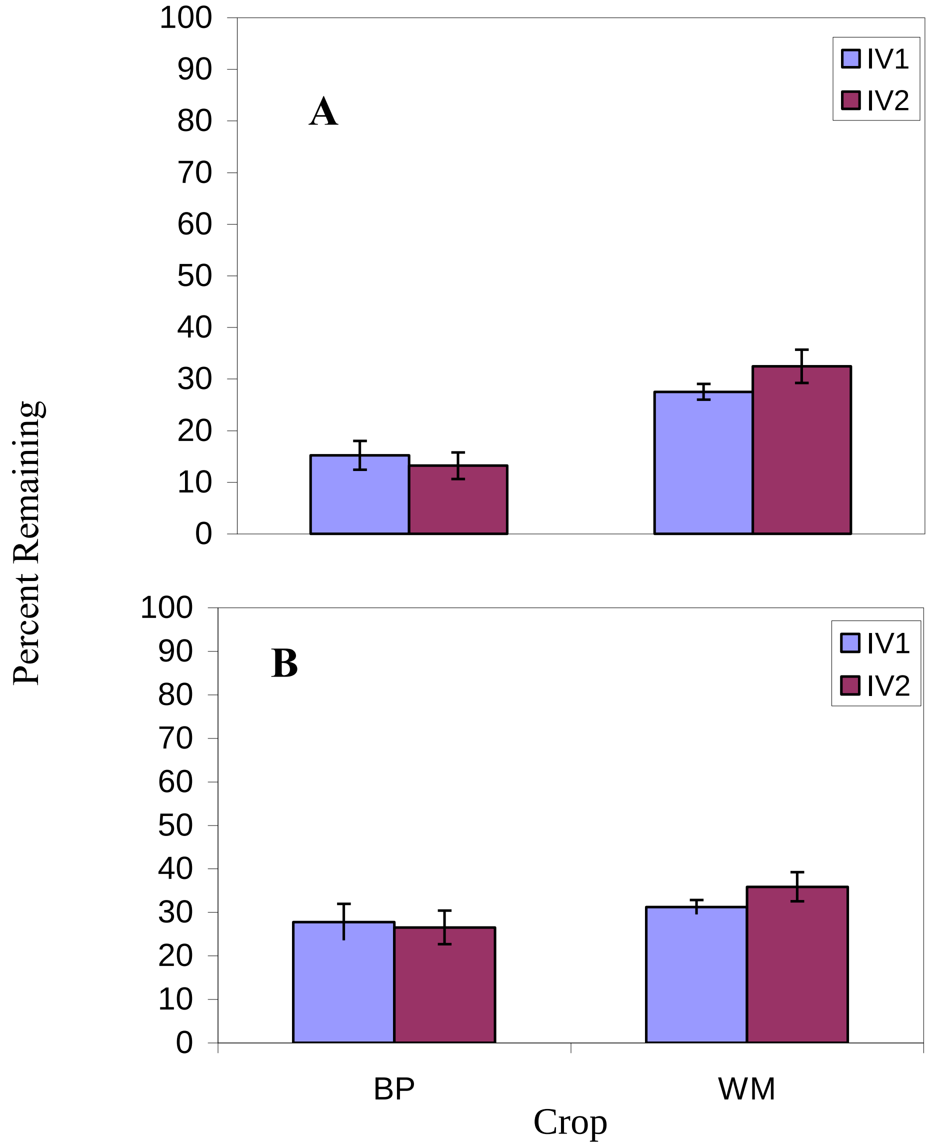

Figure 4-4. Percent of NH_4-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by irrigation volumes (IV1 and IV2) for bell pepper (BP) and watermelon (WM) crops at 1DAFFI.

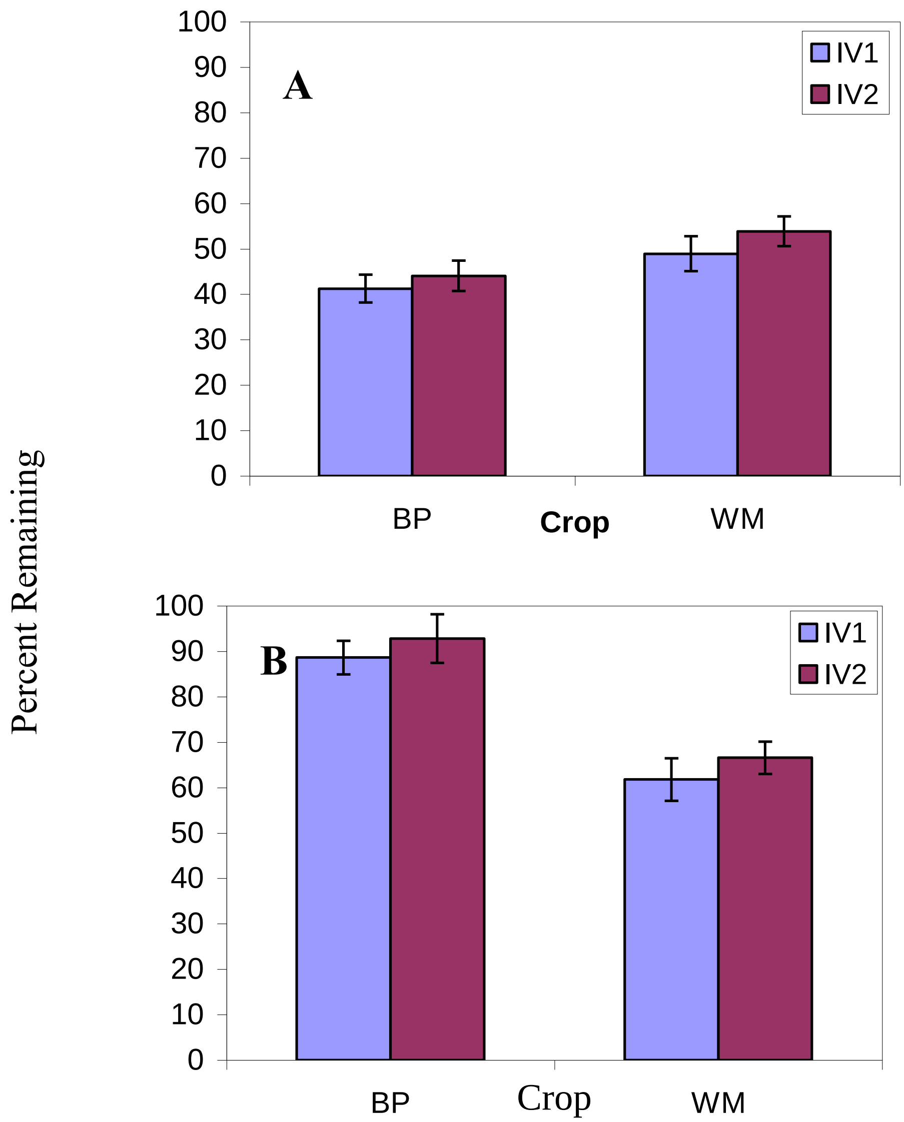

Figure 4-5. Percent of K remaining in the root-zone (A) and in the entire soil profile (B) as affected by irrigation volumes (IV1 and IV2) for bell pepper (BP) and watermelon (WM) crops at 1DAFFI.

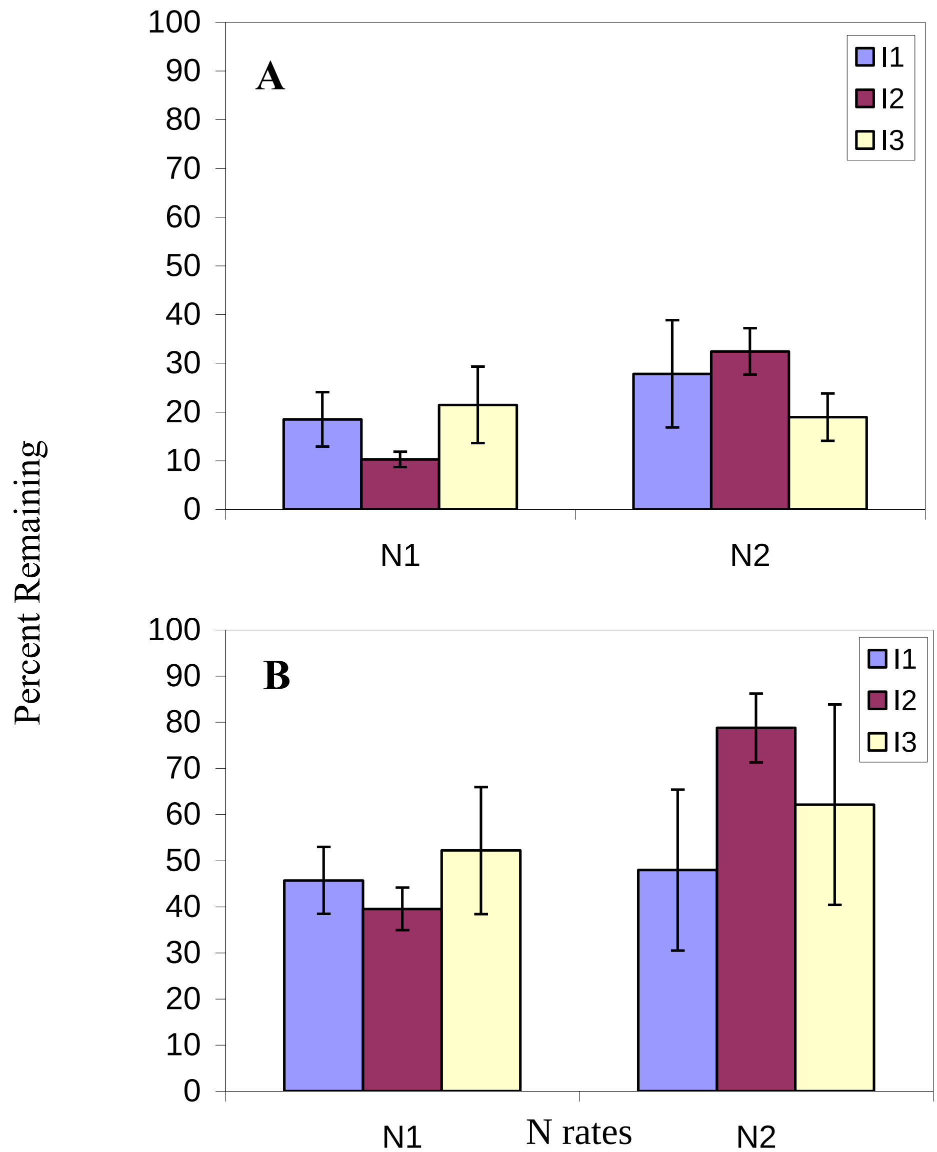

Figure 4-6. Percent of NO_3-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the bell pepper crop at 22DAFFI.

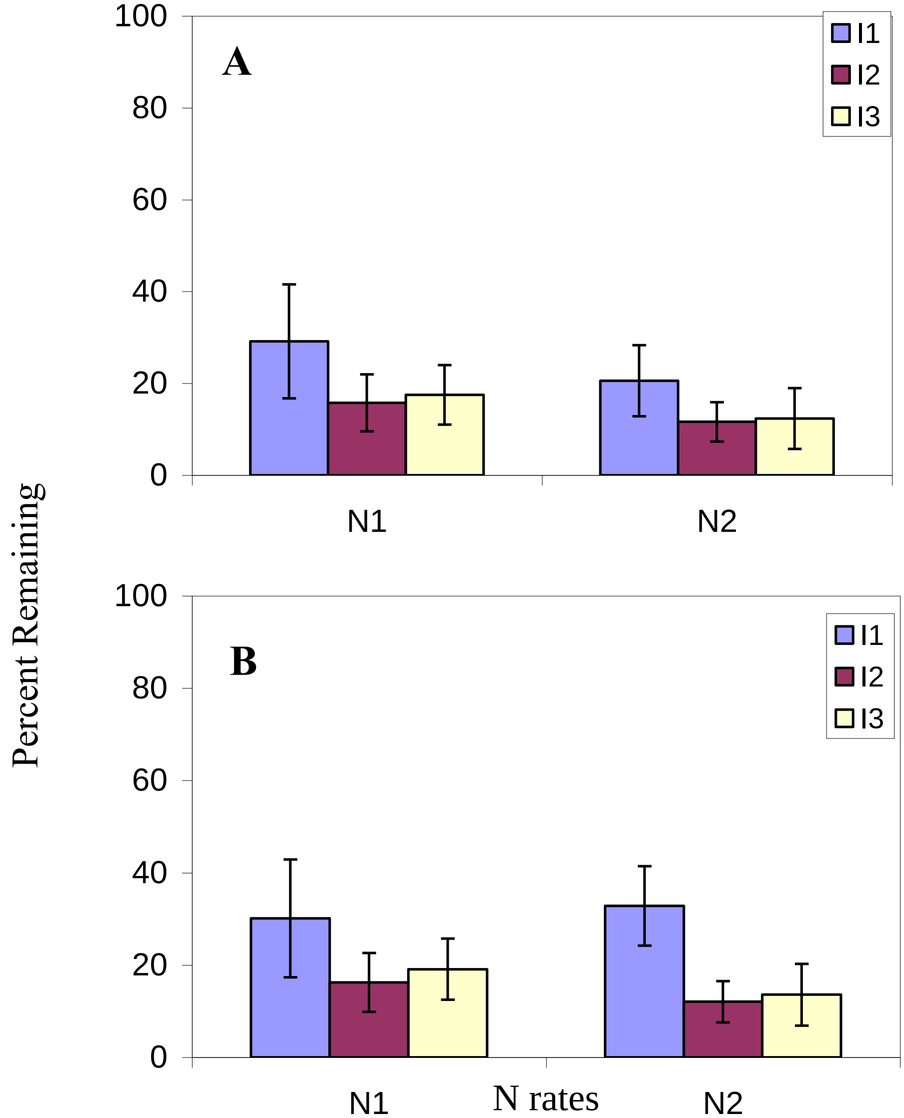

Figure 4-7. Percent of NO_3-N remaining in the root-zone (A) and in the entire soil profile B) as affected by N and irrigation rates for the watermelon crop at 22DAFFI.

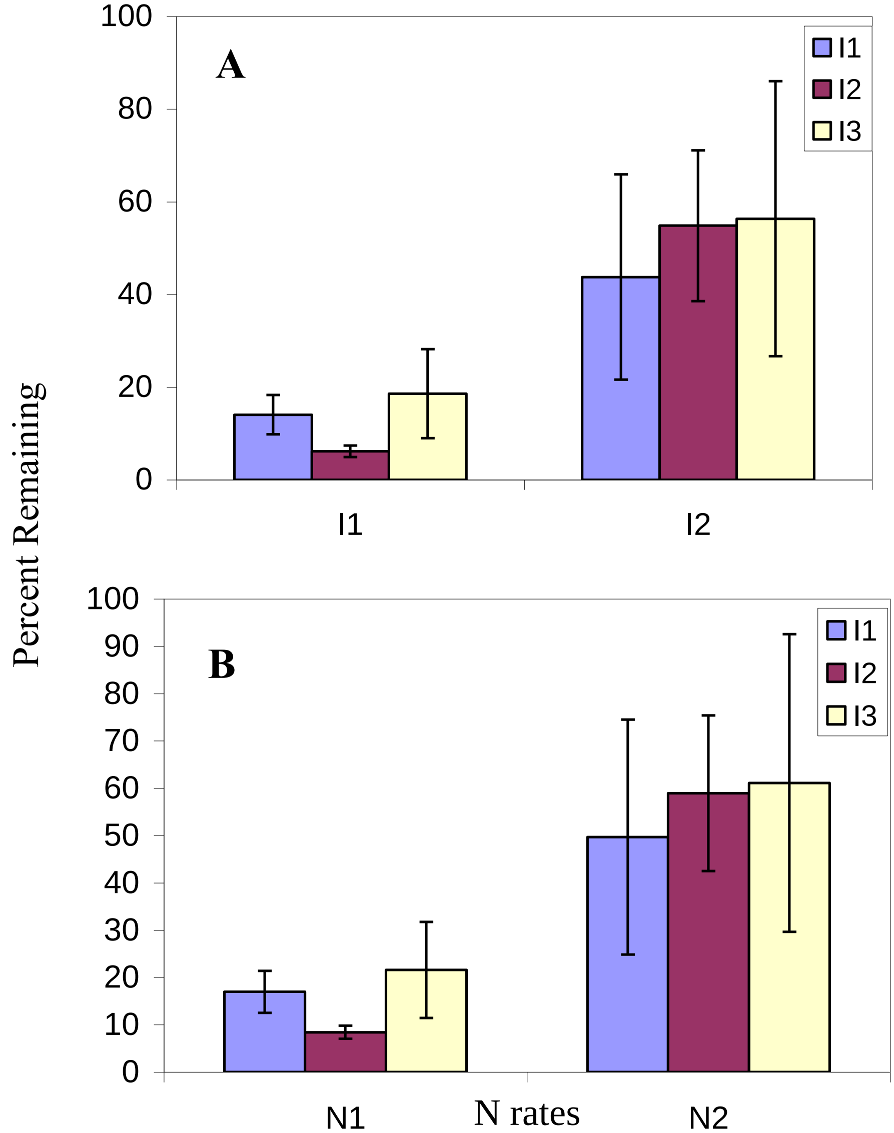

Figure 4-8. Percent of NH_4-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the bell pepper crop at 22DAFFI.

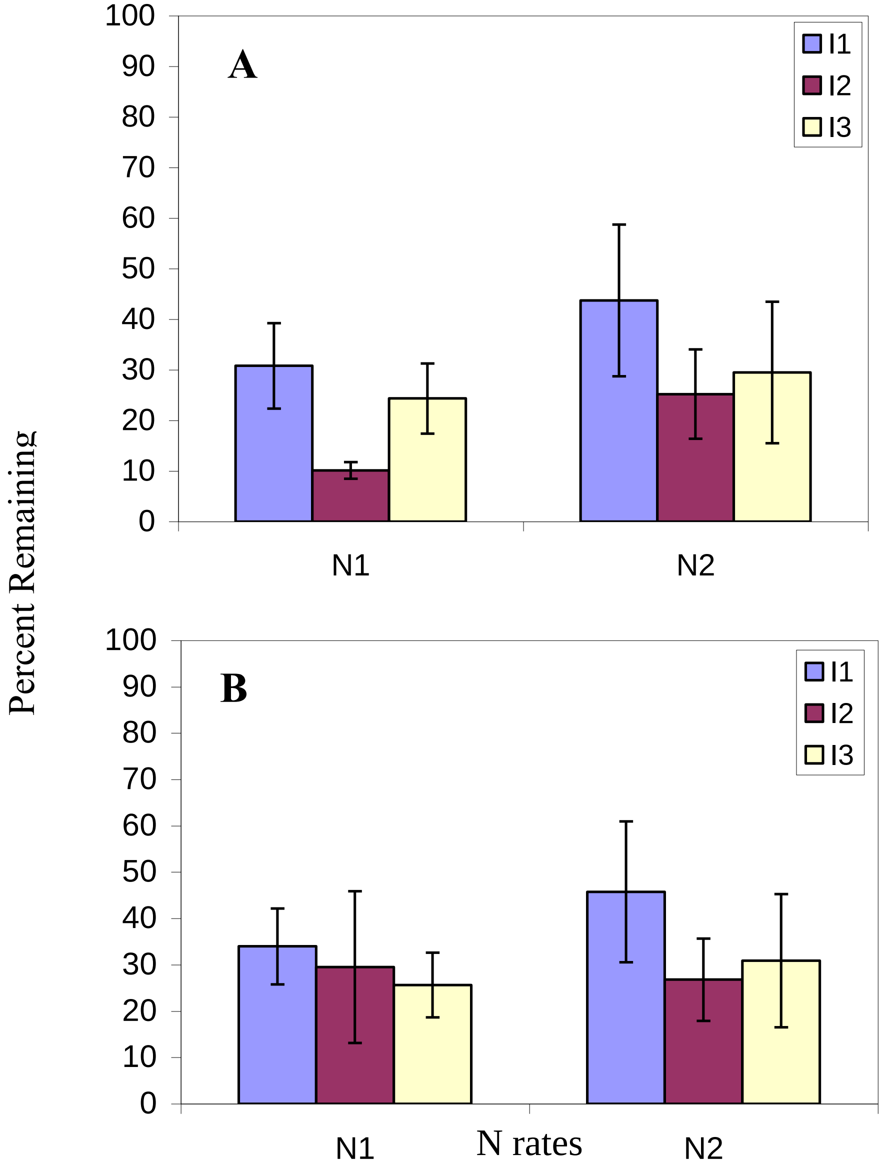

Figure 4-9. Percent of NH_4-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the watermelon crop at 22DAFFI.

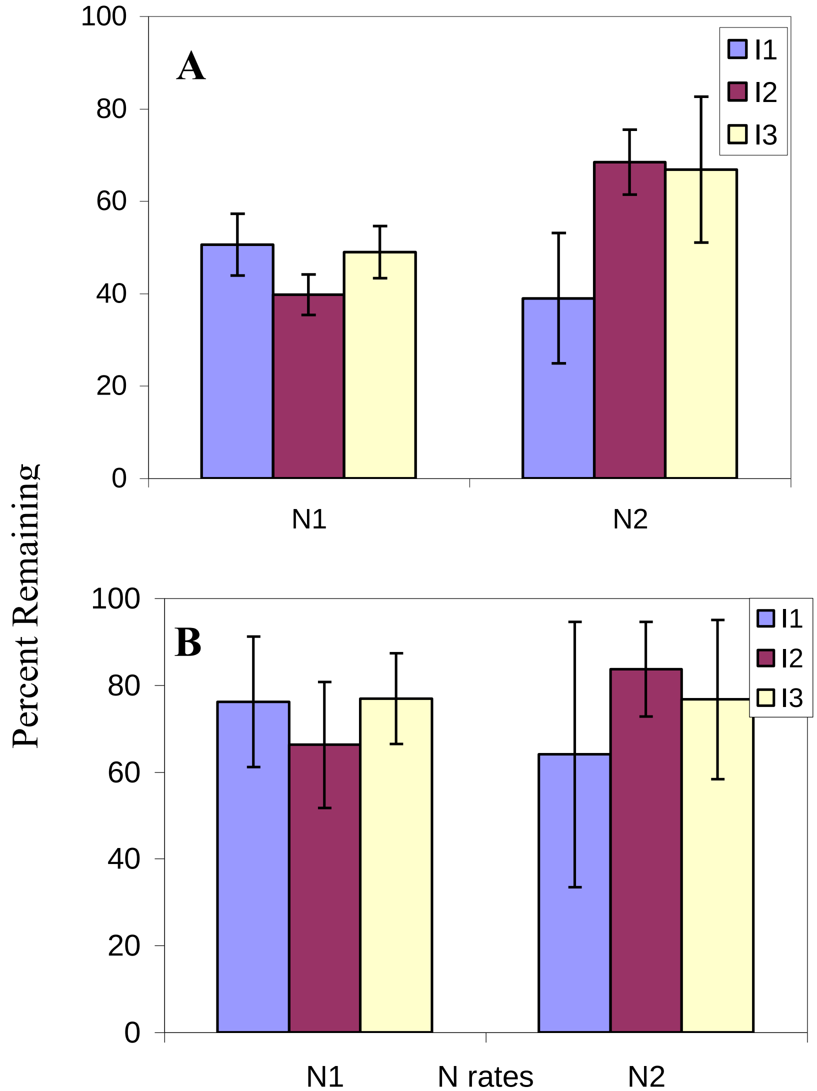

Figure 4-10. Percent of K remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the bell pepper crop at 22DAFFI.

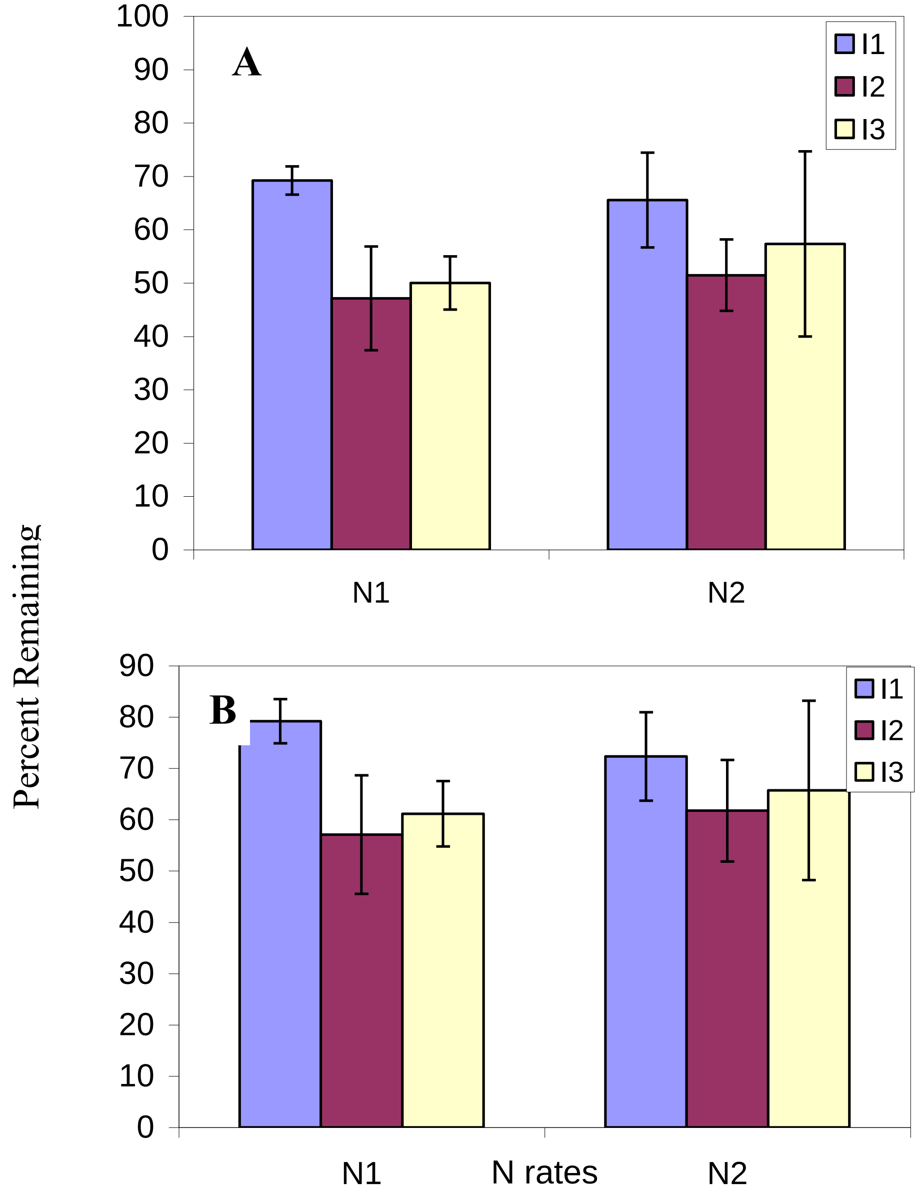

Figure 4-11. Percent of K remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the watermelon crop at 22DAFFI.

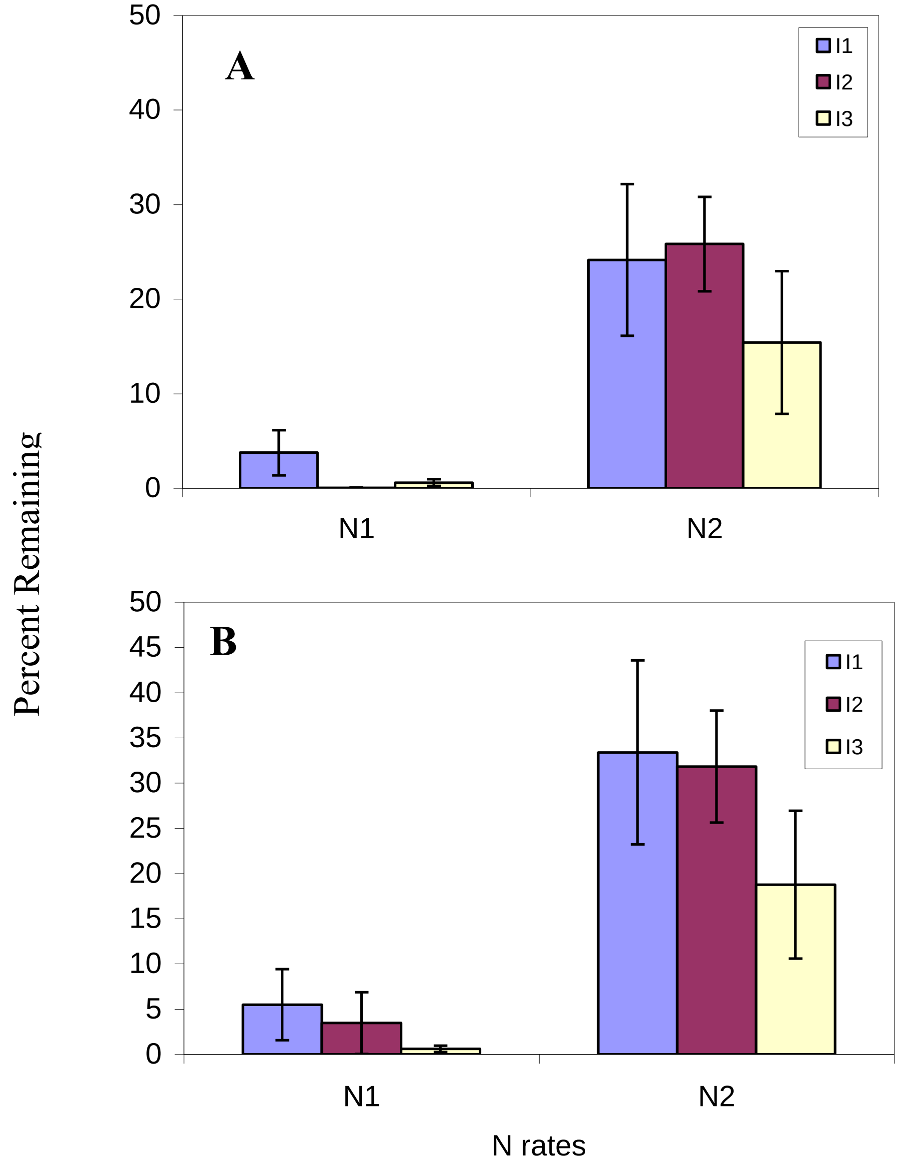

Figure 4-12. Percent of NO_3-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the bell pepper crop at 60DAFFI.

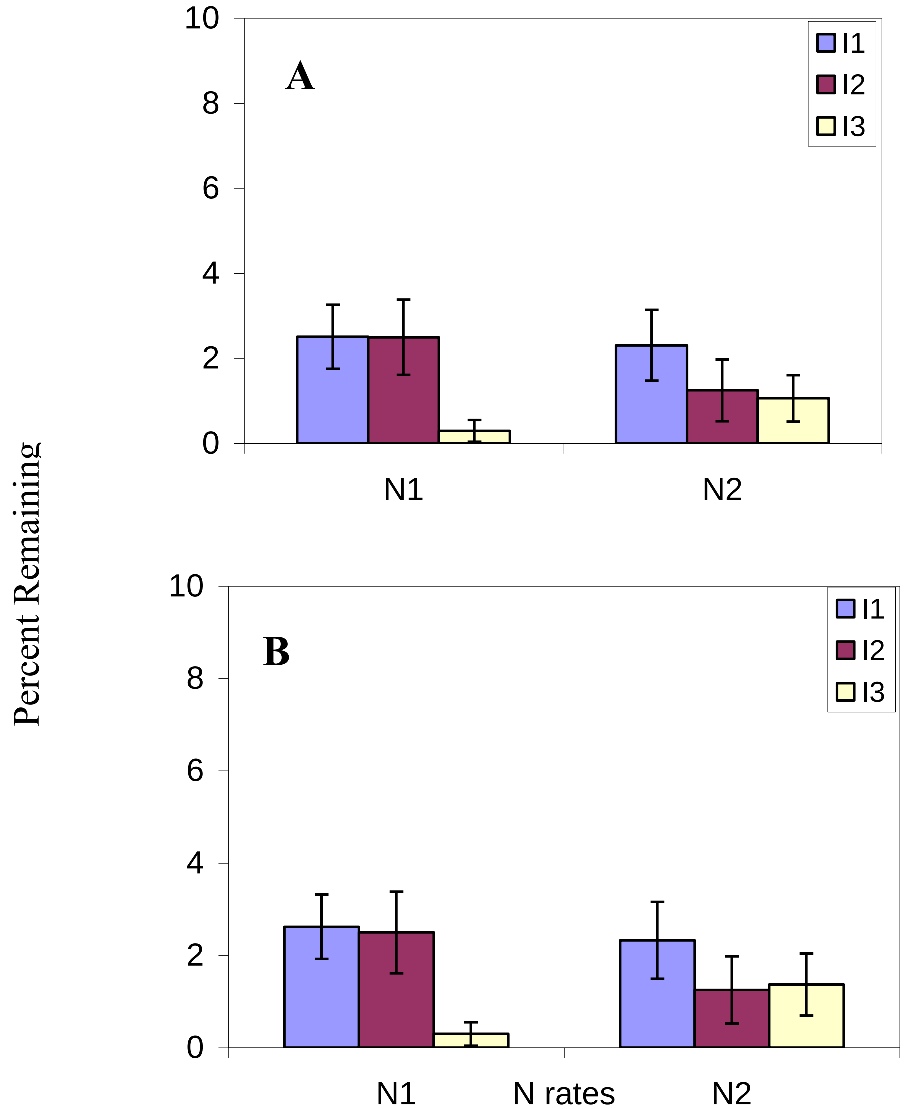

Figure 4-13. Percent of NO_3-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the watermelon crop at 60AFFI.

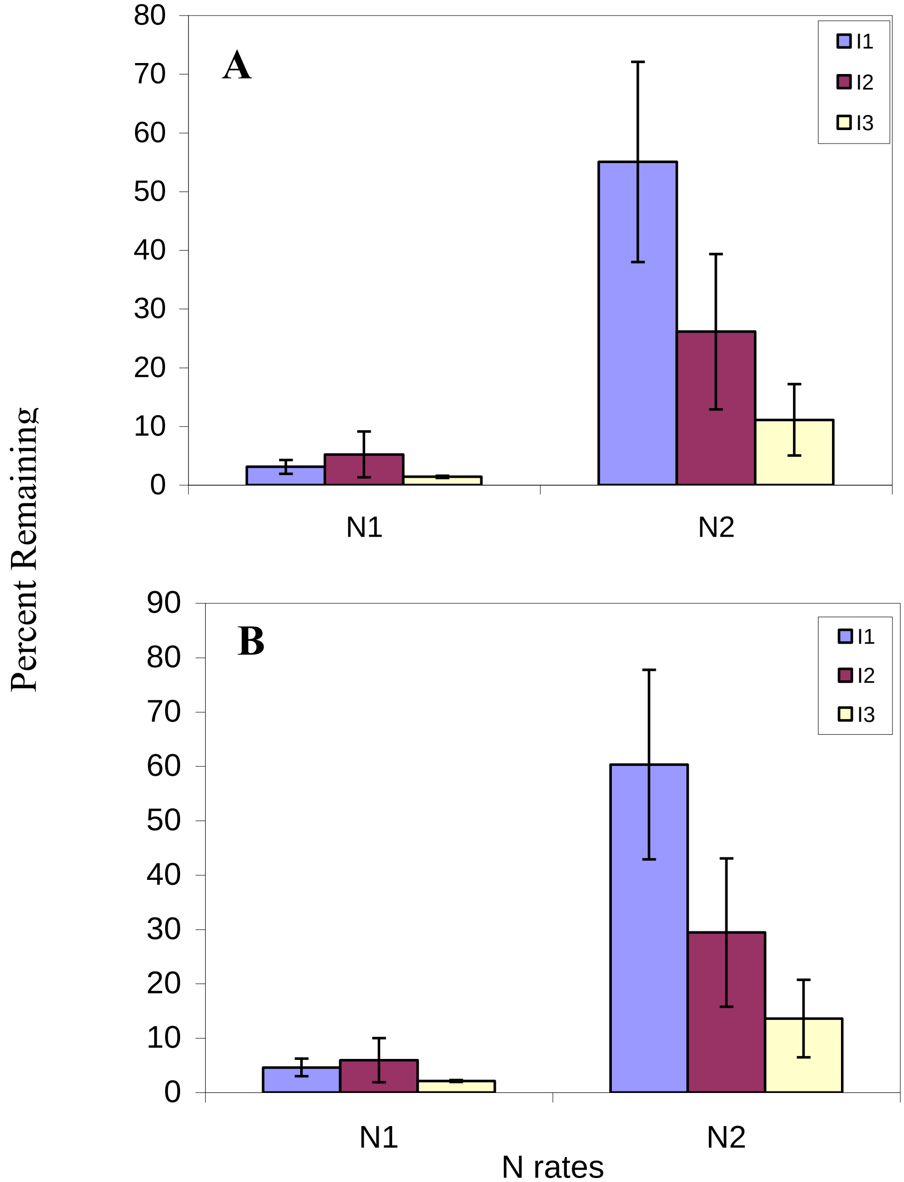

Figure 4-14. Percent of NH_4-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the bell pepper crop at 60DAFFI.

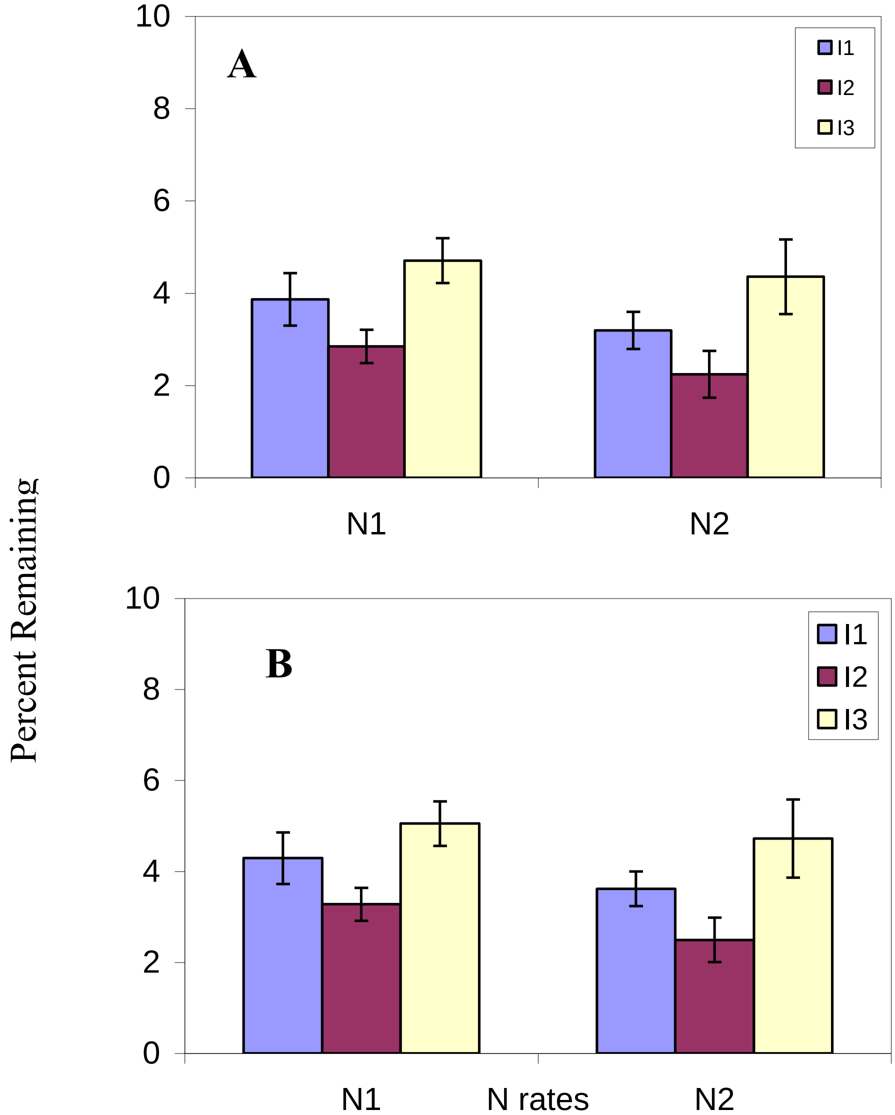

Figure 4-15. Percent of NH_4-N remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the watermelon crop at 60DAFFI.

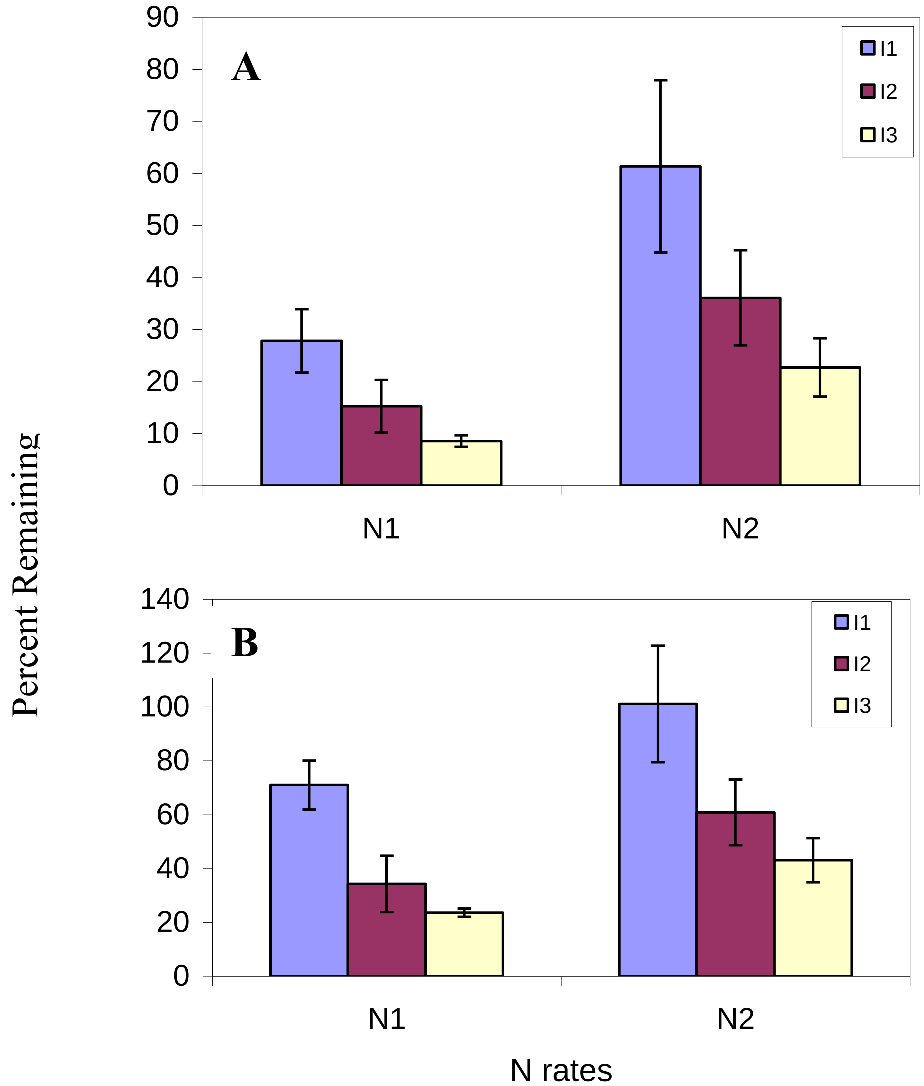

Figure 4-16. Percent of K remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the bell pepper crop at 60DAFFI.

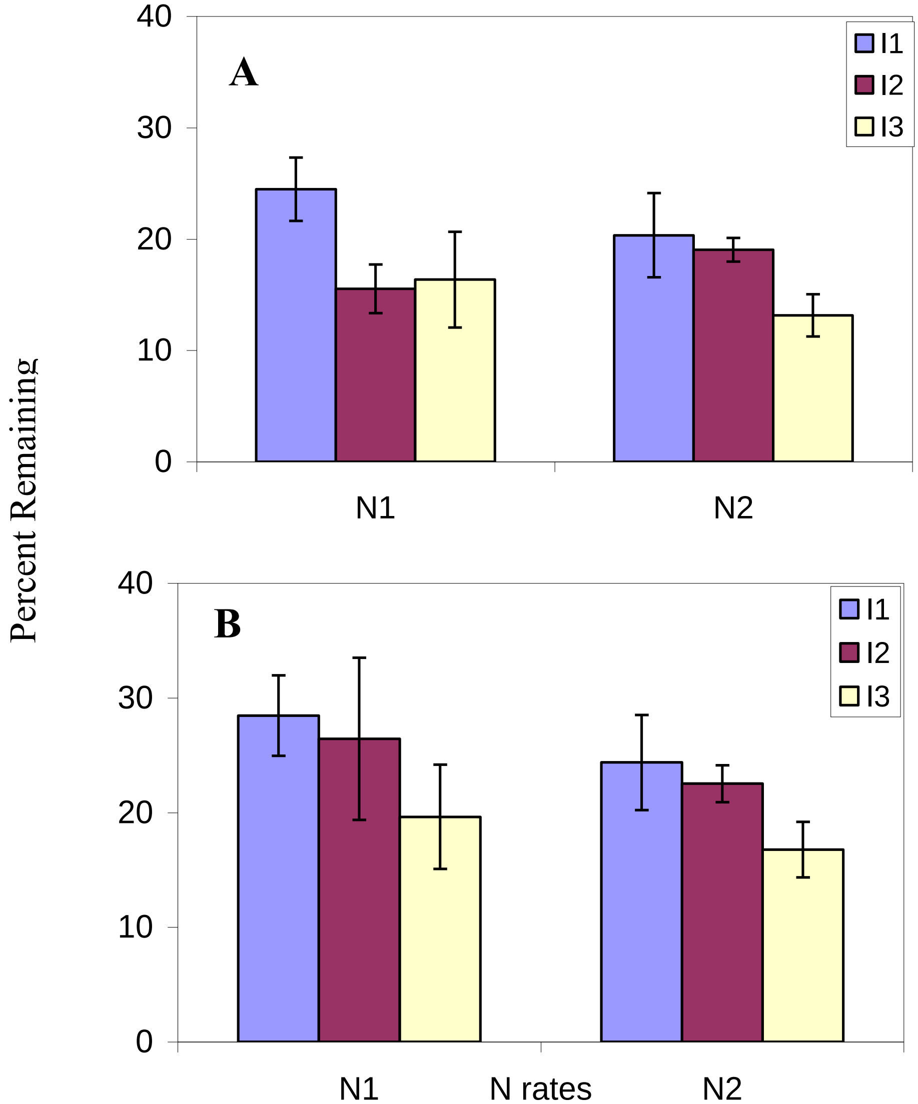

Figure 4-17. Percent of K remaining in the root-zone (A) and in the entire soil profile (B) as affected by N and irrigation rates for the watermelon crop at 60DAFFI.

CHAPTER 5
NITROGEN AND BIOMASS ACCUMULATION, AND YIELD OF BELL PEPPER AND WATERMELON CROPS AS AFFECTED BY IRRIGATION AND N RATES

Bell pepper and watermelon crops fertilized at 100 and 125% of IFAS recommended N rate were evaluated using irrigation schedules based on 66, 100, and 133% of crop evapotranspiration (ET_C). Plant samples were taken during fruit development 53 days after transplanting (53 DAT) and at harvest (75DAT) to assess the effect of treatment combinations on plant growth in terms of N and biomass accumulation and partitioning in selected plant parts as well as fruit yield. The data obtained will be discussed in two sections. In the first section, the effects of different irrigation and N rates on N concentration, biomass and N accumulation in different parts of bell pepper and watermelon crops during fruit development (53DAT) will be elucidated. In the second section, the effects of irrigation and N rates on N concentration, biomass and N accumulation in different parts of bell pepper and watermelon at harvest (75DAT) and on crop yield will be discussed.

5-1 Crop Nitrogen Concentration, Biomass and N Accumulation as Affected by Irrigation and N Rates on 53 DAT

Maximum nutrient uptake occurs during crop fruit development (Miller et al., 1979). Therefore, plant samples for both bell pepper and watermelon crops were taken to assess the effect of irrigation and N rates on crop N concentration, biomass and N accumulation and partitioning during fruit development.

5.1.1 Crop Nitrogen Concentration as Affected by Irrigation and N Rates on 53 DAT

There was no interaction between irrigation and N rates on N concentration of bell pepper (in leaves, stems and fruits) and watermelon (in leaves and stems). Therefore, the main effects of irrigation and N rates on N concentration of bell pepper and watermelon plants will be discussed (Table 5-1).

Increasing irrigation rates decreased ($P<0.01$) bell pepper leaf N concentration while it had no effect on N concentration of bell pepper stems and Fruits (Table 5-1). Similarly, applying 133% ET_C to watermelon reduced ($P<0.05$) N concentration in leaves and had no effect on stems N concentration. Increasing N rates increased ($P<0.001$) N concentration of bell pepper leaves and stems (Table 5-1). Unlike bell pepper, N rates had no effect on watermelon leaf or stem N concentration (Table5-1).These data suggest that N was adequate at the recommended N rate (N1) and the lowest irrigation rate (I1) to account for leaf N demand during fruit development for both crops. In general N partitioning for both crops was in the order: leaves > stems and for bell pepper fruits > stems (Fig 5-1). No data were obtained for N concentration in the water melon fruits.

5.1.2 Biomass Accumulation as Affected by Irrigation and N rates at 53 DAT

There was interaction between irrigation and N rates on biomass accumulation of bell pepper leaves, stems and fruits (Table 5-2). Leaf biomass accumulation of the bell pepper plants was greater under the recommended N rate (N1) with the 100% ET_C (I2) compared to 133% ET_C (I3) irrigation rate. However, leaf biomass of plants fertilized with the higher N rate (N2) was not different at any irrigation rate (Table 5-2). An increase in total biomass at the lower N rate and lowest irrigation rate would indicate potential leaching of N due to increase in irrigation rates. This is in agreement with the calculated water fluxes, soil Br, and N concentration data previously discussed (Chapter 4).

Like bell pepper, there was interaction between irrigation and N rates on watermelon biomass accumulation at 53 DAT (Table 5-2). However, leaf, stem, and total biomass of plants grown with the recommended N rate was lower with 100% ET_C irrigation rate compared to 133% ET_C (I3) irrigation rate (Table 5-2). Under the higher N rate, the total biomass was not different among irrigation rates. These data would suggest increased growth with increased irrigation rate at recommended N application rates, but no such effect with plants fertilized at the higher N rate. At N2 there is already enough N in soil solution regardless of irrigation rate. Regardless of N application rate, biomass accumulation partitioned in bell pepper was in the order: leaves > fruits > stems (Fig 5-2).For watermelon, biomass accumulation was grater in leaves than stems

5.1.3 Nitrogen Accumulation as Affected by Irrigation and N rates at 53 DAT

During fruit development (53 DAT), there was no interaction between irrigation and N rates on bell pepper stems and watermelon leaf and stem N accumulation. Therfofroe, the main effects (Table 5-3) of irrigation and N rate on N accumulation will be discussed. However, there was interaction between irrigation and N rates on nitrogen accumulation in bell pepper leaves and fruits. Therefore, the mean values (Table 5-4) for each irrigation rate for the leaves and fruits N concentration will be discussed. Unlike bell pepper,

Data in Table 5-4 show that at 53 DAT, nitrogen accumulated by bell pepper leaves and stems was not different for irrigation rate at the recommended (N1) or higher N rate (N2). The decrease in N accumulation in bell pepper fruits under the recommended N rate (N1) as irrigation rates increase is supported by the decrease in N concentration and biomass accumulation (Tables 5.1 and 5.2). This may be due to N leaching as irrigation application rates are increased. The highest percent of N accumulated in bell pepper fruits under the recommended N rate (N1) was observed with the lowest irrigation rate (I1) and decreased with increasing irrigation rates (Fig. 5-3). High amounts of N taken up by bell pepper crop during fruit development were accumulated in the leaves compared to stems similar to biomass accumulation regardless of N rate (Table 5-4). However, more N was accumulated in leaves and stems for N2 rate compared to N1 rate (Table 5-4). These data agree with the results of Olsen et al. (1993) who found that for the pepper plant N uptake increased with increase of applied N from 210 to 280 kg ha^{-1} of N. These data would indicate that more N was available for plant uptake under the higher N rate even with the higher irrigation rate. However, the N content in fruits for I1NI plots was higher than all other treatment combinations for N1 plots. These results are supported by lower soil N concentrations at higher irrigation rates due to possible leaching of N below the root-zone (Lord and Bland, 1991)

For watermelon, increasing N rates increased leaf ($P<0.05$) and stem ($P<0.01$) N accumulation. These data are similar to data reported by Miller et al. (1979) who showed that maximum nutrient uptake occurred 56-70 DAT. Regardless of N rate, N accumulation partitioned in bell pepper in the order: leaves > fruits > stems (Fig 5-4).For watermelon, higher values of N were accumulated in leaves than stems (Fig 5-4)

5.1.4 Conclusion

Increasing N application rate increased the bell pepper crop N concentrations, biomass accumulation, and N accumulation. However, increasing irrigation rates reduced N concentration, biomass accumulation and N accumulation. This implies a potential for leaching of nutrient below the root zone of shallow rooted crops compared to deep rooted crop (watermelon) where more N was available for plant uptake. For the watermelon crop increasing N application rate increased N concentration, biomass accumulation, and N accumulation, but irrigation rates had no effect on the three concentrations because there was slow water flux in the watermelon plots at this plant sampling date. Most of the N taken up by the crops was accumulated in leaves, followed by fruits (bell pepper only) and then stems during fruit development.

It appears that irrigation at 66% ET_C (I1) and 100% IFAS recommended N rate (N1) would be adequate for both crops during fruit development. This combination will minimize the potential for leaching of water and nutrients while optimizing crop growth.

5-2 Nitrogen Concentration, Biomass and N Accumulation as Affected by Irrigation and N Rates at 75 DAT

Fruits are the economic parts of both bell pepper and watermelon crops and most of nutrient taken up by the crop are accumulated in the fruits. Therefore, it is important to assess the effect of different irrigation and N rates on crop N concentration, biomass and N accumulation and on crop yield.

5.2.1 Nitrogen Concentration as Affected by Irrigation and N Rates at Harvest (75 DAT)

There was no interaction between irrigation and N rates on N concentration of bell pepper (leaves, stems and fruits) and watermelon (leaves and stems) at 75 DAT (Table 5-5). Neither irrigation nor N rates affected bell pepper leaf, stem and fruit N concentration at harvest. On the other hand, increasing irrigation rate to 133% ET_C reduced ($P<0.05$) N concentration in both leaves and stems of watermelon crop (Table 5-5). Also, watermelon leaf and stem N concentration decreased with increased N rate (Table 5-5).

In general N concentration partitioned in bell pepper was in the order: leaves > fruits > stems (Fig 5-5). Like bell pepper, higher N concentrations were observed in leaves than stems in watermelon plants fertilizer with 100% and 125% IFAS recommended N rate. In general N concentration partitioned in watermelon in the following order: leaves > fruits > stems (Fig 5-5)

5.2.2 Biomass Accumulation as Affected by Irrigation and N Rates at Harvest (75 DAT)

There were interactions between irrigation and N rates on bell pepper leaf biomass accumulation, (Table 5-6). Total bell pepper biomass (including fruits) was greater with increased N rate but was not affected by irrigation rate. Nitrogen effects on total biomass at this stage of growth were due to increased fruit biomass accumulation with increased N rate, which was not affected by irrigation rate. Dry matter accumulation data agree with the results of Carballo et al. (1994) who found that dry matter accumulation in the fruits was higher with increased fertigation rates. Biomass partitioning order at harvest was as follows: fruits > leaves > stems (Fig 5-6).

There was interaction between irrigation and N rates on watermelon stem and the whole plant biomass accumulation (Table 5-6). Under the recommended N rate (N1), stems and the whole plant biomass accumulation was greater ($P<0.01$) with the lowest irrigation rate. This result may have been due to greater N availability for plant uptake compared to the higher irrigation rates (Table 5-6). However, under the higher N rate, the opposite trend was observed with increased leaf and the whole plant biomass accumulation with the highest irrigation rate. These results would indicate the N is not limiting under the high N rate at any irrigation rate. The increase in biomass accumulation in this case is due to reduced plant stress with added irrigation.

5.2.3 Nitrogen Accumulation as Affected by Irrigation and N Rates at Harvest (75 DAT)

There was no interaction between irrigation and N rates on bell pepper leaves, stems and fruits N accumulation at 75 DAT, therefore the results of main effects (Table 5-7) of irrigation and N rate on N accumulation will be discussed. However, there was interaction effect between irrigation and N rates ($P< 0.01$) on watermelon stem N accumulation at harvest (Table 5-7).

At harvest (75 DAT), irrigation rates did not affect N accumulated in the leaves, stems and fruits of bell pepper plant (Table 5-7). Higher values of N were accumulated in fruits followed by leaves, lowest values were observed in stems under both N rates (Fig 5-7). Percent of N accumulated in bell pepper leaves, stems and fruits increased with increasing N rate and were nearly equal for the three irrigation rates (Fig 5-8). These data would indicate that more N was available for plant uptake under the higher N rate regardless of irrigation rate; little indication is given regarding leaching potential of increased irrigation rate. These data agree with percent recovery of applied N in soil samples taken at harvest where there was no N recovered at any soil depth under the recommended N rate while percent recovery of applied N was about 18% under recommended irrigation rate (I2) and high N rate (N2) treatment and decreased to 3% under I3N2 treatment.

Data in Table 5-7 indicate that irrigation rates had no effect on N accumulated in watermelon leaf, while increased N rates increased ($P<0.05$) N accumulated in stem. The low values for N accumulation for both leaves and stem under the 100% ET_C rate are due to the low values of biomass accumulation obtained under this irrigation rate (Table 5 -7)

The highest mean value of leaf and stem N accumulations were obtained under the lowest irrigation rate with the recommended N rate, the lowest N accumulation values were obtained under the lowest irrigation rate with the higher N rate. Nitrogen accumulation in both leaves and stems was affected by N rate. This maybe due to the effect of N rates on biomass accumulation. At 75 DAT, most (40-60%) of N taken up by the plant was accumulated in the fruits (Figure 5-8)

5.2.4 Yield as Affected by Irrigation and N Rates at Harvest (75 DAT)

There was interaction effect ($P< 0.0001$) between irrigation and N rates on pepper fancy, US #1, US#2, total, marketable yield and blossom end rot ($P<0.01$) (Table 5-9). Bell pepper yield increased as N rate increased where highest values of total, marketable and fancy bell pepper yields occurred with 125% N rate under the recommended irrigation rate (I2). Similar results were obtained by Carballo et al. (1994) who found that highest marketable yield and fewest discards (culls) in the first harvest were obtained with high rates of N and K. Also, a reduction in blossom end rot (BER) occurred as the N fertilizer rate increased leading to higher yields.

Under the recommended N rate (N1), the lowest irrigation rate resulted in the highest weights for fancy, total gross yield, and marketable yield, compared to those with other irrigation rates. The weights for US#1, bloom end rot, and other culls were highest with I2 rate under N1 rate. These data would suggest that yield is reduced at recommended N rates by increased irrigation. The leaching of N at increased irrigation rates previously discussed would lend support to these findings.

With the exception of US#1, the 100% ET_C irrigation rate produced more, or equal fruit yield for all fruit quality sizes than the highest irrigation rate when fertilized at the higher N rate. However, fruit yields, with the exception of US #1, blossom end rot and other culls for plants fertilized at recommended N rate were increased with 66% ET_C compared to the 100% ET_C irrigation rate. These results would indicate that 100% ET_C irrigation rates did not adversely affect crop yield when fertilized at higher than recommended N rates. The effects of N application and irrigation rates in general followed the same trend as for biomass accumulation discussed earlier. Theses results agree with Simonne et al., 2006c who found that the highest bell pepper yields occurred with 125% N rate and 133% ET_C. However, Dukes et al. (2003) conducted a field study to determine the effect of different irrigation scheduling methods and the recommended IFAS N rate and they found that higher marketable and total yields were obtained at 66% ET_C.

There was interaction ($P< 0.01$) between irrigation and N rates on watermelon marketable number and yield (Table 5-9 and Fig 5-10). Watermelon marketable numbers and yield were lower at low irrigation rate when fertilized with the recommended N rate compared with the recommended (I2) and highest (I3) irrigation rates. On the other hand, marketable number and yield was not different among irrigation rates when grown at the higher N rate. This indicates a link between low irrigation and low yield at the recommended fertilizer rate indicating that management of irrigation is important at lower N rates. These data would also support the biomass accumulation data collected at harvest (75 DAT) where biomass increased with increased irrigation. Using 66% of crop ET_C rate reduced watermelon growth and yield under the recommended N rate while it has no effect on watermelon yield under the higher N rate. Watermelon marketable yield ranged between 41,410 and 58,900 kg ha^{-1} and were comparable to watermelon yield

(53,813 kg ha^{-1}) grown on sandy soil using IFAS fertilizer and irrigation recommendation reported by Simonne., et al 2002b.

5.2.5 Conclusions

At harvest, N concentrations in bell pepper was not affected by either irrigation or N rates therefore it is recommended to use 66% ET_C and 100% IFAS recommended N rates since N was available for plant uptake regardless of irrigation or N rates. For watermelon crop with deeper root zone it is recommended to use 100% ET_C and 100% IFAS recommended N rates since N availability for plant uptake was greater under this combination. Total bell pepper and watermelon biomass accumulation was higher with the higher N rate compared to the recommended N rate. Higher values of N taken up by the crops were accumulated in fruits compared to other plant parts where N taken up by the plant was reallocated in the fruits.

5.3. General Conclusions

Since fruit yield is most important for both crops, a combination of irrigation and N rates that would give optimum yield with minimum leaching of nutrients and water should be selected from this study. As N rate increased, N concentration, biomass and N accumulation increased for both bell pepper and watermelon crops while increasing irrigation rates decrease N concentration, biomass and N accumulation for both crops suggesting N leaching occurred during fruit development. For shallow rooted crops such as bell pepper a combination of 66 % ET_C and 100% IFAS recommended N rate should be recommended during fruit development growth stage (53DAT) and at harvest (75DAT) since it gave the highest N concentrations of N in leaves, stems and fruits.

For deep rooted crops such as watermelon, a combination of 100% ET_C and 100% IFAS recommended N rate should be recommended since it gave the highest N concentrations during fruit development growth stage (53DAT) and at harvest (75DAT) in leaves, stems and fruits.

Data from this study suggest that there is need to update IFAS recommendation of irrigation rates. This should be based on stage of crop growth, implying adjusting the crop factor as a function of stage of crop growth. However, application of a higher rate of N than the recommended rate (N1) at different stages of crop development indicated that the extra N applied might end up being leached below the root zone. Enough N was available for plant uptake, growth, and optimum yield at the IFAS recommended N rate (N1), for both bell pepper and watermelon crops.

Table 5-1. Main effects of irrigation and N rates on N concentration of different parts of bell pepper and watermelon plants sampled during fruit development stage of growth (53DAT).

Treatments	Bell pepper			Watermelon	
	Leaves	Stems	Fruits	Leaves	Stems
	………………………… g kg^{-1} …………………………				
Irrigation (I)					
I1[Z]	46.43	28.39	30.28	38.78	20.60
I2	42.04	26.76	29.68	40.33	21.12
I3	42.89	24.11	30.55	37.54	19.58
Significance[X]	*	NS	NS	NS	NS
I1 vs. I2and I3	**	NS	NS	NS	NS
I2 vs. I3	NS	NS	NS	*	NS
Nitrogen (N)					
N1[Y]	38.05	21.43	29.02	38.99	20.19
N2	49.53	31.41	31.32	38.78	20.67
Significance	***	***	NS	NS	NS
Interaction I*N	NS	NS	NS	NS	NS

[Z] Irrigation rates I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration rates (ETc), respectively. Irrigation levels effects were compared to each other with contrasts.
[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.
[X] NS, *, **, *** Main effects and interactions were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

Table 5-2. Mean biomass accumulation of different parts of bell pepper and watermelon plants for each irrigation rate and N application rate sampled during fruit development stage of growth (53DAT)

Treatments	Bell pepper				Watermelon		
	Leaves	stems	fruits	Total	Leaves	Stems	Total
	……… kgha^{-1} ………						
N1[Y]							
I1[Z]	324.15ab[X]	232.73a	352.68a	909.60a	315.29ab	134.99ab	450.28ab
I2	335.58a	230.55a	306.57a	809.90a	194.11b	105.52b	299.63b
I3	233.08b	180.28a	141.55b	554.88a	360.00a	180.31a	540.31a
N2							
I1	317.23a	201.33a	266.36a	729.15a	412.79a	209.56a	622.34a
I2	386.43a	244.55a	404.24a	934.20a	369.09a	145.44a	514.54a
I3	402.05a	260.50a	346.16a	937.78a	407.97a	198.42a	606.40a

[Z] Irrigation treatment I1, I2, and I3 are 66%. 100% and 133% of crop evapotranspiration rates (ETc), respectively. Irrigation levels effects were compared to each other with contrasts.
[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[X] Means followed by the same letter are not significantly different according to Duncan Multiple Range Test

Table 5-3. Main effects of irrigation and N rates on N accumulation of different parts of bell pepper and watermelon plants sampled during fruit development stage of growth (53DAT).

Treatments	Bell pepper	Watermelon	
	Stems	Leaves	Stems
	……………………… kg ha^{-1} ………………………		
Irrigation (I)			
I1[Z]	6.15	14.20	3.57
I2	6.27	11.18	2.61
I3	5.24	14.46	3.70
Significance[X]	NS	NS	*
I1 vs. I2and I3	NS	NS	NS
I2 vs. I3	NS	NS	**
Nitrogen (N)			
N1[Y]	4.65	11.09	2.78
N2	7.33	15.46	3.81
Significance	***	*	**
Interaction I*N[X]	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration rates (ETc), respectively. Irrigation levels effects were compared to each other with contrasts.
[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[X] NS, *, **, *** Main effects and interactions were not significant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively, according to F tests.

Table 5-4. Mean N accumulation of bell pepper leaves and fruits plants sampled during fruit development stage of growth (53DAT) as affected by irrigation and N application rates.

Treatments	Leaves	Fruits
	……………………kg ha^{-1}……………………………	
N1[Y]		
I1[Z]	13.43a[X]	9.59a
I2	12.37a	8.30ab
I3	8.56a	4.48b
N2		
I1	16.38a	8.77a
I2	18.15a	12.50a
I3	19.92a	10.16a

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration rates (ETc), respectively.
[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[X]Means followed by the same letter are not significantly different according to Duncan Multiple Range Test

Table 5-5. Main effects of irrigation and N rates on N concentration of different parts of bell pepper and watermelon plants sampled at harvest (75DAT).

Treatments	Bell pepper			Watermelon	
	Leaves	stems	Fruits	Leaves	stems
	……………………………… g kg^{-1} ………………………				
Irrigation (I)					
I1[Z]	32.29	19.28	25.36	37.05	15.13
I2	31.31	19.25	23.85	42.19	19.63
I3	34.32	20.49	24.59	34.15	14.93
Significance [X]	NS	NS	NS	NS	*
I1 vs. I2and I3	NS	NS	NS	NS	NS
I2 vs. I3	NS	NS	NS	*	*
Nitrogen (N)					
N1 [Y]	31.17	19.53	25.31	41.13	18.67
N2	34.12	19.83	23.89	34.46	14.46
Significance	NS	NS	NS	*	**
Interaction I*N	NS	NS	NS	NS	NS

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration rates (ETc), respectively.

[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.

[X] NS, *, **, *** Main effects and interactions were not significant or significant at P ≤ 0.05, 0.01, or 0.001 respectively, according to F tests.

Table 5-6. Mean biomass accumulation of different parts of bell pepper and watermelon plants for each irrigation and N application rate sampled at harvest (75DAT)

Treatments	Bell pepper				Watermelon		
	Leaves	Stems	Fruits	Total	Leaves	Stems	Total
	…………………………….. kg ha^{-1}……………………………………						
N1 [Y]							
I1 [Z]	597.50a [X]	434.83a	1509.25a	2091.50a	496.05a	468.33a	964.37a
I2	468.15a	423.68a	1111.00a	2002.75a	217.04a	229.98b	447.01b
I3	427.85a	356.55a	1174.25a	1958.75a	293.36a	261.67b	555.03b
N2							
I1	713.33a	509.75a	1615.25a	2838.25a	351.39b	352.83a	704.21b
I2	817.28a	584.10a	1768.25a	3169.50a	416.27b	448.91a	865.18ab
I3	673.30a	469.55a	1689.50a	2832.25a	560.78a	441.14a	1001.93a

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration (Etc), respectively. Irrigation

[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates respectively.

[X]Means followed by the same letter are not significantly different according to Duncan Multiple Range Test

Table 5-7. Main effects of irrigation and N rates on N accumulation of different parts of bell pepper and watermelon plants sampled at harvest (75DAT).

Treatments	Bell pepper			Watermelon	
	Leaves	Stems	Fruits	Leaves	Stems
	…………………………… g kg^{-1}………………				
Irrigation (I)					
I1[Z]	21.02	9.04	33.52	16.69	6.41
I2	20.09	9.62	35.21	12.80	6.36
I3	18.64	8.38	34.89	14.79	4.94
Significance [X]	NS	NS	NS	NS	NS
I1 vs. I2and I3	NS	NS	NS	NS	NS
I2 vs. I3	NS	NS	NS	NS	NS
Nitrogen (N)					
N1[Y]	15.06	7.87	28.43	13.89	5.93
N2	24.77	10.15	40.64	15.63	5.88
Significance	**	*	**	NS	NS
Interaction I*N [X]	NS	NS	NS	NS	**

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration rates (ETc), respectively. Irrigation levels effects were compared to each other with contrasts.
[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[X] NS, *, **, *** Main effects and interactions were not significant or significant at $P \leq$ 0.05, 0.01, or 0.001 respectively, according to F tests.

Table 5-8. Mean nitrogen accumulation for each irrigation rate as a function of nitrogen application rate of different parts of watermelon plants sampled at harvest (75DAT)

Treatments & Plant part	Watermelon plant part		
	Leaves	Stems	Fruits
	……………….kg ha^{-1}……………………..		
N1 [Y]			
I1 [Z]	21.28a	8.36a	20.58
I2	9.36a	4.81a	29.27
I3	11.02a	4.62a	28.43
N2			
I1	12.09a	4.46b	28.68
I2	16.23a	7.91a	23.92
I3	18.55a	5.27ab	27.53

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of crop evapotranspiration rates (ETc), respectively. Irrigation levels effects were compared to each other with contrasts.

[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.

.[X]Means followed by the same letter are not significantly different according to Duncan Multiple Range Test.

Table 5-9. Mean yield for each irrigation and N application rate at harvest of drip-irrigated bell pepper and watermelon crops

Treatments	Bell pepper							Watermelon	
	Fancy Weight	US#1 Weight	US#2 Weight	Blossom End Rot Weight	Other Cull Weight	Total yield	Market Yield	Marketable. No.	Marketable. Weight
	………………………………………………………..ton ha^{-1}………………………								ton ha^{-1}
N1 [Y]									
I1 [Z]	18.69a[X]	8.14 b	3.42 a	1.45 b	0.41b	30.65a	30.25a	4449b	41.41b
I2	7.49 c	12.15a	2.37ba	2.02 a	0.58a	22.58b	22.01b	6386a	58.90a
I3	10.15b	6.66 b	2.75a	1.62 b	0.43ab	20.00b	19.57b	6458a	57.21a
N2									
I1	9.53 c	10.44a	1.89 b	1.42ab	0.27b	22.13b	21.85b	6530a	57.70a
I2	21.56a	8.29 b	3.29 a	1.73a	0.42a	33.55a	33.14a	4951a	48.12a
I3	17.37b	10.32a	3.30 a	0.94 b	0.36ab	31.35a	30.99a	5812a	55.38a

[Z] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% crop evapotranspiration rates (ETc), respectively
[Y] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[X] Means followed by the same letter are not significantly different according to Duncan Multiple Range Test

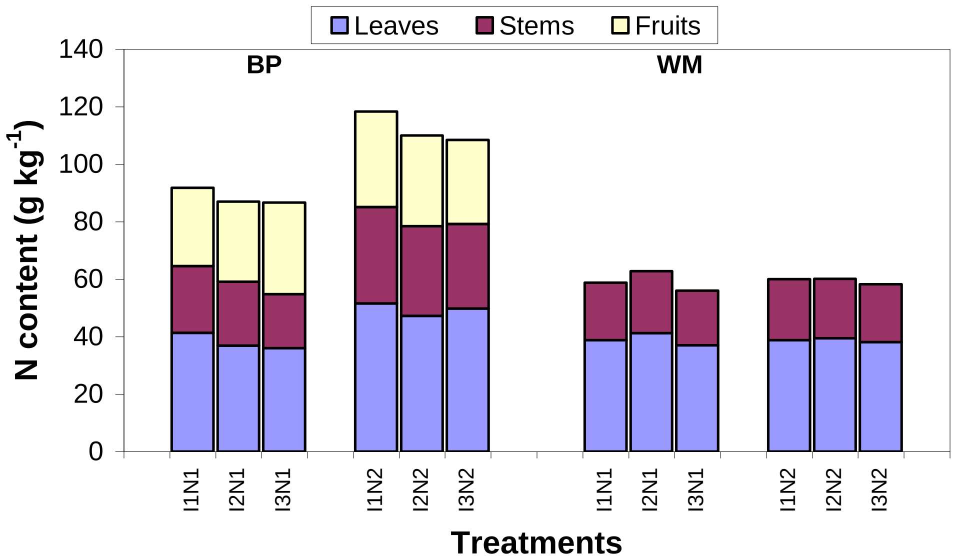

Figure 5-1. Nitrogen concentration partioning for bell pepper (BP) and watermelon (WM) plants fertilized with 100% and 125 % of IFAS recommended N rate as affected by irrigation rates at 53 DAT.

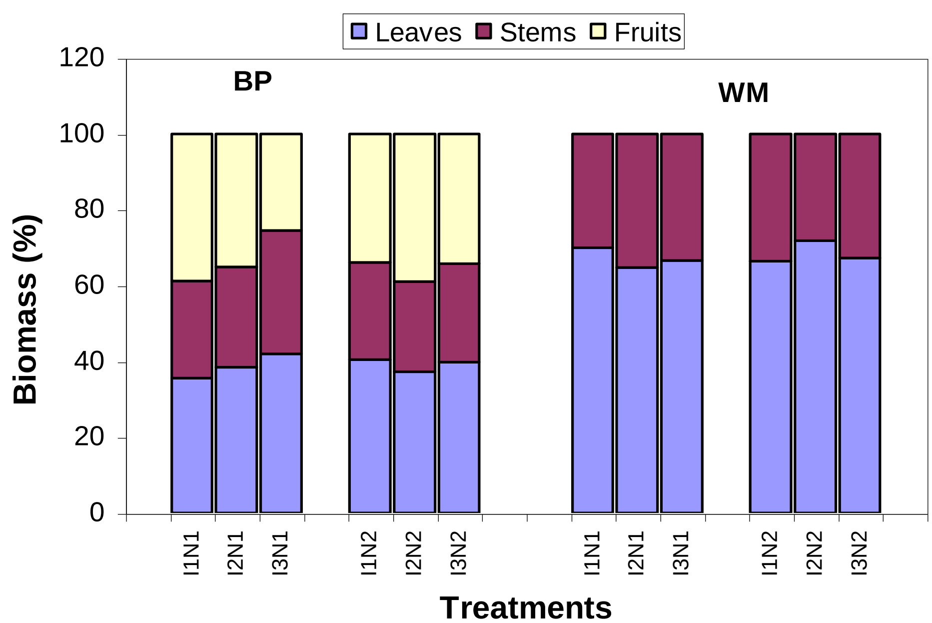

Figure 5-2. Biomass partioning for bell pepper (BP) and watermelon (WM) plants fertilized with 100 % (N1) and 125 % (N2) of IFAS rate as affected by irrigation rates at 53 DAT.

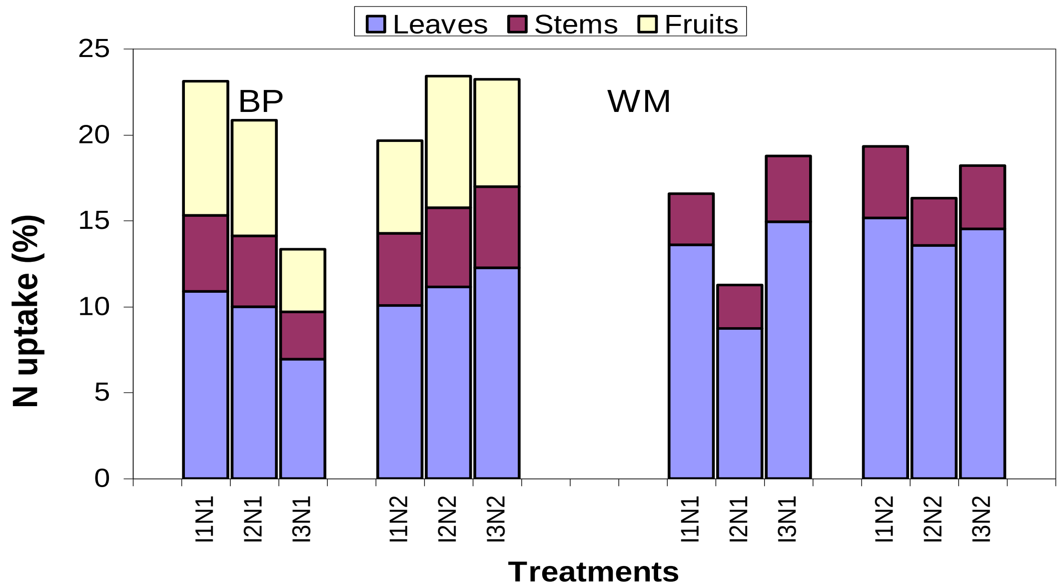

Figure 5-3. Percent uptake of applied nitrogen by bell pepper and watermelon crops during fruit development (53 DAT) as affected by N rate for each irrigation rate based on N applied prior to sampling.

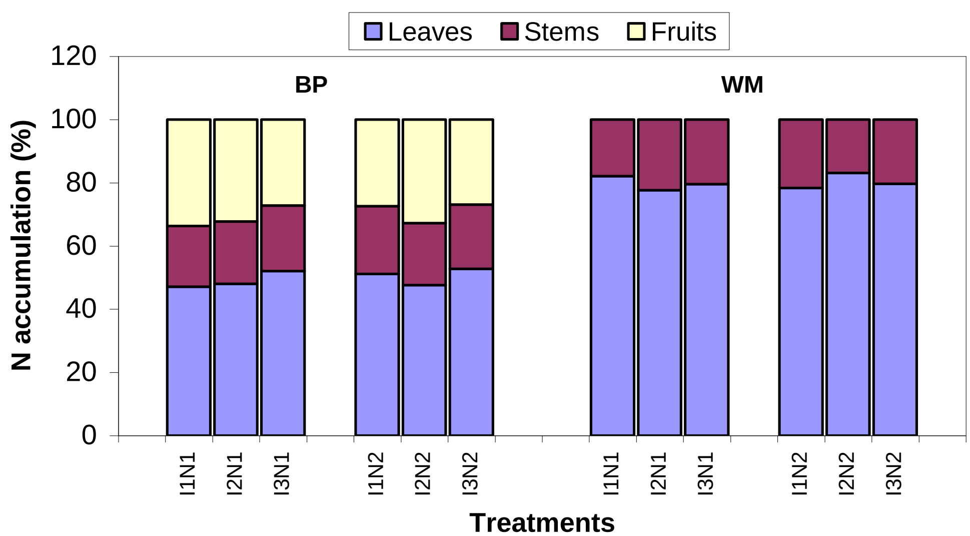

Figure 5-4. Nitrogen accumulation partioning for bell pepper (BP) and watermelon (WM) plants fertilized with 100% (N1) and 125 % (N2) of IFAS rate as affected by irrigation rates at 53 DAT

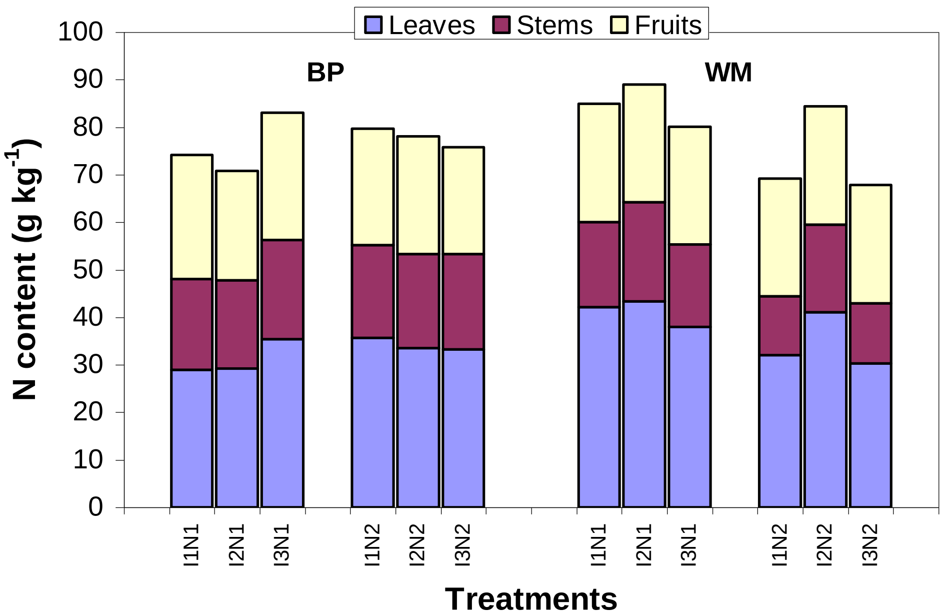

Figure 5-5. Nitrogen concentration portioning for bell pepper (BP) and watermelon (WM) plants fertilized with 100% and 125 % of IFAS rate as affected by irrigation rates at 75 DAT.

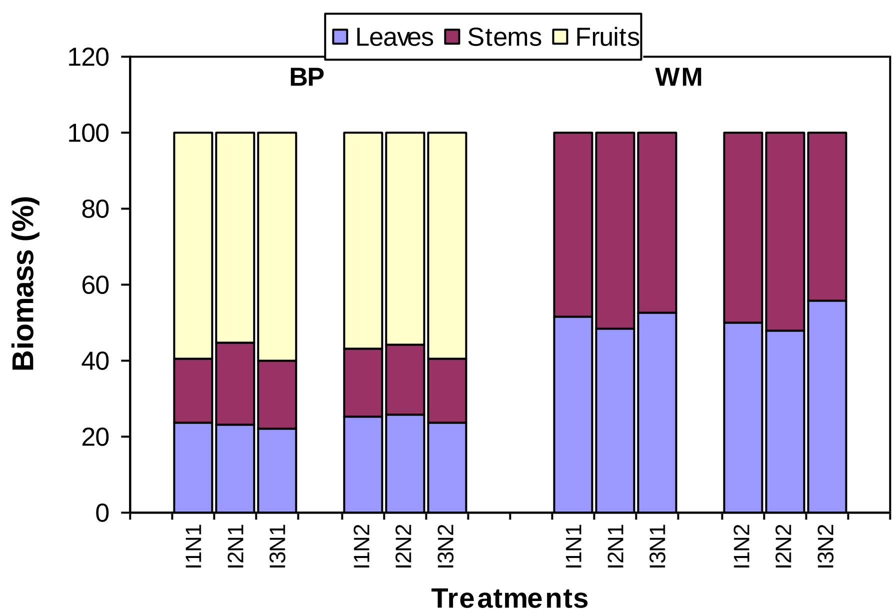

Figure 5-6. Biomass partioning for bell pepper (BP) and watermelon (WM) plants fertilized with 100% and 125 % of IFAS rate as affected by irrigation rates at 75 DAT.

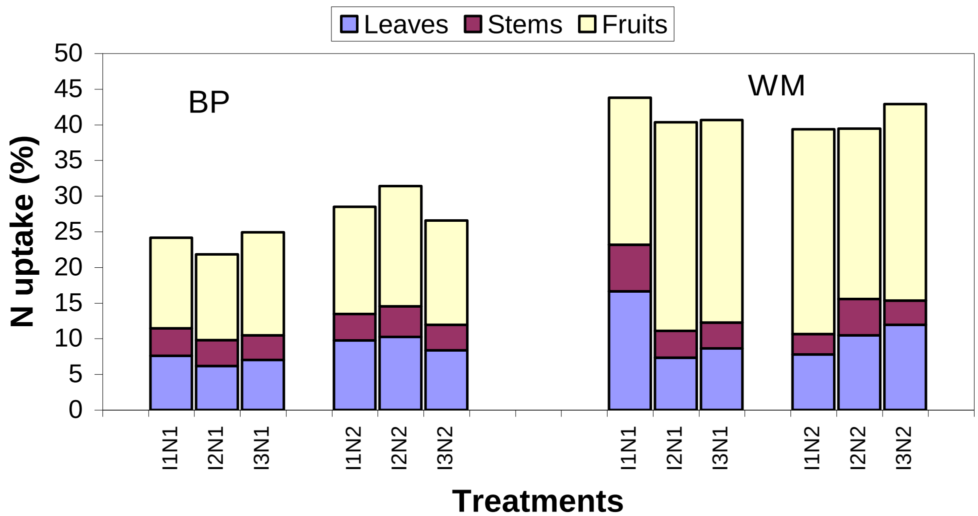

Figure 5-7. Percent uptake of applied nitrogen by bell pepper and watermelon crops at harvest (75DAT) as affected by N rate for each irrigation rate based on N applied prior to sampling.

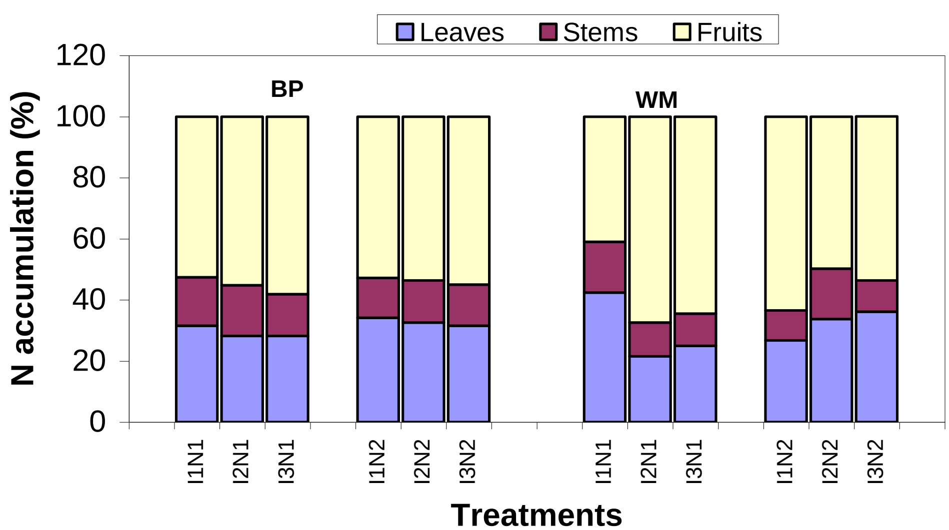

Figure 5-8. Nitrogen accumulation partioning for bell pepper (BP) and watermelon (WM) plants fertilized with 100% (N1) and 125 % (N2) of IFAS rate as affected by irrigation rates at 75 DAT.

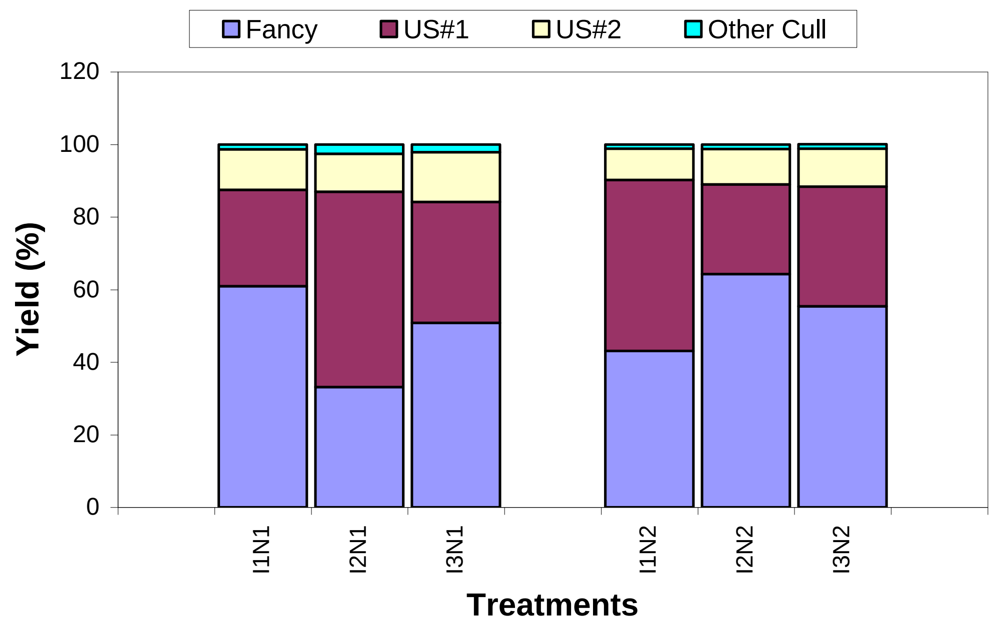

Figure 5-9. Yield components partitioning for bell pepper crop fertilized with 100% (N1) and 125 % (N2) of IFAS rate as affected by irrigation rates at 75 DAT.

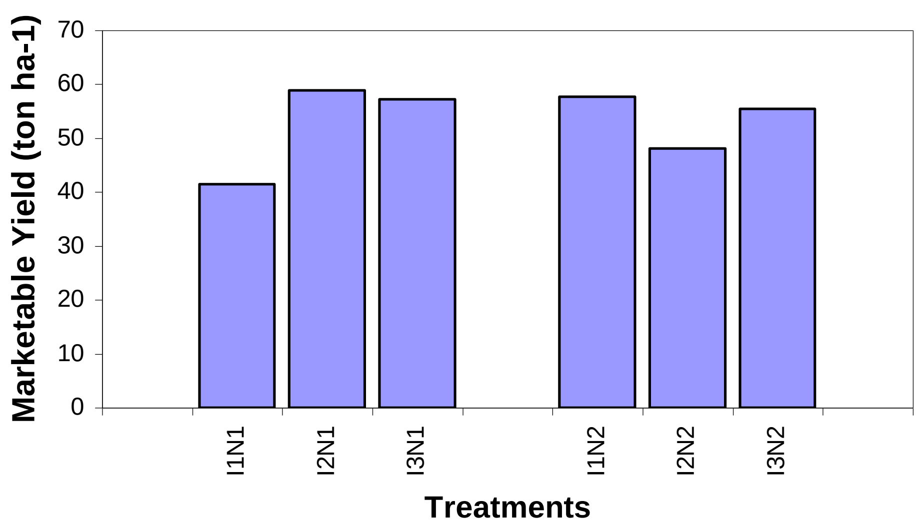

Figure 5-10. Watermelon crop yield fertilized with 100% (N1) and 125 % (N2) of IFAS rate as affected by irrigation rates at 75 DAT.

CHAPTER 6
SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH

Water movement is one of the major processes affecting solute transport in the soil profile. Because of water infiltration, evapotranspiration, variations in solute mobility, and interactions with the soil matrix, concentration and composition of the soil solution change over time. Contamination of water supplies by fertilizer nutrients is an increasingly important problem in Florida. Irrigation and nitrogen fertilizer source are the two most important factors affecting NO_3-N movement, or leaching, to surface and groundwater in certain parts of the state. Therefore, understanding the impact of current irrigation and fertilization practices under field conditions on crop yield and loss of nutrients from the root zone is necessary in order to develop best management practices (BMPs) for water, fertilizers, and irrigation application rates to crops. The BMPs should aim at optimizing crop yield while minimizing water and nutrients leaching below the root zone.

The study summarized in this chapter provides information on the effects of irrigation and N fertilization rates on movement and distribution of soil water, Br, NO_3-N, HN_4-N, and K in the soil profile of shallow rooted crop (bell pepper) and a deep rooted crop (watermelon) grown on Florida sandy soils with plastic mulched and drip irrigated soil beds. Data also provide-information on growth response of bell pepper and watermelon crops to the tested treatments in terms of biomass accumulation, N accumulation and crop yield. Results are summarized for selected time periods after transplanting.

6.1 Soil Water and Nutrient Movement

The first objective of this study was to determine the leaching potential of N and K using calculated water flux with increased irrigation and N rates over time and to test the hypothesis that applying irrigation rates equal to or greater than crop evapotranspiration (ET_C) cause nutrient leaching below the crop root zone. Potential leaching of NO_3-N, NH_4-N, and K as affected by irrigation and N rates was not measured but was estimated over time using calculated water fluxes.

6.1.1 Soil Water and Nutrient Movement during Crop Establishment

One day after the first fertilizer injection (1DAFFI), soil moisture content was above FC and was greater than the depth of available water at all soil depths regardless of water amounts used during fertilizer injection for bell pepper and watermelon crops establishment. Therefore, water was moving below the root-zone due to high water flux under both crops. The effect of calculated water fluxes on solute transport was confirmed by soil Br data where an average of 49% of applied soil Br remained in the soil profile in all plots for the bell pepper and watermelon crops, just one day after Br injection.

Most soil NO_3-N (60-66%) remained within the root zone at 1DAFFI under bell pepper crop compared to watermelon crop where less than 10% of soil NO_3-N remained within the root zone. Note that more water was applied to the watermelon crop compared to the bell pepper crop. Increasing N rate increased the percentage of NH_4-N in the root-zone but not for the watermelon crop due to differences in leaching potential.

Irrigation rates had no effect on percentage of NH_4-N remaining in the soil profile for a given N rate for both crops. However, a lower percentage of NH_4-N remained in the soil profile for both crops than NO_3-N due to nitrification of NH_4^+. Less NH_4-N remained in the soil profile for the watermelon crop compared to the bell pepper crop due to more leaching in the watermelon plots caused by more irrigation water applied. Increasing N rates tended to increase NH_4-N in the root-zone. Because of the shallower root-zone, more soil K moved below the root zone of bell pepper (48%) compared to watermelon (12%) at 1DAFF. Higher percentage of K remained in the soil profile than NO_3-N and NH_4-N.

6.1.2 Soil Water and Nutrient Movement during Flowering.

During flowering (22DAFFI), soil water content and water flux increased with increasing irrigation rates. Therefore, water moved out of bell pepper root zone in less than one day and about 1% of applied Br was left in the soil profile. However, under watermelon crop, less downward movement of water occurred because soil water content was less or equal to FC at all irrigation rates.

Soil NO_3-N had moved below bell pepper root zone and amount of soil NO_3-N leached below the root zone increased with increasing N rate. Almost all soil NO_3-N remained within watermelon crop root zone. Soil NH_4-N remained within the root zones for both crops and the amounts of soil NH_4-N in the root zones increased with increasing N rate. Soil K remained within the root zones of both crops.

6.1.3 Soil Water and Nutrient Movement during Harvest.

At harvest (60DAFFI), irrigation water was still moving soil nutrients such as NO_3-N below the root-zone. The more water applied the faster the water flux and the more water leached below the crop root-zone. By this time all the Br had essentially leached out of the soil profile (0-90 cm).

There was little soil NO_3-N remaining in the root zone for bell pepper, however, the amount of soil NO_3-N increased with increased N rate while under watermelon the amount of soil NO_3-N was the same for both N rates. More soil NH_4-N was remaining in the root zone with the higher N rate for bell pepper compared to watermelon crop. High amounts of K were in the root-zone for both crops compared to NO_3-N and NH_4-N. More soil K had moved below bell pepper root zone compared to watermelon crop. Like soil NH_4-N, in general, there was no distinct trend for the amount of K remaining in the soil profile as affected by irrigation rates. At harvest a combination of 66% ET_C irrigation rate and 100% N IFAS recommendation were adequate for the bell pepper crop. For the watermelon crop a combination of 100% ET_C irrigation rate and 100% N IFAS recommendation were adequate. However, if 66% ETc irrigation rate does not affect crop yield then the crop factors (CF) used in equation 3.1 must be too high and should be revised.

6.2 Biomass Accumulation, Nitrogen Accumulation, and Yield

The second objective of the study was to quantify effects of irrigation and N rates on bell pepper and watermelon biomass accumulation and yield to test the hypothesis that increased N rates increase biomass accumulation and crop yields. The third objective of the study was to measure N uptake and accumulation as affected by irrigation and N rates at different stages of growth to test the hypothesis that increased irrigation rates reduce N-use efficiency.

6.2.1 Biomass and Nitrogen Accumulation during Fruit Development

During fruit development (53 DAT), bell pepper biomass accumulation was reduced under the recommended N rate (N1) as irrigation rates increased but was not different at any irrigation rate for plants fertilized with the higher N rate (N2). This implies that even if leaching was taking place there was enough N in solution for plant uptake in N2 plots regardless of irrigation rate.-Watermelon biomass accumulation was higher with the higher N rate compared to the recommended N rate. Higher values of N taken up by the crops were accumulated in fruits compared to other plant parts where N taken up by the plant was reallocated to the fruits.

Increasing N rates increased N concentrations and accumulation while increased irrigation rates reduced N concentration and accumulation in bell pepper. Increasing N rates had no effect on N concentration and increased N accumulation in watermelon. Applying 100% ET_C crop resulted in higher values of N concentrations compared with 66% ET_C. However, applying 133% ET_C reduced N concentration. Most of the N taken up by the crops accumulated in leaves compared to other plant parts where maximum uptake occurs during fruit development stage of growth.

6.2.2 Biomass, Nitrogen Accumulation and Yield at Harvest

At harvest (75 DAT), total bell pepper and watermelon biomass accumulation was higher with the higher N rate compared to the recommended N rate but not affected by irrigation rate. Nitrogen effects on total biomass at harvest were due to increased fruit biomass accumulation with increased N rate. Under the recommended N rate (N1), stems and the whole plant biomass accumulation for watermelon crop was greater with the lowest irrigation rate.

Irrigation rates had no effect on N accumulation in the leaves, stems and fruits of bell pepper plant at harvest. For the watermelon crop, irrigation rates had no effect on N accumulated in the leaf, while increased N rates increased N accumulated in stem. Higher values of N taken up by the crops were accumulated in fruits compared to other plant parts where N taken up by the plant was reallocated to the fruits

Bell pepper yield increased as N rate increased where highest values of total, marketable and fancy yields was occurred with 125% N rate under the 100%ET_C irrigation rate. A reduction in blossom end rot (BER) occurred as the N fertilizer rate increased leading to higher yields. Yield reduction at the recommended N rates by increased irrigation would indicate the potential leaching of N at increased irrigation rates

Watermelon marketable numbers and yield were lower at low irrigation rate (66%ET_C) when fertilized with the 100%IFAS recommended N rate compared with 100% and 133% ET_C irrigation rates. However, under the higher N rate (125%IFAS recommended N rate) marketable number and yield was not different among irrigation rates. This indicate a link between low irrigation and low yield at the recommended fertilizer rate indicating that management of irrigation is important at lower N rates

6.3 Conclusions and Recommendations

At the beginning of the study the amount of water and nutrients applied for crop establishment were much more than the crop need. Therefore, most of the water and nutrients applied, leached below the root-zone which is not the intent of fertigation. In particular, too much fertilizer was applied to the bell pepper crop and too much water was applied to the watermelon crop. At this stage of crop growth, less water and nutrients should be applied since the plants are too small to effectively take up applied water and nutrients. Attention should also be paid to nutrient concentration in the profile before initiation of fertigation.

For cations such as NH_4^+ and K^+ the irrigation treatments tended to concentrate the solutes in the root-zone. A large percentage of NH_4^+ remained in the root-zone compared to below the root-zone due to sorption to soil particles. Most of the K remained in the root-zone for both crops due to sorption of K in the soil. However, due to more water that was applied to the watermelon plots less percentage of K was found in the watermelon plots compared to the bell pepper plots. Therefore, more soil K had moved below the root zone for bell pepper compared to the watermelon crop.

During flowering, less water should be applied to both crops, because all irrigation treatment leached mobile solutes such as Br and NO_3-N out of the root-zone. Soil K retained in the soil more than NH_4-N or NO_3-N, therefore less K should be applied to both crops. It is recommended to use 66% ET_C and 100% IFAS recommended N rate for shallow rooted crops such as bell pepper because of the potential leaching to maximize crop growth and minimize leaching losses. On the other hand, for deep rooted crops like watermelon it is recommended to use either 66% or 100% ET_C irrigation rates and 100% IFAS recommended N rate to maximize crop yield since there is less potential for nutrient leaching.

At harvest, for bell pepper it is recommended to use 66% ET_C and 100% IFAS recommended N rates since N was available for plant uptake regardless of irrigation or N rates. For watermelon crop with deeper root zone it recommended to use 66% or 100% ET_C irrigation rate and 100% IFAS recommended N rates since N availability for plant uptake was adequate under these combinations.

The results of these studies suggest that there is need to update IFAS recommendation of irrigation rates based crop requirement and crop factor for different stages of plant growth. Application of higher rates of N than the recommended affected biomass accumulation of leaves at all stages of pepper growth and could indicate that more N than needed was available for plant uptake, growth, and yield.

6.4 Future Research Considerations

Additional conclusions, considerations, and recommendations were made from this study regarding the experimental methods and are as follows:

1. It is not recommended to apply 20% of the total fertilizer application rate for bell pepper as preplant. This resulted in 60 and 40% leaching losses as NO_3-N and NH_4-N, respectively, below the root zone.

2. Using different volumes of water during the injection of different fertilizer rates can cause significant changes in soil solution concentration. Using nitrogen fertilizer lines to deliver irrigation water during crop establishment stage resulted in different amounts of water being applied to different plots when water was supposed to be applied uniformly to all plots.

3. Using different drip tapes to deliver different irrigation rates without aligning the emitters for these drip tapes with the emitters for the drip tape used to deliver specific fertilization rate might have caused high variability between replicates of the same treatments.

4. An observation that 66% ET_C irrigation rate does not affect crop yield, implies that the crop factors (CF) used to calculate irrigation rates must be too high. A crop supplied with water at 66% Etc should be under water stress. Therefore, the currently recommended crop factors for both crops should be revised

5. An observation made during these studies is that when applying K fertilizer based on soil test, it is important to take deeper soil samples (more than 15 cm) especially when deep rooted crops are planted.

6. For all nutrients, the residual concentration in the soil profile should be considered before applying preplant fertilizers.

7. It appears that much more fertilizers are recommended for the bell pepper crop compared to the watermelon crop at all stages of crop development. These recommendations should be revised.

8. As a result of these studies it is recommended that Br be applied (as a tracer for water and nutrient movement) with each fertilizer injection for better monitoring of water and fertilizer movement.

9. Soil sampling should be done more frequently at least to assess water content as a function of time during the growing season of both cops.

10. The most important category of crop yield should be used to determine the BMPs, since farmers are more interested in yield. However, the crop yield category should be one that optimizes yield while minimizing water and nutrient leaching below the root zone.

APPENDIX A
RECOMMENDED FERTILIZER INJECTION SCHEDULE

Table A-1. IFAS recommended fertilizer injection schedule for N and K for bell pepper and watermelon crops grown on sandy soils testing very low in K.

Crop	Development stage	Weeks after transplanting	Injection rate ($kg\ ha^{-1}\ week^{-1}$)	
			N	K_2O
Bell pepper	1	1-2	12	12
	2	3-4	16	16
	3	5-11	20	20
	4	12	16	16
	5	13	12	12
Watermelon	1	1-2	8	8
	2	3-4	12	12
	3	5-8	20	20
	4	9-11	12	12
	5	12-13	8	8

Source: vegetable production for Florida (Olson and Simonne, 2006)

APPENDIX B
WEEKLY AND CUMULATIVE AMOUNTS OF FERTILIZERS APPLIED AS PREPLANT AND INJECTED

Table B-1. Calculation of weekly injected and the cumulative amounts of fertilizers for the 100% IFAS recommended N rate (N1) applied to the bell pepper crop.

Injection Date	Days after transplanting (DAT)	NH_4NO_3 (kg/87.8 m)	KNO_3 (kg/87.8m)	Weekly Injected NO_3-N (kg ha^{-1})	Cumulative Applied NO_3-N (kg ha^{-1})	Weekly Injected NH_4-N (kg ha)	Cumulative Applied NH_4-N (kg ha^{-1})	Injected N (kg ha^{-1})	Cumulative Applied N	Injected K (kg ha^{-1})	Cumulative Applied K (kg ha^{-1})
		Preplant			8.00		12.00		20.00		57.00
3/29/2002	0	Transplanting									
4/4/2002	7										
4/11/2002	14	0.15	0.08	2.64	**11.00 Z**	1.85	**14.00**	4.49	24.00	2.36	**60.00**
4/18/2002	21	0.52	0.29	9.16	20.00	6.38	20.00	15.55	40.00	8.25	68.00
4/25/2002	28	0.52	0.29	9.16	29.00	6.38	27.00	15.55	55.00	8.25	76.00
5/2/2002	35	0.82	0.72	17.00	**46.00**	10.08	**37.00**	27.11	82.00	20.63	**97.00**
5/9/2002	42	0.82	0.72	17.00	63.00	10.08	47.00	27.11	109.00	20.63	117.00
5/16/2002	49	0.82	0.72	17.00	80.00	10.08	57.00	27.11	**136.00**	20.63	138.00
5/23/2002	56	0.82	0.72	17.00	97.00	10.08	67.00	27.11	163.00	20.63	159.00
5/30/2002	63	0.82	0.72	17.00	**114.00**	10.08	**77.00**	27.11	190.00	20.63	**179.00**
6/6/2002	77	0.82	0.72	17.00	131.00	10.08	87.00	27.11	**217.00**	20.63	200.00
6/13/2002	84	Harvest									
			Total Injected		123		75		198		142
			Total Applied		131		87		217		200

[Z] Bold numbers were used to calculate % recovery from the soil or the crop

Table B-2. Calculation of weekly and the cumulative injected amounts of fertilizers for the 125% IFAS recommended N rate (N2) applied to the bell pepper crop.

Injection Date	Days after transplanting	NH_4NO_3 (kg/87.8 m)	KNO_3 (kg/87.8m)	Weekly Injected NO_3-N (kg ha^{-1})	Cumulative Applied NO_3-N (kg ha^{-1})	Weekly Injected NH_4-N (kg ha$^{-1)}$	Cumulative Applied NH_4-N (kg ha^{-1})	Injected N (kg ha^{-1})	Cumulative Applied N	Injected K (kg ha^{-1})	Cumulative Applied K (kg ha^{-1})
		Preplant			8.00		12.00		20.00		57.00
3/29/2002	0	Transplanting									
4/4/2002	7										
4/11/2002	14	0.20	0.08	3.31	**11.00** [z]	2.52	**15.00**	5.83	26.00	2.36	**60.00**
4/18/2002	21	0.65	0.29	10.84	22.00	8.06	23.00	18.89	45.00	8.25	68.00
4/25/2002	28	0.65	0.29	10.84	33.00	8.06	31.00	18.89	64.00	8.25	76.00
5/2/2002	35	1.06	0.72	20.09	**53.00**	13.13	**44.00**	33.19	97.00	20.63	**97.00**
5/9/2002	42	1.06	0.72	20.09	73.00	13.13	57.00	33.19	130.00	20.63	117.00
5/16/2002	49	1.06	0.72	20.09	93.00	13.13	70.00	33.19	**164.00**	20.63	138.00
5/23/2002	56	1.06	0.72	20.09	113.00	13.13	83.00	33.19	197.00	20.63	159.00
5/30/2002	63	1.06	0.72	20.09	133.00	13.13	96.00	33.19	230.00	20.63	179.00
6/6/2002	77	1.06	0.72	20.09	**153.00**	13.13	**109.00**	33.19	**263.00**	20.63	**200.00**
6/13/2002	84	Harvest									
		Total Injected			145.00		97.36		242.75		142
		Total Applied			153.00		109.00		263.00		200

[z] Bold numbers were used to calculate % recovery from the soil or the crop

Table B-3. Calculation of weekly and the cumulative injected amounts of fertilizers for the 100% N rate applied to the watermelon crop.

Injection Date	Days after transplanting	NH_4NO_3 (kg/155m)	KNO_3 (kg/155m)	Weekly injected NO_3-N (kg ha^{-1})	Cumulative applied NO_3-N (kg ha^{-1})	Weekly injected NH_4-N (kg ha^{-1})	Cumulative applied NH_4-N (kg ha^{-1})	Injected N (kg ha^{-1})	Cumulative Applied N	Injected K (kg ha^{-1})	Cumulative Applied K (kg ha^{-1})
		Preplant	0		15.00		11.00		26.00		48.00
3/29/2002	0	Transplanting									
4/4/2002	7										
4/11/2002	14	0.09	0.26	1.36	**16.00** [Z]	0.42	11.50	1.79	27.99	2.80	**50.68**
4/18/2002	21	0.51	0.58	4.51	21.00	2.40	13.90	6.92	34.91	6.28	56.97
4/25/2002	28	0.51	0.58	4.51	26.00	2.40	16.30	6.92	41.83	6.28	63.26
5/2/2002	35	0.92	1.08	8.22	**34.00**	4.27	**20.58**	12.51	54.34	11.73	**75.00**
5/9/2002	42	1.28	1.51	11.50	46.00	5.97	26.55	17.49	71.83	16.44	91.46
5/16/2002	49	1.28	1.51	11.50	58.00	5.97	32.52	17.49	**89.32**	16.44	107.92
5/23/2002	56	1.28	1.51	11.50	69.00	5.97	38.49	17.49	106.81	16.44	124.38
5/30/2002	63	0.77	0.90	6.90	76.00	3.60	42.09	10.52	117.33	9.81	134.2
6/6/2002	77	0.77	0.90	6.90	**83.00**	3.60	**45.69**	10.52	**127.85**	9.81	**144.02**
6/13/2002	84	Harvest									
		Total Injected			67.00		35.00		102.00		96.00
		Total Applied			83.00		46.00		128.00		144.00

[Z] Bold numbers were used to calculate % recovery from the soil or the crop

Table B-4. Calculation of weekly injected and the cumulative amounts of fertilizers for the 125% N rate applied to the watermelon crop.

Injection Date	NH_4NO_3 (kg/155 m)	KNO_3 (kg/155 m)	Injected NO_3-N (kg ha^{-1})	Cumulative Applied NO_3-N (kg ha^{-1})	Injected NH_4-N (kg ha^{-1})	Cumulative Applied NH_4-N (kg ha^{-1})	Injected N (kg ha^{-1})	Cumulative Applied N	Injected K (kg ha^{-1})	Cumulative Applied K (kg ha^{-1})
	Preplant			15.00		11.00		26.00		48.00
3/29/2002	Transplanting									
4/4/2002										
4/11/2002	0.13	0.26	1.57	**17.00** [z]	0.62	**12.00**	2.19	28.00	2.8	**51.00**
4/18/2002	0.73	0.58	5.53	22.00	3.41	15.00	8.95	37.00	6.28	57.00
4/25/2002	0.73	0.58	5.53	28.00	3.41	19.00	8.95	46.00	6.28	63.00
5/2/2002	1.40	1.08	10.45	**38.00**	6.50	**25.00**	16.98	63.00	11.73	**75.00**
5/9/2002	1.76	1.51	13.76	52.00	8.22	33.00	22.01	85.00	16.44	92.00
5/16/2002	1.76	1.51	13.76	66.00	8.22	42.00	22.01	**107.00**	16.44	108.00
5/23/2002	1.76	1.51	13.76	80.00	8.22	50.00	22.01	129.00	16.44	124.00
5/30/2002	1.04	0.90	8.15	88.00	4.84	55.00	13.00	142.00	9.81	134..00
6/6/2002	1.04	0.90	8.15	**96.00**	4.84	**60.00**	13.00	**155.0**	9.81	**144.00**
6/13/2002	Harvest									
		Total Injected		81.00		49.00		129.0		96.00
		Total Applied		96.00		60.00		155.0		144.00

[z] Bold numbers were used to calculate % recovery from the soil or the crop

APPENDIX C
FERTILIZER INJECTION SCHEDULE

Table C-1. Recommended IFAS fertilizer injection schedule at different stages of growth for the bell pepper crop grown on sandy soil plastic mulched beds under drip irrigation.

Growth stage	Fertilization Rate	Weeks	100% N rate (N1)			125% N rate (N2)		
			N	P_2O_5	K_2O	N	P2O5	K_2O
	IFAS recommended rate		224	0	224	272	0	205
	Preplant fertilizer 13-4-13 (258 kg ha^{-1})		34	10	34	34	10	34
	Injection rate kg $ha^{-1}day^{-1}$	daily	0.48		0.32	0.60		0.32
Stage1	Adjusted rates	1	0.00		0.00	0.00		0.00
		2	3.36		2.24	4.20		2.24
		Total1	3.36		2.24	4.20		2.24
Stage 2	1.68 kg N and 1.12 kg K2O ha-1day-1	daily	1.68		1.12	2.10		1.12
		3	11.76		7.84	14.70		7.84
		4	11.76		7.84	14.70		7.84
		Total2	23.52		15.68	29.40		15.68
Stage 3	2.80 kg N or K_2O $ha^{-1}day^{-1}$	daily	2.80		2.80	3.50		2.80
		5	19.60		19.60	24.50		19.60
		6	19.60		19.60	24.50		19.60
		7	19.60		19.60	24.50		19.60
		8	19.60		19.60	24.50		19.60
		9	19.60		19.60	24.50		19.60
		10	19.60		19.60	24.50		19.60
		11	19.60		19.60	24.50		19.60
		Total3	137.20		137.20	171.50		137.20
Stage 4	2.24 kg N and1.12 kg K_2O $ha^{-1}day^{-1}$	daily	2.24		1.12	2.80		1.12
		12	15.68		7.84	19.60		7.84
		Total4	15.68		7.84	19.60		7.84
	1.68 kg N and 1.12 kg K_2O $ha^{-1}day^{-1}$	daily	1.68		1.12	1.88		1.12
Stage 5		13	11.76		7.84	13.16		7.84
		Total5	11.76		7.84	13.16		7.84
	Total Injected		192		171	238		171
	Total applied		226	10.10	205	272	10	205

Table C-2. Recommended IFAS fertilizer injection schedule at different stages of growth for the watermelon crop grown on sandy soil plastic mulched beds under drip irrigation.

Growth stage	Fertilization Rate	Weeks	100% N rate (N1)			125% N rate (N2)		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
	IFAS recommended rate		168.28	0.00	168.28	210.90	0.00	168.28
	Preplant fertilizer 13-4-13(194 kg ha^{-1})		25.24	7.85	25.24	25.24	7.85	25.24
	Injection Rate kg ha^{-1} day^{-1}							
Stage1	1.12 kg $ha^{-1}day^{-1}$							
	(N or K_2O)	daily	1.12		1.12	1.40		1.12
		1	0.00		0.00	0.00		0.00
		2	7.84		7.84	9.82		7.84
		Total- 1	7.84		7.84	9.82		7.84
Stage 2	1.68 kg $ha^{-1}day^{-1}$							
	(N or K_2O)	daily	1.68		1.68	2.52		1.68
		3	11.76		11.76	17.64		11.76
		4	11.76		11.76	17.64		11.76
		Total-2	23.52		23.52	35.28		23.52
Stage 3	2.8 kg $ha^{-1}day^{-1}$							
	(N or K_2O)	daily	2.80		2.80	3.48		2.80
		5	19.60		19.60	24.36		19.60
		6	19.60		19.60	24.36		19.60
		7	19.60		19.60	24.36		19.60
		8	19.60		19.60	24.36		19.60
		Total-3	78.40		78.40	97.44		78.40
Stage 4	1.68 kg $ha^{-1}day^{-1}$							
	(N or K_2O)	daily	1.68		1.68	2.52		1.68
		9	11.76		11.76	17.64		11.76
		10	11.76		11.76	17.64		11.76
		11	11.76		11.76	17.64		11.76
		Total-4	35.28		35.28	52.92		35.28
Stage 5	1.12 kg $ha^{-1}day^{-1}$							
	(N or K_2O)	daily	1.12		1.12	1.40		1.12
		12	7.84		7.84	9.80		7.84
		13	7.84		7.84	9.80		7.84
		Total-5	15.68		15.68	19.62		15.68
	Total Injected		160.72		160.72	215.07		160.72
	Total applied		185.96	7.85	185.96	240.31	7.85	185.96

Table C-3. Mixed amounts of fertilizers for recommended IFAS weekly fertilizer injection schedule of for bell pepper and watermelon crops.

Weeks	Injection Date	Fertilizer Source	Bell Pepper 100% N rate (N1)	Bell Pepper 125% N rate (N2)	Watermelon 100% N N rate (N1)	Watermelon 125% N rate (N2)
Transplanting	3/29/2002					
1	4/4/2002	KNO_3				
		NH_4NO_3				
2	4/11/2002	KNO_3	6.11	6.11	7.24	7.24
		NH_4NO_3	11.20	15.27	2.56	3.79
3	4/18/2002	KNO_3	21.38	21.38	16.28	16.28
		NH_4NO_3	38.69	48.87	14.53	20.68
4	4/25/2002	KNO_3	21.38	21.38	16.28	16.28
		NH_4NO_3	38.69	48.87	14.63	20.68
5	5/2/2002	KNO_3	53.45	53.52	30.38	30.38
		NH_4NO_3	61.08	79.56	25.89	39.42
6	5/9/2002	KNO_3	53.45	53.52	42.60	42.60
		NH_4NO_3	61.08	79.56	36.16	49.84
7	5/16/2002	KNO_3	53.45	53.52	42.60	42.60
		NH_4NO_3	61.08	79.56	36.16	49.84
8	5/23/2002	KNO_3	53.45	53.52	42.60	42.60
		NH_4NO_3	61.08	79.56	36.16	49.84
9	5/30/2002	KNO_3	53.45	53.52	25.42	25.42
		NH_4NO_3	61.08	79.56	21.82	29.34
10	6/6/2002	KNO_3	53.45	53.52	25.42	25.42
		NH_4NO_3	61.08	79.56	21.82	29.34
11	6/13/2002	KNO_3	53.45	53.52	25.42	25.42
		NH_4NO_3	61.08	79.56	21.82	29.34
12	6/20/2002	KNO_3	21.38	21.38	16.28	16.28
		NH_4NO_3	52.94	67.20	14.53	20.68
13	6/27/2002	KNO_3	21.38	21.38	16.28	16.67
		NH_4NO_3	38.69	48.87	14.52	21.18
	Total	KNO_3	465.78	466.27	306.8	307.19
	Season	NH_4NO_3	607.77	786.00	260.6	363.97

APPENDIX D
CALCULATED WEEKLY AND SEASONAL IRRIGATION WATER AMOUNTS:

Table D-1.Calculated weekly and total seasonal irrigation water amounts (L/100 m) applied to different treatments for the bell pepper crop experiment.

Date	Weeks after transplanting (WAT)	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	(Transplanting)						
4/4/02	1	760	760	760	1050	1050	1050
4/11/02	2	760	760	760	1050	1050	1050
4/18/02	3	760	760	760	1050	1050	1050
4/25/02	4	1570	2350	3140	1570	2350	3140
5/02/02	5	1680	2510	3350	1670	2510	3350
5/09/02	6	3290	4940	6580	3290	4940	6580
5/16/02	7	4910	7360	9820	4910	7360	9820
5/23/02	8	4570	6850	9140	4570	6850	9140
5/30/02	9	2230	6700	8930	2230	6700	8930
6/06/02	10	2780	4170	5560	2780	4170	5560
6/13/02	(Harvest) 11	2870	8680	11490	2870	8680	11490
	Total season	26180	45840	60290	27040	46710	61160

[Z] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of daily ET_C, respectively.

Table D-2. Calculated weekly and total seasonal water amounts (L /100 m) applied from fertilizer and bromide injection to different treatments for the bell pepper experiment.

Date	Weeks after transplanting (WAT)	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	(Transplanting)						
4/4/02	1						
4/11/02	2	50	50	50	120	120	120
	bromide	160	160	160	160	160	160
4/18/02	3	60	60	60	30	30	30
4/25/02	4	50	50	50	30	30	30
5/02/02	5	70	70	70	60	60	60
5/09/02	6	50	50	50	60	60	60
5/16/02	7	80	80	80	40	40	40
5/23/02	8	60	60	60	40	40	40
5/30/02	9	60	60	60	50	50	50
6/06/02	10	40	40	40	40	40	40
6/13/02	Total	690	690	690	640	640	640

[Z] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.

[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of daily ET_C, respectively.

Table D-3. Calculated weekly and total seasonal water amounts (L/100 m) applied from irrigation, fertilizer and bromide injection to different treatments for the bell pepper experiment.

Date	Weeks after transplanting (WAT)	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	(Transplanting)						
4/4/02	1	760	760	760	1050	1050	1050
4/11/02	2	970	760	760	1050	1050	1050
4/18/02	3	820	810	810	1170	1170	1170
4/25/02	4	1620	2410	3200	1600	2380	3170
5/02/02	5	1750	2560	3400	1700	2540	3380
5/09/02	6	3340	5010	6650	3350	5000	6640
5/16/02	7	4990	7410	9870	4970	7420	9880
5/23/02	8	4630	6930	9220	4610	6890	9180
5/30/02	9	2290	6760	8990	2270	6740	8970
6/06/02	10	2820	4230	5620	2830	4220	5610
6/13/02	(Harvest) 11	2871	8720	11530	2910	8720	11530
	Total Season	26860	45520	60970	27670	47340	61790
	Irrigation ratios[X]	0.59	1	1.34	0.61	1.04	1.36

[Z] Nitrogen applications rates N1 and N2 were 100 and 125% of IFAS recommended rates, respectively.
[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of daily ET_C, respectively.
[X] Irrigation ratios are calculated by normalizing irrigation amounts with [N1-I2] amounts

Table D-4. Calculated cumulative water amounts (L /100 m) applied from irrigation, fertilizer and bromide injection to different treatments for the bell pepper experiment up to soil sampling date.

Sampling date	Week/activity	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	Transplanting						
4/12/02	2/1DAFFI: after	1730	1730	1730	2380	2380	2380
Irrigation ratio	fertilizer injection	1	1	1	1.38	1.38	1.38
5/03/02	5/22DAFFI:	5920	7530	9160	6790	8410	10040
Irrigation ratio[X]	flowering	0.79	1	1.22	0.90	1.12	1.33
6/10/02	10/60DAFFI: close	23990	37840	49480	24800	36660	50300
Irrigation ratio	to harvest	0.63	1	1.31	0.66	0.97	1.33

[Z] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of daily ET_C, respectively.
[X] Irrigation ratios are calculated by normalizing irrigation amounts with [N1I2] amounts

Table D-5. Calculated weekly and total seasonal irrigation water amounts (L /100 m) applied to different treatments for the watermelon crop experiment.

Date	Weeks after Transplanting (WAT)	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	(Transplanting)						
4/4/02	1	1780	1780	1780	1910	1910	1910
4/11/02	2	1780	1780	1780	1910	1910	1910
4/18/02	3	1780	1780	1780	1910	1910	1910
4/25/02	4	2930	3890	6170	2930	4390	5180
5/02/02	5	3090	4100	9100	3090	4630	5460
5/09/02	6	4550	6050	12700	4550	6830	8060
5/16/02	7	6360	8660	11520	6360	9530	11250
5/23/02	8	5410	7650	11400	5410	8640	10200
5/30/02	9	5700	7570	8810	5700	7970	10090
6/06/02	10	4410	5850	9370	4410	6610	7800
6/13/02	(Harvest) 11	4690	6220	9370	4690	7030	8300
	Total	42480	55330	83780	42870	61360	72070

[Z] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of Daily ET_C, respectively.

Table D-6. Calculated weekly and total seasonal water amounts (L/100 m) applied from fertilizer and bromide injection to different treatments for the watermelon crop experiment.

Date	Weeks after transplanting (WAT)	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	(Transplanting)						
4/4/02	1						
4/11/02	2	20	20	20	30	30	30
	Bromide	80	80	80	80	80	80
4/18/02	3	20	20	20	20	20	20
4/25/02	4	30	30	30	30	30	30
5/02/02	5	50	50	50	50	50	50
5/09/02	6	40	40	40	40	40	40
5/16/02	7	50	50	50	70	70	70
5/23/02	8	50	50	50	50	50	50
5/30/02	9	30	30	30	50	50	50
6/06/02	10	30	30	30	40	40	40
6/13/02	(Harvest) 11	320	320	320	360	360	360
	Total	400	400	400	440	440	440

[Z] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.

[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of daily ET_C, respectively.

Table D-7. Calculated weekly and total seasonal water amounts (L/100 m) applied from irrigation, fertilizer and bromide injection to different treatments for watermelon experiment.

Date	Weeks after transplanting (WAT)	N1[Z]			N2		
		I1[Y]	I2	I3	I1	I2	I3
3/29/02	(Transplanting)						
4/4/02	1	1780	1780	1780	1910	1910	1910
4/11/02	2	1780	1780	1780	1910	1910	1910
	bromide	80	80	80	80	80	80
4/18/02	3	1800	1800	1800	1940	1940	1940
4/25/02	4	2950	3910	6190	2950	4410	5200
5/02/02	5	3120	4130	9130	3120	4660	5490
5/09/02	6	4600	6100	12750	4600	6880	8110
5/16/02	7	6400	8700	11560	6400	9570	11290
5/23/02	8	5460	7700	11450	5480	8710	10270
5/30/02	9	5750	7620	8860	5750	8020	10140
6/06/02	10	4440	5880	9400	4460	6660	7850
6/13/02	(Harvest) 11	4720	6250	9400	4730	7070	8340
	Total	42880	55730	84180	43310	61800	72510
	Irrigation ratios[X]	0.77	1	1.51	0.78	1.11	1.30

[Z] Nitrogen applications rates N1 and N2 were 100% and 125% of IFAS recommended rates, respectively.
[Y] Irrigation treatment I1, I2, and I3 are 66%, 100% and 133% of daily ET_C, respectively.
[X] Irrigation ratios are calculated by normalizing irrigation amounts with [N1I2] amounts

Table D-8. Calculated cumulative water amounts (L/100 m) applied from irrigation, fertilizer and bromide injection to different treatments for the watermelon experiment up to soil sampling date.

Soil sampling date	Week/activity	N1			N2		
		I1	I2	I3	I1	I2	I3
3/29/02	Transplanting						
4/12/02	2/1DAFFI: after	3640	3640	3640	3900	3900	3900
Irrigation ratio[Z]	fertilizer injection	1	1	1	1.07	1.07	1.07
5/03/02	5/22DAFFI:	11510	13480	20760	11910	14910	16530
Irrigation ratio	flowering	0.85	1	1.54	0.88	1.10	1.23
6/10/02	10/60DAFFI:	38160	49480	74780	38600	54750	64190
Irrigation ratio	close to harvest	0.77	1	1.51	0.78	1.11	1.30

[Z] Irrigation ratios are calculated by normalizing irrigation amounts with [N1I2] amounts

APPENDIX E
VOLUMETRIC WATER CONTENT VALUES USED TO CALCULATE WATER FLUX:

Table E-1. Average volumetric water content (θ_v) as a function of irrigation volume (IV^Z) at different soil depths one day after first fertilizer injection under drip irrigated bell pepper and watermelon crops. No irrigation treatments were applied.

Crop	Irrigation volume	Soil depth (cm)			
		0-15	15-30	30-60	60-90
Bell Pepper	IV_1	0.16	0.16	0.13	0.11
	IV_2	0.15	0.16	0.13	0.12
Watermelon	IV_1	0.20	0.21	0.15	0.13
	IV_2	0.20	0.21	0.15	0.13

^{Z} IV = Irrigation volumes were applied through fertilizer and bromide lines

Table E-2. Average volumetric water content (θ_v) as a function of irrigation rates (I) at different soil depths and sampling dates under drip irrigated bell pepper crop.

Sampling date (DAFFI) ^{Z}	Irrigation rate	Soil depth (cm)			
		0-15	15-30	30-60	60-90
22	I_1	0.18	0.15	0.10	0.09
	I_2	0.20	0.16	0.11	0.09
	I_3	0.19	0.16	0.12	0.10
60	I_1	0.09	0.10	0.10	0.11
	I_2	0.08	0.11	0.10	0.10
	I_3	0.08	0.10	0.10	0.09

^{Z} DAFFI = Days after first fertilizer injection which was on 4/11/2002.

Table E-3. Average water content (θv) as a function of irrigation rates (I) at different soil depths and sampling dates under drip irrigated watermelon crop.

Sampling date (DAFFI)[Z]	Irrigation rate	Soil depth (cm)			
		0-15	15-30	30-60	60-90
22DAFFI[Z]	I1	0.11	0.07	0.07	0.07
	I2	0.10	0.07	0.08	0.07
	I3	0.13	0.08	0.07	0.08
60DAFFI	I1	0.07	0.08	0.08	0.07
	I2	0.06	0.08	0.08	0.08
	I3	0.08	0.09	0.11	0.09

[Z] DAFFI = Days after first fertilizer injection which was on 4/11/2002

APPENDIX F
CALCULATED WATER FLUX FOR THE BELL PEPPER AND WATERMELON EXPERIMENTS

Table F-1. Calculated water fluxes one day after first fertilizer injection (1DAFFI) under drip irrigated bell pepper crop before irrigation treatments using fertilizer drip tapes for irrigation volume one (IV1) and irrigation volume two (IV2). Relevant water volumes are IV1 for N1 plots and IV2 for N2 plots.

Soil depth (cm)	Water content ($\theta_{v,\ cm^3\ cm^{-3}}$)	Hydraulic conductivity (cm/h)	Matric potential (h, cm)	Gravitational potential (z, cm)	Total potential (H, cm)	Soil layer for calculated flux (cm)	Gradient	Water flux[Z] (q, cm/d)
IV1-N1								
0	0.16		-63	90	27	0 to 15	-1	20
15	0.16	0.84	-63	75	12	15 to 30	-1.47	30
30	0.16	0.85	-70	60	-10	30 to 60	-1.23	28
60	0.13	0.95	-77	30	-47	60 to 90	-0.10	11
90	0.11	0.47	-77	0	-77			
	K_{eff} 0-30 cm	0.84			Effective flux [Y]	0-30	-1.23	**25**
	K_{eff} 30-90 cm	0.63			Effective flux	30-90	-1.12	**17**
IV2-N2								
0	0.15		-66.5	90	23.5	0 to 15	-1	16
15	0.15	0.66	-66.5	75	8.5	15 to 30	-1.23	25
30	0.16	0.85	-70	60	-10	30 to 60	-1.23	28
60	0.13	0.95	-77	30	-47	60 to 90	-0.88	10
90	0.12	0.47	-73.5	0	-73.5			
	K_{eff} 0-30 cm	0.74			Effective flux	0-30	-1.12	**20**
	K_{eff} 30-90 cm	0.63			Effective flux	30-90	-1.06	**16**

[Z] Water flux is calculated for soil layers: (0-15, 15-30, 30-60, and 60-90 cm)

[Y] Effective water flux is calculated for the root zone (0-30 cm), and below the root zone (30-90 cm)

Table F-2. Calculated water fluxes at 22 days after first fertilizer injection (22 DAFFI) for irrigation rates 66% (I1), 100% (I2) and 133% (I3) of daily ET_C under drip irrigated bell pepper crop.

Soil depth (cm)	Water content ($\theta_{v,cm^3\ cm^{-3}}$)	Hydraulic conductivity (cm/h)	Matric potential (h, cm)	Gravitational potential (z, cm)	Total potential (H, cm)	Soil layer for calculated flux (cm)	Gradient	Water flux[Z] (q, cm/d)
I1								
0	0.18		-56	90	34	0 to 15	-1	33
15	0.18	1.36	-56	75	19	15 to 30	-2.17	68
30	0.15	1.29	-73.5	60	-13.5	30 to 60	-1.82	22
60	0.1	0.51	-98	30	-68	60 to 90	-0.77	42
90	0.09	0.24	-91	0	-91			
	K_{eff} 0-30cm	1.32			Effective flux [Y] 0-30 cm		-1.58	50
	K_{eff} 30-90 cm	0.33			Effective flux 30-90 cm		-1.29	10
I2								
0	0.2		-49	90	41	0 to 15	-1	56
15	0.2	2.32	-49	75	26	15 to 30	-2.40	93
30	0.16	1.61	-70	60	-10	30 to 60	-1.70	31
60	0.11	0.77	-91	30	-61	60 to 90	-1.00	6
90	0.09	0.24	-91	0	-91			
	K_{eff} 0-30cm	1.90			Effective flux 0-30 cm		-1.70	78
	K_{eff} 30-90 cm	0.37			Effective flux 30-90 cm		-1.35	12
I3								
0	0.19		-52.5	90	37.5	0 to 15	-1	42
15	0.19	1.77	-52.5	75	22.5	15 to 30	-2.17	84
30	0.16	1.61	-70	60	-10	30 to 60	-1.47	27
60	0.12	0.77	-84	30	-54	60 to 90	-1.00	9
90	0.1	0.37	-84	0	-84			
	K_{eff} 0-30 cm	1.69			Effective flux 0-30 cm		-1.58	64
	K_{eff} 30-90 cm	0.50			Effective flux 30-90 cm		-1.23	15

[Z]Water flux is calculated for soil layers : (0-15, 15-30, 30-60, and 60-90 cm)

[Y] Effective water flux is calculated for the root zone (0-30 cm), and below the root zone (30-90 cm)

Table F-3. Calculated water fluxes at 60 days after first fertilizer injection (60 DAFFI) for irrigation rates for irrigation rates 66% (I1), 100% (I2) and 133% (I3) of daily ET_C under drip irrigated bell pepper crop.

Soil depth (cm)	Water content ($\theta_{v,cm^3\ cm^{-3}}$)	Hydraulic conductivity (cm/h)	Matric potential (h, cm)	Gravitational potential (z, cm)	Total potential (H, cm)	Soil layer for calculated flux (cm)	Gradient	Water flux[Z] (q, cm/d)
I1								
0	0.09		-112	90	-22	0 to 15	-1	1
15	0.09	0.06	-112	75	-37	15 to 30	-2.17	3
30	0.1	0.11	-112	60	-52	30 to 60	-1.47	3
60	0.1	0.20	-101.5	30	-71.5	60 to 90	-1	2
90	0.11	0.37	-77	0	-77			
	K_{eff} 0-30 cm	0.08			Effective flux [Y] 0 – 30 cm		-1	2
	K_{eff} 30-90 cm	0.26			Effective flux 30-90 cm		-0.42	3
I2								
0	0.08		-122.5	90	-32.5	0 to 15	-1	1
15	0.08	0.04	-122.5	75	-47.5	15 to 30	0.40	-1
30	0.11	0.11	-101.5	60	-41.5	30 to 60	-0.88	6
60	0.1	0.29	-101.5	30	-71.5	60 to 90	-0.53	3
90	0.1	0.24	-77	0	-77			
	K_{eff} 0-30 cm	0.06			Effective flux 0-30 cm		-0.3	0.4
	K_{eff} 30-90 cm	0.26			Effective flux 30-90 cm		-0.71	4
I3								
0	0.08		-122.5	90	-32.5	0 to 15	-1	1
15	0.08	0.04	-122.5	75	-47.5	15 to 30	-0.30	1
30	0.1	0.07	-112	60	-52	30 to 60	-0.53	3
60	0.1	0.20	-98	30	-68	60 to 90	-0.77	4
90	0.09	0.24	-91	0	-91			
	K_{eff} 0-30 cm	0.04			Effective flux 0-30 cm		-0.65	1
	K_{eff} 30-90 cm	0.22			Effective flux 30-90 cm		-0.65	3

[Z]Water flux is calculated for soil layers : (0-15, 15 – 30, 30-60, and 60 -90 cm)

[Y] Effective water flux is calculated for the root zone (0-30 cm), and below the root zone (30-90 cm)

Table F-4. Calculated water fluxes during 1 day after first fertilizer injection (1DAFFI) for drip irrigated watermelon before irrigation treatments using fertilizer drip tapes for 100% (N1) and 125% (N2) of IFAS recommended fertilizer rates application. Relevant water volumes (IV1 and IV2) are IV1 for N1 plots and IV2 for N2 plots.

Soil depth (cm)	Water content (θ_{v}, cm^3 cm^{-3})	Hydraulic conductivity (cm/h)	Matric potential (h, cm)	Gravitational potential (z, cm)	Total potential (H, cm)	Soil layer for calculated flux (cm)	Gradient	Water flux[Z] (q, cm/d)
IV1-N1								
0	0.2		-49	90	41	0 to 15	-1	56
15	0.2	2.32	-49	75	26	15 to 30	-1	78
30	0.21	3.26	-49	60	11	30 to 60	-1.66	102
60	0.15	2.49	-70	30	-40	60 to 90	-0.88	21
90	0.13	0.98	-66.5	0	-66.5			
	K_{eff} 0-60 cm	2.56			Effective flux [Y] 0-60		-1.35	84**
	K_{eff} 60-90 cm	0.98			Effective flux 60-90		-0.88	21
IV2-N2								
0	0.2		-49	90	41	0 to 15	-1	56
15	0.2	2.32	-49	75	26	15 to 30	-1	78
30	0.21	3.26	-49	60	11	30 to 60	-1.66	102
60	0.15	2.49	-70	30	-40	60 to 90	-0.88	21
90	0.13	0.98	-66.5	0	-66.5			
	K_{eff} 0-60 cm	2.56			Effective flux 0-60		-1.35	84
	K_{eff} 60-90 cm	0.98			Effective flux 60-90		-0.88	21

[Z] Water flux is calculated for soil layers: (0-15, 15-30, 30-60, and 60-90 cm).

[Y] Effective water flux is calculated for the root zone (0-60 cm), and below the root zone (60-90 cm).

Table F-5. Calculated water fluxes at 22 days after first fertilizer injection (22 DAFFI) for irrigation rates 66% (I1), 100% (I2) and 133% (I3) of daily ET_C under drip irrigated watermelon crop.

Soil depth (cm)	Water content ($\theta_{v,cm^3\,cm^{-3}}$)	Hydraulic conductivity (cm/h)	Matric potential (h, cm)	Gravitational potential (z, cm)	Total potential (H, cm)	Soil layer for calculated flux (cm)	Gradient	Water flux[Z] (q, cm/d)
I1								
0	0.11		-91	90	-1	0 to 15	-1	4
15	0.11	0.17	-91	75	-16	15 to 30	-5.43	9
30	0.07	0.07	-157.5	60	-97.5	30 to 60	-0.18	0.2
60	0.07	0.05	-133	30	-103	60 to 90	-0.30	0.4
90	0.07	0.06	-112	0	-112			
	K_{eff} 0-60 cm	0.04				Effective flux[Y] 0-60 cm	-1.70	3**
	K_{eff} 60-90 cm	0.05				Effective flux 60-90 cm	-0.30	0.4
I2								
0	0.1		-101.5	90	-11.5	0 to 15	-1	2
15	0.1	0.1	-101.5	75	-26.5	15 to 30	-4.73	8
30	0.07	0.07	-157.5	60	-97.5	30 to 60	0.28	-0.5
60	0.08	0.08	-119	30	-89	60 to 90	-0.77	2
90	0.07	0.09	-112	0	-112			
	K_{eff} 0-60 cm	0.08				Effective flux 0-60 cm	-1.29	3
	K_{eff} 60-90 cm	0.09				Effective flux 60-90 cm	-0.77	2
I3								
0	0.13		-80.5	90	9.5	0 to 15	-1	7
15	0.13	0.29	-80.5	75	9.5	15 to 30	-4.95	21
30	0.08	0.18	-140	60	-80	30 to 60	-0.77	1
60	0.07	0.07	-133	30	-103	60 to 90	0.05	-0.1
90	0.08	0.09	-101.5	0	-101.5			
	K_{eff} 0-60 cm	0.05				Effective flux 0-60 cm	-1.88	5
	K_{eff} 60-90 cm	0.09				Effective flux 60-90 cm	0.05	-0.1

[Z] Water flux is calculated for soil layers: (0-15, 15-30, 30-60, and 60-90 cm).
[Y] Effective water flux is calculated for the root zone (0-60 cm), and below the root zone (60-90 cm).

Table F-6. Calculated water fluxes at 60 days after first fertilizer injection (60 DAFFI) for irrigation rates 66% (I1), 100% (I2) and 133% (I3) of daily ET_C under drip irrigated watermelon.

Soil depth (cm)	Water content ($\theta_{v, cm^3 cm^{-3}}$)	Hydraulic conductivity (cm/h)	Matric potential (h, cm)	Gravitational potential (z, cm)	Total potential (H, cm)	Soil layer for calculated flux (cm)	Gradient	Water flux[Z] (q, cm/d)
I1								
0	0.07		-140	90	-50	0 to 15	-1.00	0.5
15	0.07	0.02	-140	75	-65	15 to 30	-1.00	1
30	0.08	0.04	-140	60	-80	30 to 60	-0.30	1
60	0.08	0.08	-119	30	-89	60 to 90	-0.77	2
90	0.07	0.09	-112	0	-112			
	K_{eff} 0 – 60 cm	0.04			Effective flux [Y] 0 – 60 cm		-0.65	1
	K_{eff} 60-90 cm	0.05			Effective flux 60-90 cm		-0.77	2
I2								
0	0.06		-157.5	90	-67.5	0 to 15	-1	0.2
15	0.06	0.01	-157.5	75	-82.5	15 to 30	0.17	-0.1
30	0.08	0.02	-140	60	-80	30 to 60	-0.30	1
60	0.08	0.08	-119	30	-89	60 to 90	-0.42	1
90	0.08	0.06	-101.5	0	-101.5			
	K_{eff} 0 – 60 cm	0.0.3			Effective flux 0 – 60 cm		-0.36	0.2
	K_{eff} 60-90 cm	0.09			Effective flux 60-90 cm		-0.42	1
I3								
0	0.08		-122.5	90	-32.5	0 to 15	-1	1
15	0.08	0.04	-122.5	75	-47.5	15 to 30	-1.23	2
30	0.09	0.07	-126	60	-66	30 to 60	0.17	-1
60	0.11	0.20	-91	30	-61	60 to 90	-1.00	4
90	0.09	0.24	-91	0	-91			
	K_{eff} 0 – 60 cm	0.08			Effective flux 0 – 60 cm		-0.48	1
	K_{eff} 60-90 cm	0.24			Effective flux 60-90 cm		-1	6

[Z] Water flux is calculated for soil layers: (0-15, 15-30, 30-60, and 60-90 cm).
[Y] Effective water flux is calculated for the root zone (0-60 cm), and below the root zone (60-90 cm).

APPENDIX G
SOIL MOISTURE RELEASE CURVES DATA

Table G-1. Volumetric water content (θ_v) and suction (h) at different soil depths.

Soil depth (cm)							
0-15		15-30		30-60		60-90	
h (cm)	θ_v ($cm^3\ cm^{-3}$)	h (cm)	θ_v ($cm^3\ cm^{-3}$)	h (cm)	θ_v ($cm^3\ cm^{-3}$)	h (cm)	θ_v ($cm^3\ cm^{-3}$)
0	0.42	0	0.37	0	0.41	0	0.42
3.5	0.40	3.5	0.35	3.5	0.38	3.5	0.4
20	0.38	20	0.34	20	0.38	20	0.37
30	0.32	30	0.31	30	0.31	30	0.3
45	0.18	45	0.23	45	0.21	45	0.18
60	0.13	60	0.15	60	0.14	60	0.12
80	0.11	80	0.11	80	0.11	80	0.09
100	0.10	100	0.10	100	0.09	100	0.08
150	0.08	150	0.08	150	0.08	150	0.07
200	0.08	200	0.08	200	0.07	200	0.06
345	0.07	345	0.07	345	0.06	345	0.05
5000	0.02	5000	0.02	5000	0.02	5000	0.01
15000	0.01	15000	0.01	15000	0.01	15000	0.01

Table G-2. Suction (h), volumetric water content (θ_v), and hydraulic conductivity [K (h)] calculated from soil moisture release curves with van Genuchten Model (1980) at different soil depths.

Soil depth (cm)											
0-15			15-30			30-60			60-90		
h (cm)	θ_v cm^3 cm^{-3}	K(h) (cm/h)	h (cm)	θ_v cm^3 cm^{-3}	K(h) (cm/h)	h (cm)	θ_v cm^3 cm^{-3}	K(h) (cm/h)	h (cm)	θ_v cm^3 cm^{-3}	K(h) (cm/h)
0	0.42	165	0	0.37	110	0.0	0.410	210.0	0.0	0.420	225.0
38.5	0.243	5.625	38.5	0.247	7.073	38.5	0.249	10.254	38.5	0.231	8.282
42.0	0.227	4.139	42.0	0.234	5.423	42.0	0.233	7.581	42.0	0.213	5.894
45.5	0.213	3.082	45.5	0.222	4.187	45.5	0.219	5.656	45.5	0.197	4.244
49.0	0.200	2.322	49.0	0.210	3.258	49.0	0.205	4.261	49.0	0.183	3.093
52.5	0.189	1.769	52.5	0.199	2.555	52.5	0.193	3.242	52.5	0.170	2.282
56.0	0.178	1.364	56.0	0.190	2.019	56.0	0.181	2.492	56.0	0.159	1.704
59.5	0.168	1.062	59.5	0.180	1.608	59.5	0.171	1.933	59.5	0.148	1.287
63.0	0.159	0.835	63.0	0.172	1.291	63.0	0.162	1.514	63.0	0.139	0.983
66.5	0.151	0.663	66.5	0.164	1.044	66.5	0.153	1.196	66.5	0.130	0.759
70.0	0.144	0.532	70.0	0.157	0.850	70.0	0.145	0.954	70.0	0.123	0.592
73.5	0.137	0.430	73.5	0.150	0.697	73.5	0.138	0.766	73.5	0.116	0.466
77.0	0.131	0.350	77.0	0.144	0.575	77.0	0.131	0.620	77.0	0.109	0.370
80.5	0.125	0.287	80.5	0.138	0.478	80.5	0.125	0.506	80.5	0.103	0.296
84.0	0.119	0.237	84.0	0.132	0.399	84.0	0.119	0.416	84.0	0.098	0.239
87.5	0.114	0.197	87.5	0.127	0.335	87.5	0.114	0.344	87.5	0.093	0.195
91.0	0.110	0.165	91.0	0.122	0.283	91.0	0.109	0.286	91.0	0.089	0.159
94.5	0.105	0.139	94.5	0.118	0.240	94.5	0.105	0.239	94.5	0.084	0.131
98.0	0.101	0.118	98.0	0.114	0.205	98.0	0.100	0.201	98.0	0.081	0.109
101.5	0.098	0.100	101.5	0.110	0.176	101.5	0.096	0.170	101.5	0.077	0.091
105.0	0.094	0.086	105.0	0.106	0.151	105.0	0.093	0.145	105.0	0.074	0.076

108.5	0.091	0.073	108.5	0.103	0.131	108.5	0.089	0.123	108.5	0.071	0.064
112.0	0.088	0.063	112.0	0.099	0.113	112.0	0.086	0.106	112.0	0.068	0.055
115.5	0.085	0.055	115.5	0.096	0.099	115.5	0.083	0.091	115.5	0.065	0.046
119.0	0.082	0.048	119.0	0.093	0.086	119.0	0.080	0.079	119.0	0.063	0.040
122.5	0.080	0.042	122.5	0.091	0.076	122.5	0.078	0.068	122.5	0.060	0.034
126.0	0.077	0.036	126.0	0.088	0.067	126.0	0.075	0.060	126.0	0.058	0.029
129.5	0.075	0.032	129.5	0.086	0.059	129.5	0.073	0.052	129.5	0.056	0.025
133.0	0.073	0.028	133.0	0.083	0.052	133.0	0.070	0.046	133.0	0.054	0.022
136.5	0.071	0.025	136.5	0.081	0.046	136.5	0.068	0.040	136.5	0.052	0.019
140.0	0.069	0.022	140.0	0.079	0.041	140.0	0.066	0.036	140.0	0.051	0.017
143.5	0.067	0.020	143.5	0.077	0.037	143.5	0.064	0.031	143.5	0.049	0.015
147.0	0.065	0.018	147.0	0.075	0.033	147.0	0.062	0.028	147.0	0.047	0.013
150.5	0.063	0.016	150.5	0.073	0.030	150.5	0.061	0.025	150.5	0.046	0.012
154.0	0.062	0.014	154.0	0.071	0.027	154.0	0.059	0.022	154.0	0.045	0.010
157.5	0.060	0.013	157.5	0.069	0.024	157.5	0.058	0.020	157.5	0.043	0.009
161.0	0.059	0.011	161.0	0.068	0.022	161.0	0.056	0.018	161.0	0.042	0.008
164.5	0.057	0.010	164.5	0.066	0.020	164.5	0.055	0.016	164.5	0.041	0.007
168.0	0.056	0.009	168.0	0.065	0.018	168.0	0.053	0.014	168.0	0.040	0.006
171.5	0.055	0.008	171.5	0.063	0.016	171.5	0.052	0.013	171.5	0.039	0.006

APPENDIX H
CALCULATION OF SOIL MASS (kg ha^{-1})

Appendix H-1. Soil mass calculation for bell pepper experiment.

Based on 1 acre = 43560 ft^2 and bed spacing of 5 ft.
Linear bed feet per acre = 43560/5 = 8712 LBF ac^{-1}
Based on drip tape with emitter 12 inch spacing maximum wetting width = 12 inch.
Based on sampling depth: 0-15, 15-30, 30-60, and 60-90 cm.
Based on measured soil bulk density (BD) for different sampling depths.
1.46, 1.55, 1.42, and 1.48 gcm^{-3} for 0-15, 15-30, 30-60, and 60-90 cm, respectively.

1- Mass of soil for one hectare for 0-15 cm sampling depth.
= volume of soil * bulk density
= (Length * Width* Depth) * Bulk Density (BD)
= (8712LBF * 30.48 cm ft^{-1} * 30.48 cm * 15cm) * 1.46 gcm^{-3}
= (265541.76 cm* 30.48 cm * 15cm) * 1.46 gcm^{-3}
= (121405692.67 cm^{-3})* 1.46 g cm^{-3}
= 177252311.30 g ac^{-1} * 2.471 ac ha^{-1}
= 437990461.23 g ha^{-1}/1000 = 437990 kg ha^{-1}

2- Mass of soil for one hectare for 15-30 cm sampling depth
= volume of soil * bulk density
= (Length * Width * Depth) * Bulk Density (BD)
= (8712 LBF * 30.48 cm ft^{-1} * 30.48 cm * 15cm) * 1.55 gcm^{-3}
= (265541.76 cm * 30.48 cm * 15cm) * 1.55 gcm^{-3}
= (121405692.67 cm^{-3}) * 1.55 gcm^{-3}
= 188178823.64 g ac^{-1} * 2.471 ac ha^{-1}
= 464989873.22 g ha^{-1}/1000 = 464990 kg ha^{-1}

3- Mass of soil for one hectare for 30-60 cm sampling depth
= volume of soil * bulk density
= (Length * Width* Depth) * Bulk Density (BD)
= (8712 LBF*30.48 cm ft^{-1}* 30.48 cm *30.48cm) * 1.42 g cm^{-3}
= (265541.76 cm* 30.48 cm *30.48cm) * 1.42 gcm^{-3}
= (246696367.51 cm^{-3})* 1.42 gcm^{-3}
= 350308841.86 g ac^{-1} *2.471 ac ha^{-1}
= 865613148.24 g ha^{-1}/1000 =865613 kg ha^{-1}

4- Mass of soil for one hectare for 60-90cm sampling depth
= volume of soil * bulk density
= (Length * Width* Depth) * Bulk Density (BD)
= (8712 LBF*30.48 cm ft^{-1}* 30.48 cm *30.48cm) * 1.48gcm^{-3}
= (265541.76 cm* 30.48 cm *30.48cm) * 1.48gcm^{-3}
= (246696367.51cm^{-3})* 1.48 gcm^{-3}
= 365110623.91 g ac^{-1} *2.471 ac ha^{-1}
= 902188351.69 g ha^{-1}/1000 = 902188.35 kg ha^{-1}= 902188 kg ha^{-1}

Appendix H-2. Soil mass calculation for watermelon experiment.

Based on 1 acre = 43560 ft^2 and bed spacing of 7.5 ft.
Linear bed feet per acre (LBF) = 43560/6 = 5808 LBF
Based on drip tape with emitter 12 inch spacing maximum wetting width = 12 inch.
Based on sampling depth: 0-15, 15-30, 30-60, and 60-90 cm
Based on measured soil bulk density (BD) for different sampling depths.
1.46, 1.55, 1.42, and 1.48 gcm^{-3} for 0-15, 15-30, 30-60, and 60-90 cm respectively.

1-Mass of soil for one hectare for 0-15 cm sampling depth.
= volume of soil * bulk density
= (Length * Width* Depth) * BD
= (5808 LBF*30.48 cm ft^{-1}* 30.48 cm *15cm) * 1.46 gcm^{-3}
= (177027.84 cm* 30.48 cm *15cm) * 1.46 gcm^{-3}
= (80937128.45 cm^{-3})* 1.46 gcm^{-3}
= 118168207.53 g ac^{-1}*2.471 ac ha^{-1}
= 291993640.82 g ac^{-1}/1000 = 291993.64 kg ha^{-1} = 291994 kg ha^{-1}

2- Mass of soil for one hectare for 15-30 cm sampling depth
= volume of soil * bulk density
= (Length * Width* Depth) * BD
= (5808LBF*30.48 cm ft^{-1}* 30.48 cm *15cm) * 1.55 gcm^{-3}
= (177027.84 cm* 30.48 cm *15cm) * 1.55 gcm^{-3}
= (80937128.45 cm^{-3})* 1.55 g cm^{-3}
= 125452549.09 g ac^{-1} *2.471 ac ha^{-1}
= 309993248.81 g ha^{-1}/1000 = 309993.25 g ha^{-1}= 309993 kg ha^{-1}

3- Mass of soil for one hectare for 30-60 cm sampling depth
= volume of soil * bulk density
= (Length * Width* Depth) * BD
= (5808LBF*30.48 cm ft^{-1}* 30.48 cm *30.48 cm) * 1.42 gcm^{-3}
= (177027.84 cm* 30.48 cm *30.48cm) * 1.42 gcm^{-3}
= (164464245.01cm^{-3})* 1.42 gcm^{-3}
= 233539227.91 g ac^{-1} *2.471 ac ha_{-1}
= 577075432.16 g ha^{-1}/1000 = 577075.43 kg ha^{-1}=577075 kg ha^{-1}

4- Mass of soil for one hectare for 60-90cm sampling depth

$= \text{volume of soil} * \text{bulk density}$

$= (\text{Length} * \text{Width} * \text{Depth}) * BD$

$= (5808\ LBF * 30.48\ cm\ ft^{-1} * 30.48\ cm * 30.48 cm) * 1.48 gcm^{-3}$

$= (177027.84\ cm * 30.48\ cm * 30.48 cm) * 1.48 gcm^{-3}$

$= (164464245.01 cm^{-3}) * 1.48\ gcm^{-3}$

$= 243407082.61\ g\ ac^{-1} * 2.471\ ac\ ha^{-1}$

$= 601458901.13\ g\ ha^{-1}/1000 = 601458.90\ kg\ ha^{-1} = 601459\ kg\ ha^{-1}$

APPENDIX I
PERCENT OF NO_3-N, BR, NH_4-N AND K REMAINING IN THE ROOT ZONE AND THE ENTIRE SOIL PROFILE

Table I-1. Percent of NO_3-N, Br, NH_4-N and K remaining in the root-zone and the entire soil profile of bell pepper and watermelon crops 1DAFFI as affected by irrigation volumes (IV1 and IV2)

Crop	Irr.vol^{Y}.	Soil depth (cm)	NO_3-N		Br		NH_4-N		K	
			% Rem^{X}.	$^{£}$SE	% Rem	SE	% Rem	SE	%Rem	SE
BP^{Z}	IV1	0-30	67	8	44	3	15	3	41	3
	IV2	0-30	60	7	23	4	13	3	44	3
	IV1	30-90	12	1	17	4	13	2	47	3
	IV2	30-90	18	5	14	4	13	2	48.	3
	IV1	0-90	78	10	61	5	28	4	89	4
	IV2	0-90	79	9	37	4	27	4	93	5
WM	IV1	0-60	6	1	31	2	28	1	49	4
	IV2	0-60	9	1	31	3	32	3	54	3
	IV1	60-90	2	1	19	1	3	1	13	1
	IV2	60-90	3	1	18	1	3	1	13	1
	IV1	0-90	8	2	50	2	31	2	62	5
	IV2	0-90	12	1	49	3	35	3	67	3

^{Z}BP = Bell pepper; WM = Watermelon; ^{Y}Irr. Vol. = Irrigation volume
¶SE = Standard error; Rem^{X} = Remaining
Data = Mean of 4 replicates

Table I-2. Percent of NO_3-N, NH_4-N and K remaining in the root-zone of bell pepper and watermelon crops at 22DAFFI as affected by N and irrigation rates

Crop	N-Rate	I-Rate[Y]	Soil depth (cm)	NO_3-N %Rem	NO_3-N SE	NH_4-N %Rem[X]	NH_4-N SE[£]	K %Rem	K SE
BP[Z]	N1	I1	0-30	18	6	14	4	51	7
		I2	0-30	10	2	6	2	40	4
		I3	0-30	21	8	19	9	49	6
		I1	30-90	27	2	3	1	26	2
		I2	30-90	29	4	2	0.22	26	3
		I3	30-90	31	6	3	1	28	3
		I1	0-90	46	7	17	5	76	8
		I2	0-90	40	5	8	2	66	7
		I3	0-90	52	14	22	10	77	5
	N2	I1	0-30	28	11	44	22	39	14
		I2	0-30	32	5	55	17	68	7
		I3	0-30	19	5	56	30	67	16
		I1	30-90	20	7	6	3	25	3
		I2	30-90	46	11	4	0.20	34	3
		I3	30-90	43	18	5	2	32	8
		I1	0-90	48	18	50	25	64	16
		I2	0-90	79	8	59	17	102	6
		I3	0-90	62	22	61	31	99	19
WM	N1	I1	0-60	29	13	31	8	69	3
		I2	0-60	16	6	10	2	47	10
		I3	0-60	18	7	24	7	50	5
		I1	60-90	1	0.5	3	1	10	2
		I2	60-90	1	0.5	4	3	10	2
		I3	60-90	2	0.5	1	0.15	7	0.5
		I1	0-90	30	13	34	8	79	5
		I2	0-90	16	7	30	17	57	12
		I3	0-90	19	7	26	7	61	7
	N2	I1	0-60	21	8	44	15	66	9
		I2	0-60	12	5	25	9	51	7
		I3	0-60	12	7	29	14	57	18
		I1	60-90	1	0.25	2	1	7	0.5
		I2	60-90	1	0.50	2	1	10	4
		I3	60-90	1	0.50	1	1	8	1
		I1	0-90	33	8	46	15	72	8
		I2	0-90	12	5	27	9	62	10
		I3	0-90	14	7	31	15	66	18

[Z]BP = Bell pepper; WM = Watermelon; [Y]IN-Rate. = Irrigation rate per N rate
[£]SE = Standard error; Rem[X]= Remaining; N1 and N2 = Nitrogen rates

Table I-3. Percent of NO_3-N, NH_4-N and K remaining in the root-zone of bell pepper and watermelon crops at 60DAFFI as affected by N and irrigation rates

Crop	Treatments	Soil depth (c)m	NO_3-N % Rem[¶]	NO_3-N SE[£]	NH4-N % Rem	NH4-N SE	K % Rem	K SE
BP[Z]	I1N1	0-30	4	2	3	1	28	6
	I2N1	0-30	24	8	55	17	61	11
	I3N1	0-30	0	0	5	4	15	5
	I1N2	0-30	26	5	26	13	36	9
	I2N2	0-30	1	0.5	1	0.15	9	1
	I3N2	0-30	15	8	11	6	23	6
	I1N1	30-90	2	2	2	0.50	43	5
	I2N1	30-90	9	3	5	1	40	9
	I3N1	30-90	0	0	1	0.15	19	6
	I1N2	30-90	6	3	3	1	25	4
	I2N2	30-90	0	0	1	0.05	15	1
	I3N2	30-90	3	1	3	1	20	4
	I1N1	0-90	6	4	5	2	71	9
	I2N1	0-90	33	10	60	18	101	22
	I3N1	0-90	0	0	6	4	34	11
	I1N2	0-90	32	6	29	14	61	12
	I2N2	0-90	1	0.50	2	0.2	24	2
	I3N2	0-90	18	8	14	7	43	8
WM	I1N1	0-60	3	1	4	0.50	24	3
	I2N1	0-60	2	1	3	0.50	20	4
	I3N1	0-60	3	1	3	0.50	16	2
	I1N2	0-60	1	0.50	2	0.50	19	1
	I2N2	0-60	0	0	5	0.50	16	5
	I3N2	0-60	1	0.50	4	1	13	2
	I1N1	60-90	0	0	0	0	4	0.50
	I2N1	60-90	0	0	0	0	4	0.50
	I3N1	60-90	0	0	0	0	4	0.50
	I1N2	60-90	0	0	0	0	3	0.50
	I2N2	60-90	0	0	0	0	3	0.50
	I3N2	60-90	0	0	0	0	4	0.50
	I1N1	0-90	3	0.50	4	0.50	28	4
	I2N1	0-90	2	1	3	0.50	24	4
	I3N1	0-90	3	1	3	0.50	26	7
	I1N2	0-90	1	0.5	2	0.50	23	2
	I2N2	0-90	0	0	5	0.50	20	5
	I3N2	0-90	1	0.50	4	1	17	3

[Z]BP = Bell pepper; WM = Watermelon; [Y]I-Rate. = Irrigation rate per N rate
[£]SE = Standard error; Rem[¶] = Remaining; N1 and N2 = Nitrogen rates

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