THE EFFECTS OF IRRIGATION AND NITROGEN MANAGEMENT ON POTATO TUBER YIELD, N RECOVERY AND LEACHING IN NORTHEAST FLORIDA

By

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To my husband, Guang, and my daughter, Lerong

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Nitrate leaching from agricultural fields under potato production in northeast Florida is a potential water quality concern in the St. Johns River watershed. A 3-year study was conducted to investigate the effect of an alternate seepage irrigation method and a controlled-release N source, polymer sulfur coated urea (PSCU), on potato tuber yield, crop N recovery and N leaching loss into the shallow water table. The experimental plots were arranged in a split-split-plot design. The whole plot factors were two irrigation treatments: traditional seepage irrigation (TSI) and intermittent seepage irrigation (ISI). A factorial design with two N sources (PSCU and urea) and two N rates (168 and 224 kg ha^{-1}) constituted the split plot factors, where the subplots included two potato cultivars (*Atlantic* and *Fabula*). The average total and marketable yields in 3 years were 31.9 and 25.2 Mg ha^{-1}, 32.1 and 28.5 Mg ha^{-1}, and 22.4 and 16.4 Mg ha^{-1}, respectively. Compared with the 20-year (1990 to 2009) average yield (28.3 Mg ha^{-1}) in Florida, yield in 2007 was similar yield while yields in 2006 and 2008 were lower. In both 2006 and 2007, both N factors had little effect on tuber yields and crop N recovery. In 2008, a ”leaching rainfall” (9 cm in 3 days) occurred 2 days after planting, which resulted in a lower N recovery, lower tuber yield, and higher N leaching loss compared

with 2007. Higher marketable and total yield were produced with PSCU compared with urea in a single fertilizer application. There was no benefit of higher N rate in increasing tuber yield. Based on this study, we concluded PSCU has a potential to improve tuber yield, even with the occurrence of a leaching rainfall in the spring season. Also, increasing N rate from 168 to 224 kg ha^{-1} did not benefit tuber yields, but increased the potential of N leaching losses. Overall, the ISI system successfully reduced water use by 59%, 50% and 43% compared with TSI method in three experimental years. In 2006, the TSI had a better impact on potato tuber yield than the ISI. Potato tuber yield was maintained by ISI treatment in 2007 and increased in 2008. Irrigation strategy was critical in minimizing nitrate leaching under ISI. In the first 2 years, irrigation water was supplied at night for 12 hours whereas, the irrigation schedule was changed to supply water during the day for 12 hours in the last experimental year. Nitrate concentrations in the shallow water table were minimized by supplying irrigation during the day due to less fluctuation of the water table depth under ISI.

Another 3-year study was conducted to investigate the feasibility of fertigation method for potato production. Five N rates (0, 112, 168, 224, 280 kg N ha^{-1}) were used as the whole plot factor in a split-plot design, while the split plot factor was two potato cultivars (*Atlantic* and *Fabula*). An average of 28.8 cm irrigation water was applied by drip throughout 3 experimental years, compared with 45 to 50 cm of the average irrigation applied with seepage irrigation systems. Water use was reduced 35 to 42% of that use by seepage irrigation. However, potato marketable yields were not maintained when the UF-IFAS recommended N rate (224 kg N ha^{-1}) was applied. The undesirable yields were resulted from the late application of fertilizers and water through drip, which was because drip tapes could not be installed until potato emerged. Therefore, a booster dose of fertilizer at planting to meet the nutrient requirement and establishment of potato plants is probably necessary to overcome the delayed fertigation problem.

CHAPTER 1
INTRODUCTION

Potatoes are an important economic crop in Tri-County Agricultural Area (TCAA) in northeast of Florida. In this area, approximately 9,000 ha of potatoes are grown annually on coarse sandy soils (Figure 1-1), which was approximately 60% of Florida's potatoes with an average annual value of 74 million dollars (Figure 1-2). The averaged potato yield from 1990 to 2009 in Florida State was 28.3 Mg ha^{-1}, which valued 123.2 million dollars averagely. The concern over increasing NO_3-N concentrations in the St. Johns River became a great challenge for competitive agricultural production, particularly potatoes, due to their high N requirement and low N recovery. Munoz et al. (2006) reported that more than 90% of potato root length for *Atlantic* cultivar was confined to the top 25 cm of the soil hills. The shallow root system associated with coarse sandy texture can result in a high potential for N leaching loss into the shallow water table.

Best Management Practices

Best Management Practices (BMPs) for potato production such as appropriate N rate with proper application time, optimum crop and irrigation management and control of N release are being developed by the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) to minimize N losses from agricultural fields (Cockx et al., 2003). An N rate of 224 kg ha^{-1} is the standard recommendation for potato production in the state (Hutchinson et al., 2009). Hochmuth et al. (2008) found that optimum potato yields were obtained at 196 kg N ha^{-1}, and that yield decreased with N rates greater than 224 kg ha^{-1}. Feibert et al. (1998) found that potato yield was maximized at the application N rate of 211 and 175 kg ha^{-1} with proper sprinkler irrigation management in 2 study years.

Seepage Irrigation

Seepage irrigation is commonly used in Florida due to cost-effectiveness and low maintenance requirement. Under this type of irrigation system, a shallow water table is maintained approximately 45 to 60 cm below the top of the row during the potato growing season. Water is pumped from a well and is then distributed to individual water furrows. Drainage ditches are usually arranged at the other end of the field to carry off excess water that could occur due to heavy rainfall. In a typical rainfall year, growers usually start irrigating about 30 days after planting, and turn off the system, except around heavy rainfall events, only at harvest. Proper management of the shallow water table was considered necessary to increase water use efficiency and tuber yields when seepage irrigation was used for potato production (Campbell et al., 1978).

Drip Irrigation

Applying both fertilizer and irrigation water through drip tubing has the potential to reduce both fertilizer application rate and water use. Sammis (1980) found that highest potato yields were produced with subsurface drip irrigation and achieved high water use efficiency by delivering uniform soil moisture in the root zone, compared with sprinkler, surface drip and furrow irrigation methods. Advances in drip tubing design allow the system to be installed below the tillage depth for use across multiple seasons. Additionally, drip tubing can be installed either in or above the root zone and can be removed after each crop. Equipment is available that will retrieve drip tubing from the field before harvest. Retrieved drip tubing can be used for multiple seasons. Simonne et al. (2002) showed that drip irrigation can be an economical practice for potato production in southeastern United States due to an addition profit from costs and returns using drip irrigation. Smajstrla et al. (1995) studied the effect of an automatically controlled subsurface drip irrigation system on potato yield compared with a conventional semi-closed seepage irrigation system. In their work, drip tubing was installed below the tillage depth with laterals spaced every 6 m. Similar potato yield was reported with subsurface drip irrigation compared with seepage irrigation, but with 33% less water use. The water saving was assumed to come from the fact that the shallow water table was maintained just below the bottom of the water furrow, reducing run-off during the season. No fertilizers were applied through the buried drip tubing in their study. However, in our study, the drip tubing was installed in each potato row. No shallow water table was maintained. Irrigation was based on estimated evapotranspiration rates for each 24 hour period during the season.

The act of applying fertilizer through the drip tubing is called fertigation - a combination of irrigation and fertilization. Fertigation allows precise applications of fertilizers. Fertilizer rates can be altered on a daily basis if needed. Certainly, with this system, one can adjust fertilizer application rates based on plant size, plant demand, and/or physiological state. When fertilizer application can be matched with plant demand, fertilizer use efficiency is improved, which means more of the applied fertilizer is taken up by the plant and does not leach beyond the root zone.

Irrigation Scheduling

Irrigation scheduling was defined by Jensen (1981) as "a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season for each crop that is grown." It is the process by which an irrigator determines the timing and quantity of water to be applied to the crops. With proper irrigation scheduling, crop yields will not be limited by water stress from droughts, and the wastage of water and the energy used in pumping will be minimized. Other benefits include reduced loss of nutrients from leaching as a result of excess water applications, and reduced pollution of groundwater or surface water from the leaching of nutrients. It is essential to know exactly how much water the plant is using by accurately measuring the water use for the particular site. Traditional crop factors and evaporation may give a general indication, but the actual water use varies significantly from site to site, depending on climatic factors, the growth stage of crops, bed spacing or crop density, the terrain etc.

It is important to develop irrigation scheduling techniques that are suited to local climatic conditions. To irrigate correctly, knowing of the amount of water using by plants and the water holding capacity of the soil is necessary. Because the objective of irrigation is to meet crop water requirement, the plants themselves are the best indicators of the need for irrigation. Irrigators should schedule the irrigation carefully to avoid losses from under- or over-watering. Insufficient water can lead to fruit quality and yield reduction, whereas over-watering can lead to losses of water, leaching nutrients and reduction in yield and quality. Van loon (1981) found that water stress could result in yield reduction by limiting leaf area and/or photosynthesis/unit leaf area. Potato yield could be diminished more greatly due to water deficit during tuber bulking stage than at any other growth stage.

Water is used in a crop production in several ways: 1) assimilation into the plants, 2) direct evaporation from the soil or other surfaces, 3) transpiration, and 4) other beneficial uses such as leaching of salts, crop cooling, and freeze protection. Most of the water applied to meet the water requirements of a crop is used in evaporation and transpiration. Evaporation and transpiration are important for cooling a crop in order to maintain temperatures in the range that permits optimal photosynthetic activity and crop growth to occur. Transpiration also helps transport nutrients into and through the plants.

The crop root zone can be visualized as a reservoir where water is temporarily stored for use by the crop. Inputs to that reservoir occur from both rainfall and irrigation. Unfortunately, rainfall is relatively unpredictable, and any rain that immediately follows irrigation is not very effective. Irrigation can be minimized by anticipating rainfall and providing soil storage capacity to increase rainfall effectiveness. If the capacity of soil water content and daily rates of ET are known, the date of next irrigation and the amount of water to be applied can be determined. Therefore, the soil water storage capacity in the root zone and ET comprise the basic information needed for irrigation scheduling.

Irrigation Scheduling Methods

To avoid under- or over- irrigation, it is important to estimate how much water is required by crops and how efficiently they can use it. Shock et al. (1998) concluded that deficit irrigation (70% of accumulated ET or less) for potato production in Oregon was not a feasible management scheme due to the risk of tuber yield reduction. There are many methods to measure these factors. They include direct measurements such as plant observation, feel and appearances of the soil, and using the soil moisture monitoring devices; or through indirect measurements that estimate available water using weather data. Among these methods, the indirect way is the most recommended.

A crop coefficient (Kc) relates crop water use at particular development stage to the amount of reference crop evapotranspiration (ETo) as calculated from automatic or manually collected weather data (Simonne et al, 2006). Crop coefficients are seasonally adjusted values that take into account the crop type, stage of growth, and crop cover. Water evaporates from soil and transpires from plant leaves. Together, these two phenomena are referred to as evapotranspiration (ET). ETc or ET crop is the water use rate of the crop that is being scheduled or managed. ETc is the amount of water that evaporates from the soil surface and transpires from the leaf surface to the atmosphere.

$$\text{Crop water use (ETc)} = \text{Crop coefficient (Kc)} * \text{Evapotranspiration (ETo)}$$

$$\text{Or, } ETc = Kc * ETo$$

Evapotranspiration

Evaporation is the change of water from liquid to vapor form. Energy is required for evaporation to occur. Solar radiation intensity is the main climatic factor that determines the ET rate, although air temperature, humidity, and wind also affect ET rates. The most significant crop factors that affect ET from a well-irrigated crop are crop species, the stage of growth, and the plant size or leaf area on which radiation is incident. ET rates are greatest when the entire soil surface is covered by the crop canopy. When the crop canopy is not complete, the ET rate is strongly influenced by the area of the leaf surface that intercepts sunlight. As growth increases, ET reaches its maximum at nearly complete ground cover. Alva et al. (2002) found that effects of irrigation management on potato yield were mainly significant with high ET than with lower ET growing conditions. Hang and Miller (1986) concluded that potato yield and quality were maintained when irrigation rate was near estimated ET on sandy soils. Yield and quality would not be increased if water application was higher than 100% ET.

Soil water storage

During irrigation, water infiltrates the soil and then distributes within the soil by gravity and soil capillary forces. When soils become wetter, gravitational forces dominate and water drains downward through. Drainage is rapid at first, but after 1 or 2 days, it decreases to a very low rate. At this time, soil moisture in the root zone may be considered to be in storage and available for depletion primarily by evapotranspiration. This upper limit of water storage is called “field capacity” (FC). A practical lower limit of soil water is defined as the soil water content below which severe crop water stress and permanent wilting occurs. This lower limit is defined as the permanent wilting point (PWP). The difference between FC and PWP is called the available water capacity (AWC). Once AWC is known, the total depth of water available, and thus the capacity of the soil water storage can be obtained by multiplying AWC by the crop effective root zone depth. The allowable soil water depletion is the fraction of the available soil water that will be used to meet ET demands. Since a lower ET will generally reduce yields, growers should irrigate before the root zone water content reaches a level that restricts ET.

Soil moisture monitoring

Soil moisture monitoring is used as a basis for irrigation scheduling as it can provide accurate information about the extraction of available water by the crop. Soil moisture can be measured as a suction or volume of water. Soil moisture suction can be used as a measure of plant stress and for that reason it is a handy tool for growers to use in scheduling their irrigations. Soil moisture monitoring instruments are most effectively used in combination with ET data. The instruments are read to determine when to irrigate, and the ET data are used to calculate the volume of water lost since the last irrigation. From this information, the volume to be replaced can be determined. Stieber and Shock (1995) concluded that soil moisture should be maintained between -50 and -60 J K^{-1} to achieve optimum potato yield. The potato plants were found to be particularly sensitive to soil water potential during tuber development, and tuber yield was positively related to mean soil moisture (Harris, 1978).

Controlled-Released Fertilizers

Nitrate-N is considered as a high potential source of non-point source pollution due to its negative charge repelled by soil colloids and its high solubility in water. Therefore, ammoniacal nitrogen fertilizers are recommended for use in sandy soils (Bundy et al., 1986). However, the potato plants have a preference for NO_3-N over NH_4-N (Havlin et al., 1999). Therefore, use of controlled-release fertilizers (CRF) and slow-release fertilizers (SRF) may help reduce nitrate leaching and increase nutrient use efficiency. The CRFs have been found to have certain negative effects on tuber yields. Lorenz et al. (1974) found lower yields were produced with sulfur-coated urea (SCU) than potatoes fertilized with $(NH_4)_2SO_4$. Liegel and Walsh (1976) also found that SCU produced lower yields compared with the use of urea in single or split applications. Cox and Addiscot (1976) compared SCU and calcium nitrate in potato production. They found no advantage to SCU in maintaining tuber yields. Lower yields were also found by Elkashif et al. (1983) with both 100% pre-plant isobutylidene diurea (IBDU) and SCU due to reduced N release from these sources during cold winter and cooler spring soil temperatures. Reduced yields with SCU could be attributed to lack of synchronization between N release and potato demand (Waddell et al., 1999). A slow initial release of N was not sufficient to meet the high N demand of potato plants early in the growing season, whereas N may have been released late in the season when crop did not need it. Improved N recovery and tuber yield with polyolefin-coated urea (POCU) was reported by Zvomuya et al. (2003). Due to a more synchronous association between availability and demand of N, Zvomuya et al. (2001) found that POCU had a potential to increase N uptake efficiency.

Application Timing

Kidder et al. (1992) proposed that since N could be easily leached in a sandy soil following a leaching rainfall (defined as 7.6 cm in 3 days or 10.2 cm in 7 days), a supplemental application of 34 kg ha^{-1} N should be applied to the crop. Wang and Alva (1996) found that the first rainfall event after application may be critical for urea-N losses from both urea and urea-based slow release fertilizers. Therefore, the timing of N application is critical to successful potato production. Hutchinson et al. (2009) suggested that two-thirds of the recommended N should be applied at planting and the remainder should be applied between 30 and 40 days after planting. Reduced amounts of N applied at planting were also recommended by Errebhi et al. (1998) to reduce NO_3-N leaching and improve N recovery and tuber yield. Munoz et al. (2008) suggested that use of sorghum as a summer cover crop could reduce the risk of nitrate leaching after potato harvesting by recovering the residual N from the potato season.

Polymer-Coated Sulfur-Coated Urea

A polymer-coated sulfur-coated urea (PSCU) consists of two coatings - an external polymer coating and an internal sulfur coating. The nutrient release from PSCU mostly depends on soil temperature rather than soil moisture or microbial activity (Paramasivam and Alva, 1997). The nutrient release rate from PSCU is regulated by the thickness of coating. Polymer provides a more uniform cover than sulfur. Sharma (1979) indicated that most sulfur-coated products contain about 10-15% imperfectly coated particles, which allows nutrients to diffuse rapidly. Zvomuya et al., (2001; 2003) used a 70-day release POCU, which was designed to release N at a faster rate than SCU, with however only 60% of N released by harvest time (about 150 days after application). Wilson et al. (2009) reported that more than 90% of the applied N had been released by 100 days after planting (DAP) using a 90-d release polymer-coated urea (PSU). Nutrient release rate from PSCU was not determined in this study. However, referring to Paramasivam and Alva (1997), it was established that 80% of N from PSCU had been released by about 100 days.

Objectives of This Study

In order to determine the feasibility of alternate irrigation systems in conjunction with nutrient management to improve water and N fertilizer use efficiencies in potato production in the St. Johns River watershed area, a 3-year study was established at the Hastings research center with the following objectives:

i) Determine the feasibility of the Intermittent Seepage Irrigation and Drip Irrigation for successful potato production as an alternate method to traditional seepage in conserving water resources,

ii) Determine the potential of PSCU as a controlled release N source for optimum potato production, efficient N uptake and minimized N leaching, and

iii) Determine if fertigation through the drip irrigation tubes is effective for optimum potato production and N use efficiency.

Hypotheses of This Study

The hypotheses of this study were: 1) The ISI is a more efficient irrigation method in reducing water use, increasing potato yield and N uptake as well as minimizing N leaching compared with the TSI, 2) The PSCU increases potato yield and N uptake and reduces N leaching compared with urea, and 3) Fertigation increases N use efficiency and reduces water use compared with seepage irrigation.

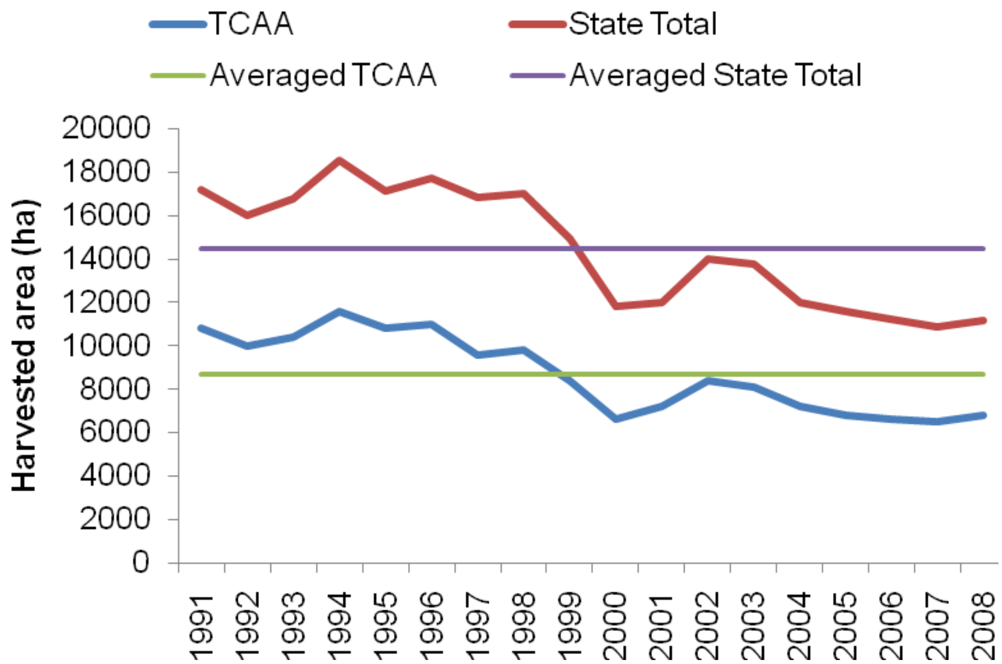


Figure 1-1. The harvested areas for potatoes from 1991 to 2008 in TCAA and Florida.

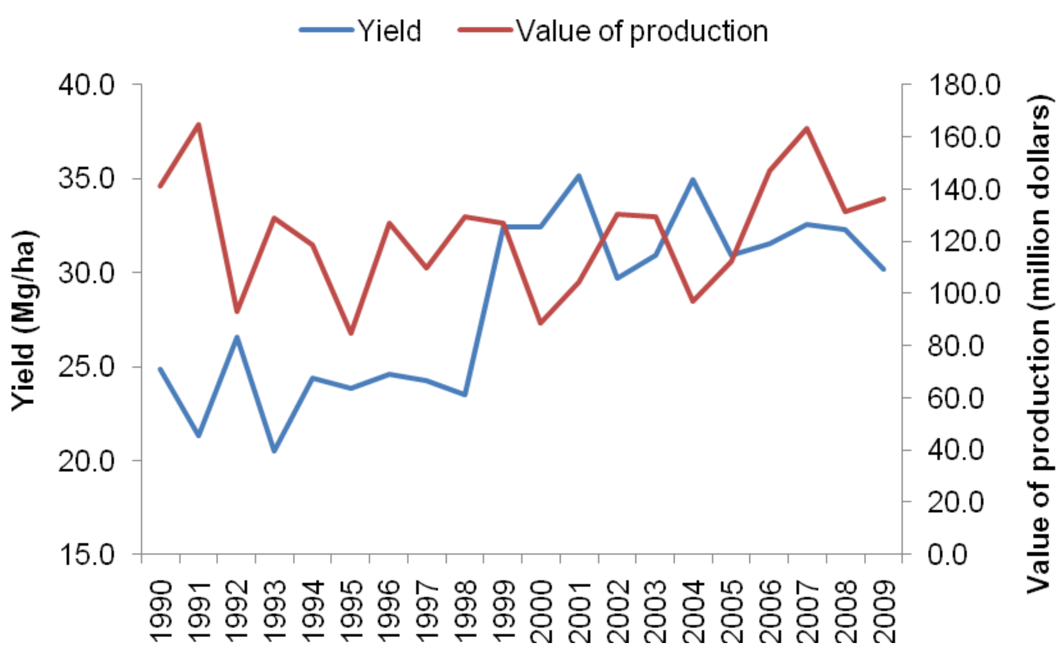


Figure 1-2. Potato yields and production values from 1990 to 2009 in Florida.

CHAPTER 2
MATERIALS AND METHODS

Controlled-Released Fertilizer and Alternate Seepage Irrigation Experiment

Site Description

This study was conducted during 2006 to 2008 growing seasons on Ellzey fine sand at the UF/IFAS Plant Science and Education Unit, Hastings Farm in Hastings, FL. The soil at this site has a loamy fine sand layer (Bt layer) at a depth of 90 to 150 cm (USDA, 1983), which contributes to poor water drainage and may preventing downward movement of N. Seepage irrigation in conjunction with rainfall during the spring seasons is a typical water management practice for growing potatoes in the northeast agricultural production area of Florida. Water was pumped from deep wells and a temporary water table over the Bt layer was built at 40-60 cm depth from the surface, and the root zone was supplied with moisture through capillary rise. Two irrigation methods were used in this study. The TSI, commonly used by farmers in northeast Florida, pumped water continuously through the crop season, except when a leaching rain event occurred. An alternate seepage irrigation method, the ISI, was also employed during this study for comparison, which supplied irrigation water 12 hours at nights in 2006 and 2007 and 12 hours during the days in 2008.

Experimental Design

The experimental plots were arranged in a split-split-plot design (Figure 2-1). The nature of seepage irrigation restricted whole-plot randomization. The whole plot factors were two irrigation treatments (TSI and ISI), the split plot factors were four N treatments that included a combination of two N sources (uncoated urea and polymer-coated sulfur-coated urea) and two N rates (168 and 224 kg N ha^{-1}), and the split-split plot factors were two potato cultivars (*Atlantic* and *Fabula*). Nitrogen treatments were arranged in a 2-way factorial design with four replications.

Irrigation Systems

Along with Traditional Seepage Irrigation (TSI), an alternate seepage irrigation method, Intermittent Seepage Irrigation (ISI), was also studied, reducing irrigation water use while supporting optimum potato yields. Under the ISI, water was turned on and off, automatically at a pre-set irrigation schedule, to maintain the desired water table depth.

Irrigation Volumes Calculation

The diagram of seepage irrigation was showed in Figure 2-2. The volumes of irrigation water were monitored by a flow meter at the inlet to the field for TSI treatment in 2008. The flow meter was connected to the one of the faucets in TSI plot on April 15th in 2008, and started recording irrigation volumes until harvesting. The flow meter data was manually collected twice a week. The flow rate of ISI treatment was assumed as same as the rate of TSI treatment because same pumping system was used for both treatment. The duration time of irrigation was manually recorded for both irrigation treatments. The averaged flow rate in liters per minute (L/min) was calculated by dividing total volumes of irrigation water by duration time of TSI treatment in 2008 grow season. Since the record of irrigation volumes were not available in 2006 and 2007, the flow rate was assumed to remain constant throughout all the experimental years, even though it might change in response to changes of pumping pressure or other reasons. Therefore, the total irrigation volumes in 2006 and 2007 were calculated by multiplying the averaged flow rate and duration time in these years. Water use (cm) was determined by dividing total volumes of irrigation water by the irrigated area of each treatment.

Planting

Potato seed pieces weighing approximately 55 g were hand-planted on Mar 1st, Feb 23rd and Mar 5th in 2006, 2007 and 2008, respectively, with 102 cm spacing between rows and 20 cm spacing within rows. Each individual plot consisted of four 15-m-long rows. Furrows used to supply irrigation were located between every 16 potato rows, which formed a bed.

Fertilizing

Polymer-coated sulfur-coated urea (PSCU) was compared with uncoated urea, applied at the rates of 168 and 224 kg N ha^{-1} with four replications, the latter rate being the standard N recommendation of UF/IFAS (Hochmuth and Hanlon, 1995) and is considered a significant part of the Best Management Practices for potatoes in Florida. All plots received 34 kg P_2O_5 and 197 kg K_2O ha^{-1} pre-plant. All fertilizers were banded and incorporated in a single application 10, 2 and 3 days prior to planting in 2006, 2007 and 2008, respectively (Figure 2-3).

Soil Sampling and Analysis

In 2006, soils were collected 17 days before planting and 56, 76, and 112 DAP. In 2007, soils were sampled 7 days before planting and subsequently at 29, 64, and 91 DAP, and in 2008, 20 days before planting followed by 37, 54, and 81 DAP. A representative consolidated soil sample was collected from twelve points randomly selected in the two center rows within each subplot. A one-side-open tubular auger with a 1.9 cm diameter was used to collect soil samples to a depth of 20 cm below the surface. Samples were collected in labeled plastic bags, air-dried, and passed through a 2-mm sieve for subsequent laboratory analyses. Soil samples were analyzed for pH, NO_3-N and NH_4-N. All the laboratory analyses were determined at the UF/IFAS

Analytical Services Laboratories (ASL) as per the standard procedures (Mylavarapu, 2008).

Tissue Sampling and Analysis

Whole potato plants with tubers were collected around 64 DAP at full flowering in three study years. Two plants were randomly selected from each subplot. Potato vines were separated into leaves and stems, oven-dried, weighed and ground for nutrient analyses. Also, two of the tubers selected from each subplot at harvest were diced, fresh weighed, oven-dried, dry weighed and ground for further analysis. All ground tissue and tuber samples were analyzed for total Kjeldahl nitrogen (TKN).

Shallow Water Table Depth and Water Sampling

A 10-cm diameter PVC pipe was installed in each subplot to a depth of 80 cm from the top of the center row after emergence (about 40 DAP) in each experimental year. Water samples were taken from the wells at 41, 55, 69, 83 and 97 DAP in 2006, 43, 57, 71, 84, and 99 DAP in 2007 and at 42, 58, 72 and 86 DAP in 2008. The fifth sampling was not done in 2008 due to the early harvest that year. Water samples were collected in 20-mL vials, frozen, and analyzed for NO_3-N and NH_4-N. Shallow water table depth inside each observation well was measured manually with a meter stick.

Soil Moisture

Soil moisture profile probe access tubes were installed within 30 cm of observation wells in one of two replicated irrigation beds. Volumetric soil moisture was measured at 10, 20, 30, 40, 60 and 100 cm below the top of the potato rows using a soil moisture profile probe (PR2) (Delta T Devices, 2005). Both soil moisture and water table depth were recorded at the same time on weekly schedule until harvest.

Harvesting

Potatoes were harvested on June 20th in 2006, June 4th in 2007 and June 10th in 2008, which corresponded with 110, 104 and 99 DAP in the three experimental years, respectively. Potato tuber yields were determined by harvesting plants from 7.6 m row-length in the two center rows from each subplot and grading the tubers into five size categories based on tuber diameters according to USDA standards for grades of chipping potatoes (B=<4.8, A1=4.8-6.4, A2=6.4-8.3, A3=8.3-10.2, A4=>10.2 cm) (USDA, 1978). Categories A1 to A3 were considered marketable yield. Total yield was calculated by the summation of all of the categories as well as culls (greens, cracked, misshapen, sunburn and rotten tubers). A sample of 20 tubers randomly selected from each subplot was used to determine the specific gravity using the weight-in-air/weight - in-water method.

Data Analysis

Data for each year were analyzed separately with PROC MIXED (SAS Institute, 2008). Treatment means were compared using Tukey's honest significant differences multiple comparison method.

Drip Irrigation Experiment

A split-plot design with four replications was used in this experiment (Figure 2-4). The whole plot factor was five N rates (0, 112, 168, 224, 280 kg N ha^{-1}), while the split plot factor was two potato cultivars (*Atlantic* and *Fabula*). Potato seed pieces weighing approximately 55 g were hand-planted on Mar 1st, Feb 23rd and Mar 5th in 2006, 2007 and 2008, respectively, with 102 cm spacing between rows and 20 cm spacing within rows. Each individual plot consisted of four 15-m-long rows. The drip tubing (Netafim USA, Inc., Fresno, CA) was placed above the seed piece, approximately 6 cm below the soil surface but was offset from the center of the row. It had a drip spacing of 30.5 cm and a dripper flow of 0.38 mL/s at 69 kpa. No shallow water table was maintained. ETc was calculated by multiplying ET_0 by Kc. The ET_0 values were recorded at the Florida Automated Weather Network (FAWN) weather system at the research station. The crop coefficient numbers at each crop growth stage were referred to the work of Simonne et al. (2006). The fertilizer treatment delivered 25% of the total nutrients by tuber initialization, 50% between tuber initialization and full flowering, and 25% during tuber bulking.

Irrigation Water Treatment

Irrigation water was chemically treated and filtered to prevent clogging of the drip emitters. Water for the drip irrigation system was taken from a deep well. Water passed through three filters before delivery to the field. The first one was a mesh filter to retain soil particles and two disc filters before adding the fertilizer solution. The drip fertigation system was composed basically of a water treatment unit and a fertilizer mixer unit. The objective of the water treatment unit was to flocculate impurities in order to retain them in the filters before delivering water to the drip lines. Initially, hydrochloric acid (muriatic acid, 31.5%) was added to decrease water pH from approximately 7.3 to 6.5. At pH 6.5, hypochlorite added reaches the maximum concentration of free chlorine. Free chlorine concentration after injection of sodium hypochlorite should be 15 mg/L at the injection point and at least 2 mg/L at the end of the drip lines. Hydrochloric acid and hypochlorite solutions were prepared in 208 L plastic drums and injected to the water supply main line through chemical injectors (Chemilizer, HN55) with a mixing ratio of 1:100.

Drip Fertigation

In 2006, a liquid 10-0-11 blend fertilizer was used and supplemented with KCl (62%) to maintain the same N:K proportion (1:1.5). Phosphoric acid (59% P_2O_5) was used as P source and applied at a rate of 33.6 kg P_2O_5 ha^{-1} in two applications. In 2007 and 2008, a liquid 7-0-7 blend fertilizer was used for K and N source. Fertilizers and water were mixed in 208 L plastic drums and injected to drip tubes for each N treatment. The control treatment was only supplying water throughout the seasons. Fertigation and irrigation schedule was set up weekly regarding to the ET values calculated by multiplying ET_0 and crop factors for each growth stage.

Calculation of Irrigation Volumes

Irrigation volumes were recorded by a flow meter at the inlet to the fertilizer injectors. Irrigation occurrence and durations were automatically controlled and manually recorded. Irrigation schedule was set up once a week based on ET_0 information by FAWN.

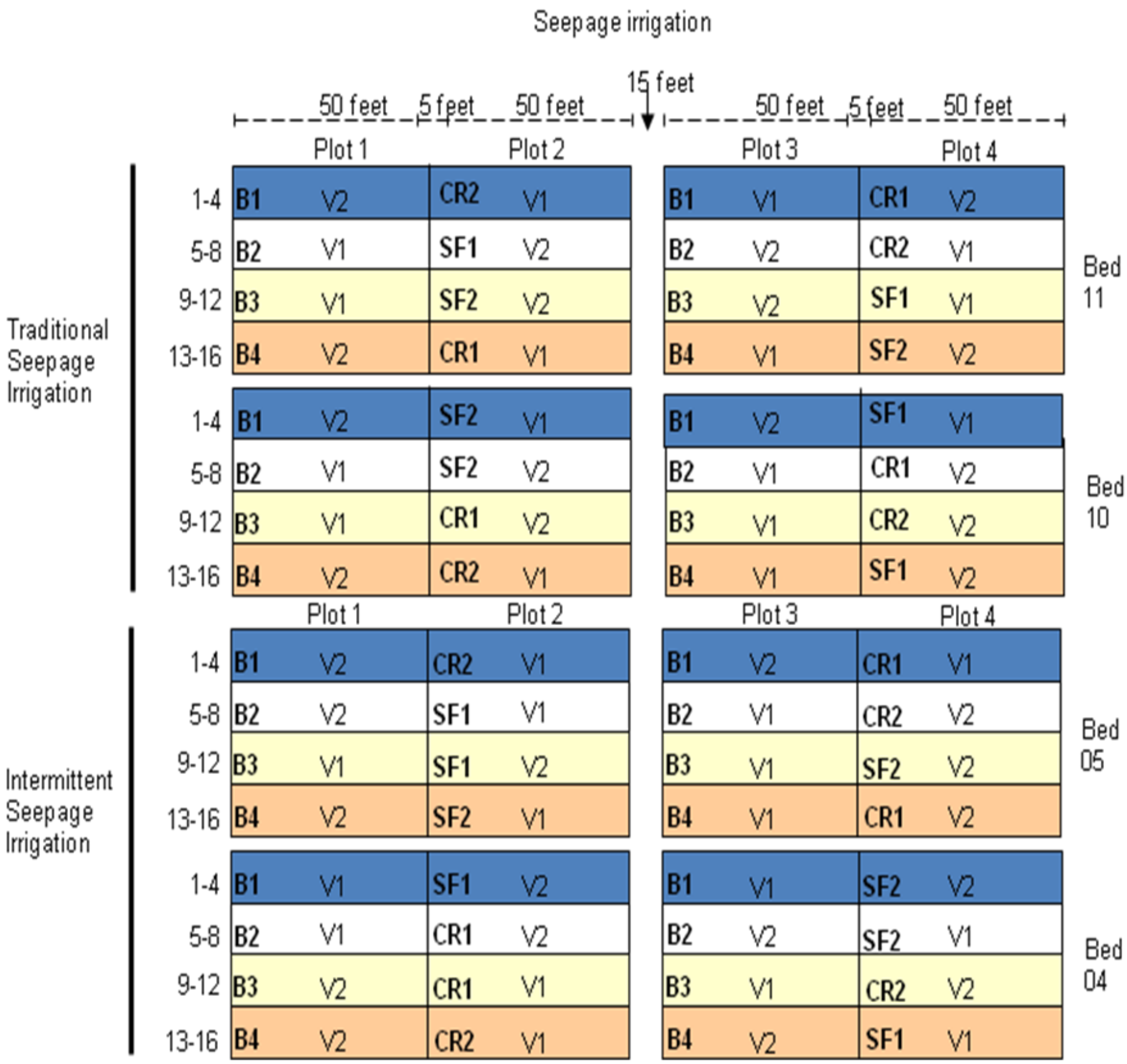


Figure 2-1. Experimental design used for seepage irrigation during 3 years. SF1: soluble urea at rate of 168 kg ha^{-1}. SF2: soluble urea at rate of 224 kg ha^{-1}. CR1: control released fertilizer at rate of 168 kg ha^{-1}. CR2: control released fertilizer at rate of 224 kg ha^{-1}. V1: Atlantic. V2: Fabula.

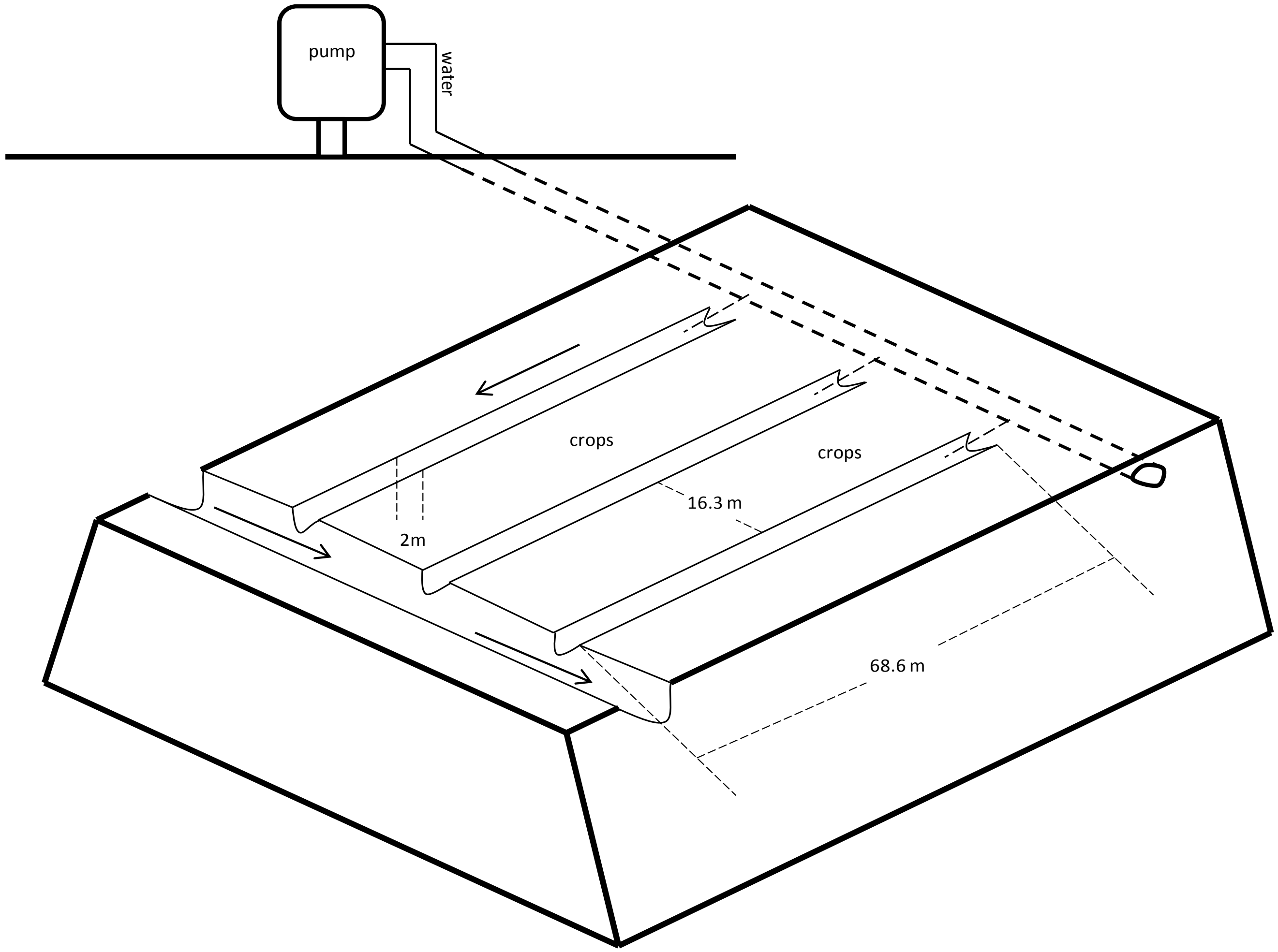


Figure 2-2. Diagram of seepage irrigation system used for potato production.

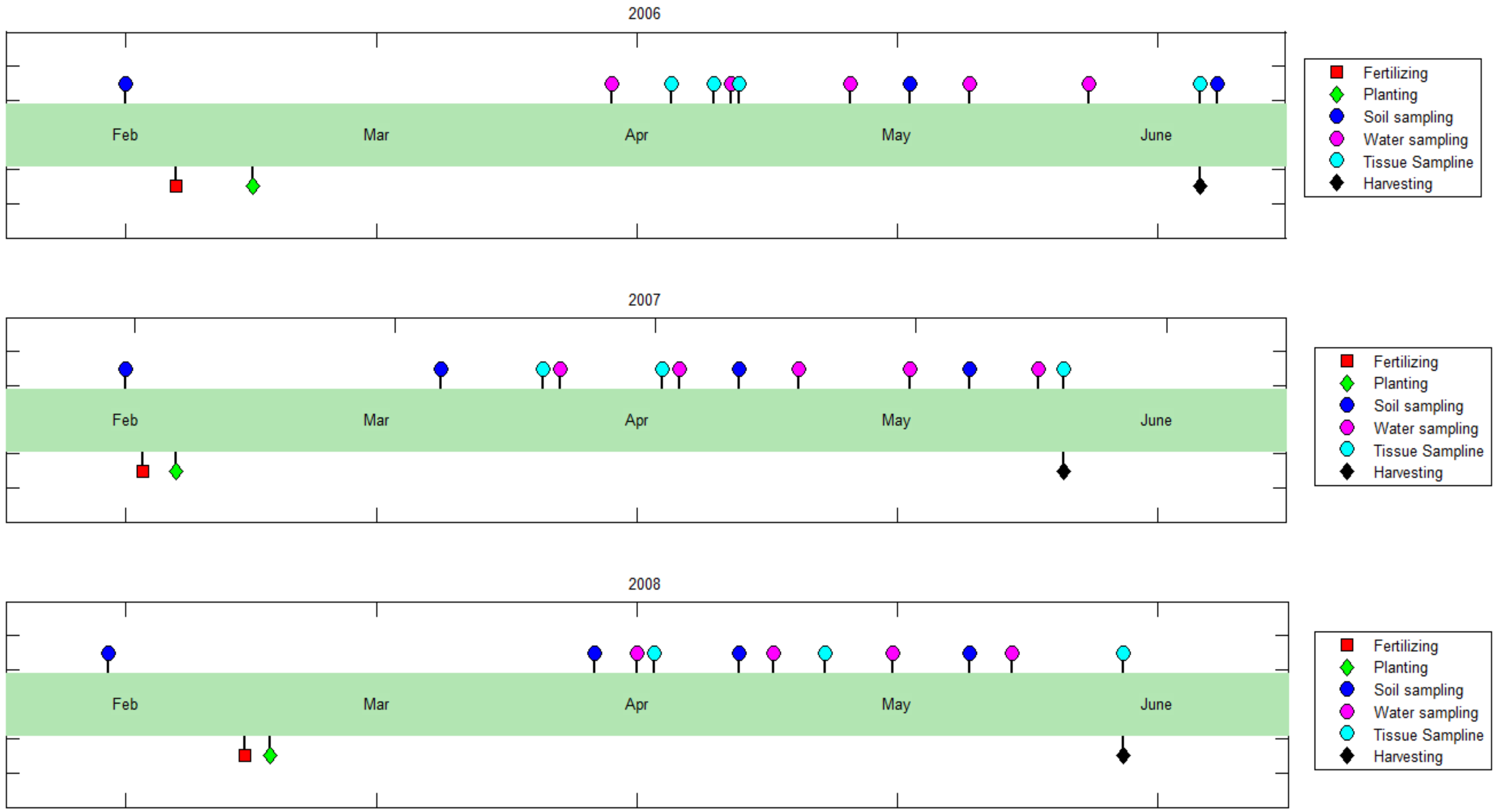


Figure 2-3. Sampling schedules used for 3 years.

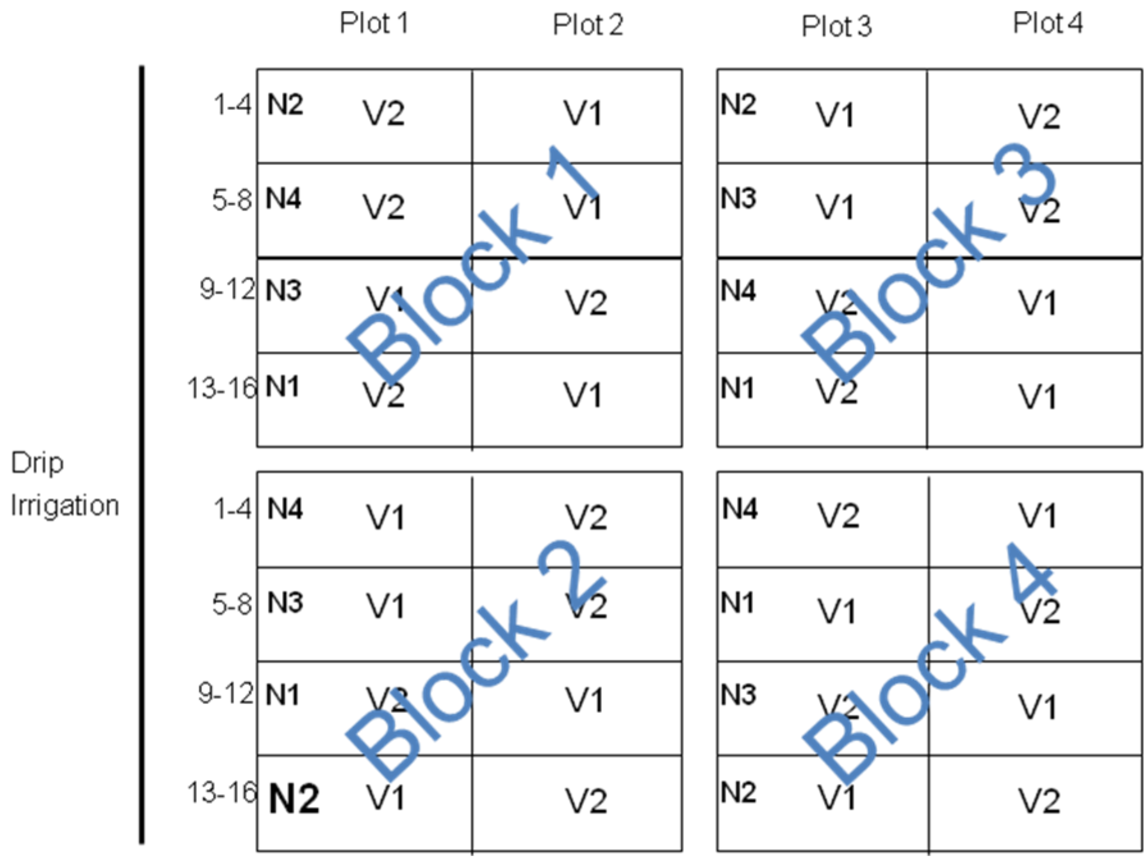


Figure 2-4. Experimental design used for drip irrigation during 3 years. N1=112 kg ha^{-1}, N2=168 kg ha^{-1}, N3=224 kg ha^{-1}, N4=280 kg ha^{-1}. V1: Atlantic; V2: Fabula.

CHAPTER 3
THE EFFECT OF N MANAGEMENT ON POTATO TUBER YIELD, N RECOVERY AND LEACHING

Weather and Irrigations

Mean rainfall and soil temperature (-10 cm) during the 2006, 2007 and 2008 growing seasons are presented in Table 3-1. In 2006, only 4.8 cm rainfall occurred from March to May, which was the critical period for potato growth. The total rainfall was 13.8 cm, which was about 10 cm lower than the 10-yr average (24 cm) (FAWN database). Therefore, the 2006 growing season was identified as a dry season. Crop water requirement was supplemented by 79 and 33 cm of irrigation water with TSI and ISI, respectively (Figure 3-1). In 2007, total rainfall during the potato season was 23.4 cm, which was similar to the 10-yr average for the same period. This rainfall was supplemented with 73 cm of TSI and 36 cm of ISI. The biggest rainfall event early in the season was 5.9 cm. It occurred from Mar 1st to Mar 3rd, which was 1.7 cm less than a leaching rainfall, followed by a deficit of rainfall (3.7 cm) from Mar 17th through May 13th. In 2008, total rainfall during the growth season was 19 cm, which was approximately 21% below the average. A leaching rainfall (8.7 cm in 3 days) occurred at 2 DAP, which was 7 days after fertilizing. A severe rainfall deficit occurred from Mar 21st through May 22nd, when only 0.4 cm rain fell in 63 days. Traditional seepage and ISI supplied 57 and 34 cm irrigation water, respectively, to supplement this deficit during the middle and late season. Soil temperature averaged from planting to emergence in 2007 (18.5°C) was similar to that in 2008 (18.6°C), even though planting was 8 days later in 2008. However, from emergence to tuber initiation, soil temperature in 2007 (20.4°C) was 1.4 °C lower than that in 2008. This difference was a factor influencing tuber initiation, and subsequently affecting tuber yields. Waddell et al. (1999) reported a lower tuber yield and crop N uptake in the warmer season, suggesting that warm soil temperature can inhibit or even reverse tuberization.

Tuber Yield and Quality

After statistical analysis of the data, interactions were found between year and N treatments, as well as year and cultivar treatments. In 2006, similar total and marketable tuber yields were recorded with two N sources (Table 3-2). Meanwhile, the higher N rate (224 kg ha^{-1}) did not increase tuber yields compared with the lower N rate (168 kg ha^{-1}). The only differences in marketable yield were observed between two cultivars; marketable yield of *Atlantic* was significantly higher than *Fabula*. Besides, N sources and N rates also had similar impact on specific gravity of potato tubers, even though *Atlantic* had a higher specific gravity than *Fabula*.

In 2007, neither N source nor N rate had an effect on any of the tuber yield categories (Table 3-3). The only difference in total and marketable yield detected was between the two potato cultivars. Cultivar *Fabula* produced a significantly higher total and marketable yield than var. *Atlantic*. However, *Atlantic* significantly yielded more A3 (8.3-10.2 cm) tubers, which were considered as large-sized tubers for marketable yield, compared with *Fabula*. Cultivar *Atlantic*, the standard variety for chipping, had a significantly higher specific gravity of 1.0958 compared with var. *Fabula* (1.0759).

In 2008, potatoes did not emerge 100% due to heavy rainfall right after planting. Reduction in both total and marketable yield was recorded in this year. Leaching rainfall early in the season and poor tuber set was significantly responsible for the lower yields. Compared with urea, PSCU with a single application at pre-plant significantly increased total yield from 20.03 to 24.85 Mg ha^{-1}, and marketable yield from 14.98 to 17.90 Mg ha^{-1}. However, it also increased undesirable tubers and culls (Table 3-4). There was no advantage from applying N fertilizer at a higher rate (224 kg N ha^{-1}) for total and marketable yield. Tubers produced at the application rate of 168 kg N ha^{-1} had a similar size distribution compared with tubers produced at the higher N rate. Yield response to cultivars in 2008 followed the trend of 2007, except that more medium-sized (6.4-8.3 cm) and equivalent large-sized tubers resulted from var. *Fabula* compared with var. *Atlantic*. Similar to 2007, in 2008 also, var. *Atlantic* had higher average specific gravity than var. *Fabula*. However, specific gravity values of all treatments in 2008 were numerically lower than in 2007.

As a controlled-release N source, PSCU produced different tuber yields in 3 production years compared with uncoated urea. Several factors could be the reason for the difference. The most critical reason was that a significant leaching rainfall occurred 7 days after fertilizing, which may have contributed to a significant leaching loss of urea-N from uncoated urea than from PSCU. Wang and Alva (1996) found that in sandy soils, leaching of N from a soluble N source may depend on the first few leaching events. Paramasivam and Alva (1997) reported after 10 cm rainfall, 19.6% of urea-N was leached from uncoated urea 12 days after N application to the soil. However, in case of PSCU, a significant portion of urea-N was leached from 18 to 48 days after N application. Therefore, early season rainfall gives PSCU an advantage over soluble N for reducing leaching losses.

Previous studies have found certain CRFs can produce yields similar to soluble N sources at the equivalent rates. Hutchinson et al. (2003) found no difference in total and marketable yield by using a combination of 50% PSU and 50% PSCU compared with a combination of 50% ammonium nitrate (AN) and 50% urea at N rates of either 168 or

224 kg N ha^{-1}. Similar potato yields and tuber sizes with PSCU and AN were also reported by Pack et al. (2005).

The average potato yield in Florida from 1990 to 2009 was 28.3 Mg ha^{-1} (USDA database). In our study, the average total and marketable yields in 3 years were 31.9 and 25.2 Mg ha^{-1}, 32.1 and 28.5 Mg ha^{-1}, and 22.4 and 16.4 Mg ha^{-1}, respectively. The highest potato yield was produced in 2007, which was characterized with the highest precipitation and the lowest soil temperature throughout the season. The highest yield probably resulted from slow release of PSCU which supplied more N late in the season after soluble N was leached or used. Leaching from the soluble N source was also reduced since the rainfall events occurred more even compared with the other two years. Total yields in 2006 and 2007 were similar, however, marketable yield in 2006 was approximately 3 Mg ha^{-1} less than in 2007 and 20-year average in state. The difference was due to more culls produced in 2006, which probably resulted from dry and warm weather conditions in that year. Both total and marketable yields were low in 2008. The undesirable tuber set and excessive leaching influenced by the unpredictable leaching rainfall contributed to the poor production. Besides, side-dress of urea about 40 DAP usually required for the typical fertilization practices. However, in our study, in order to compare the impact of CRF and soluble sources with the same field operations, side-dresses were not conducted for urea source, which was also resulted in poor potato yields.

Nitrogen Recovery

Nitrogen uptake by tubers was higher with PSCU in 2006 (Table 3-5), however, the N uptake by vines was lower with PSCU than with urea, which resulted in a significant higher total N recovery with urea. Nitrogen rate did not affect N uptake either by tubers or vines. The *Atlantic* tubers took up more N than the *Fabula* tubers, however, no differences in N uptake were found in their vines. Nitrogen uptake by tubers and vines was unaffected by N sources or N rates in 2007. Cultivar *Fabula* accumulated more N in vines and tubers than var. *Atlantic*, reflecting the yields obtained. In 2008, the PSCU contributed to higher N recovery by potato tubers compared with urea. The N uptake by vines, along with the total N uptake, increased with N rate. The total N accumulation by tubers of var. *Fabula* was higher than the tubers of var. *Atlantic*, although the total accumulation in both cultivars was similar. Similarly, N recovery by the potato crop varied considerably among years. An average of 130.6 kg N ha^{-1} was recovered by the crop in 2007, which exceeded the average total N of 76.6 kg N ha^{-1} recovered in 2008. All the N recovery results agreed with the effect of N and cultivar treatment on total and marketable tuber yields. Nitrogen content in potato roots was not measured in this study. It is likely that there were some differences of N content in the roots for various N treatments. The difference in N recovery between 2007 and 2008 was a result of higher leaching losses in 2008. Hutchinson et al. (2003) also reported on the differences of N uptake by plants by using PSCU and urea. Joern and Vistosh (1995) found N rates of 112-168 kg N ha^{-1} maximized dry matter production and plant tissue N concentration at harvest. Zvomuya et al. (2001) recorded better N use efficiency with polyolefin-coated urea (POCU) than with urea which could reduce loss of N through leaching. Errebhi et al. (1998) also found higher N recovery associated with higher tuber yield and better tuber quality because the more N taken up by crops and converted into organic forms, the less potential for leaching loss.

Nitrogen Use Efficiency

In this study, nitrogen use efficiency (NUE) was determined by dividing the marketable yield by the N application rate for each treatment. The PSCU was expected to be a more efficient N source in NUE for both N application rates compared with urea, since less leaching with PSCU was expected especially under the condition of uneven distribution of rainfall events. In 2007 and 2008, PSCU at 168 kg N ha^{-1} rate had the highest NUE compared with other treatments (Figure 3-2). However, the significant difference was not observed in 168 kg N ha^{-1} rate in 2006 and 224 kg N ha^{-1} rate in 2007. In 2006, the averaged soil temperature throughout the potato season was 23.4°C, which was higher than 21.2°C and 22.5°C in 2007 and 2008, respectively. The high soil temperature could result in fast release of N from PSCU and increasing the risk of leaching as urea treatment. In 2007, the low soil temperature throughout the growing season slowed down the N release from PSCU, which reduced the leaching risk with PSCU treatment. Combined with the most rainfall events, PSCU at 168 kg N ha^{-1} rate had the highest NUE compared with other treatments. However, similar NUE with two N sources at 224 kg N ha^{-1} rate could result in the late supplying of N from PSCU in the season due to the slow release. In 2008, NUE values with PSCU treatment were significantly higher than urea treatment for both N rates. A leaching rainfall occurred 3 DAP rendered PSCU superiority in increasing NUE values. In 2006 and 2008, the lowest NUE values were recorded with urea at 224 kg N ha^{-1} rate. Therefore, urea with a single application was not recommended for maintaining marketable yields and NUE values. Hutchinson et al. (2003) demonstrated that NUE for all N sources they used including the PSCU were not significantly different for the 168 and 224 kg N ha^{-1} rate. However, the PSCU was not tested only as a controlled release source. They used 50%

of polymer coated urea (PCU) and 50% of PSCU as a combined CRF treatment at 168 and 224 kg N ha^{-1} rate.

NO_3-N and NH_4-N Concentrations in the Shallow Water Table

In 2006, PSCU reduced both NO_3-N and NH_4-N concentrations at the first sampling event under TSI system (Figure 3-3). A difference in NO_3-N concentrations was also recorded between two N application rates at the first event. Under ISI (Figure 3-4), however, no evidence was showed that PSCU contributed to a lower NO_3-N concentration than urea, even though the NH_4-N concentrations with PSCU were significantly lower at the first and second sampling events. The NO_3-N concentrations in the shallow water table were barely affected by N sources under both TSI and ISI system for all sampling events in 2007 (Figures 3-5, 3-6). Compared with N sources, NO_3-N leaching was influenced more by N rates, especially in the earlier sampling events under TSI system. Significantly higher NO_3-N concentrations were found in the first (43 DAP) and second (57 DAP) sampling events with the N rate of 224 kg ha^{-1} under TSI system, however, no effect of N application rate was observed for nitrate concentrations under ISI system. Similar NH_4-N concentrations were determined by both N sources and rates under two seepage systems. In 2008, N sources had no effect on NH_4-N concentrations under both TSI and ISI system across the sampling events (Figure 3-7, 3-8), whereas the lower N application rate (168 kg ha^{-1}) reduced NH_4-N loss at the early sampling events for both seepage systems. Different results of NO_3-N concentrations influenced by N sources were found relative to irrigation system. Under TSI system, PSCU barely reduced nitrate loss except for the first sampling event, whereas under ISI system, nitrate concentrations with PSCU were higher than the concentrations with urea at the second and third events. The higher N rate also contributed to a higher NH_4-N concentration across all sampling events under TSI system. However, no variance in NH_4-N concentration was determined between two N rates under ISI system. The result indicated that the difference of NO_3-N losses with two N application rates could be minimized by reducing water application amounts during the season. The greatest difference in 3 years was observed at the first sampling event, when an average of 0.75, 4.50 and 7.96 mg L^{-1} NO_3-N was measured in 2006, 2007 and 2008, respectively. The leaching rainfall in 2008 occurred 2 DAP, possibly resulting in the difference of N leaching loss, and in the subsequent lower N recovery by crop and lower tuber yields that year. Pack et al., (2005) found no significant difference in NO_3-N concentration between treatments in shallow water table samples. The authors suggested that no difference was due to a high dilution of nutrients in the large shallow water table below the plots. Besides, wells in our study could not be installed in the field until about 40 days after planting, which was too late to observe the leaching losses in the early season.

Generally, the average concentrations of NO_3-N and NH_4-N across all treatments decreased with sampling dates, except for the dynamic of NO_3-N concentrations with 168 kg N ha^{-1} treatment in 2006 and 2007 and with PSCU treatment in 2006. All of the exceptions were observed under TSI system. Since no early observations of nitrogen loss were available in our study, we assumed that higher nitrogen concentrations might have been determined before the first sampling event in each year, especially after the heavy precipitation events occurring early during each growing season. Besides, PSCU reduced nitrate concentrations at the first sampling event in 2006 and 2008 under TSI system, which suggested with high rate of irrigation, PSCU had the potential to reduce nitrate leaching compared with urea. It was also assumed that significant variance of leaching loss by using PSCU and urea was possibly found early in the season.

Wang and Alva (1996) reported up to 30% of the total N applied as slow-release fertilizer was leached from sandy soils, whereas, more than 88% of total N was leached when AN was used. The authors also suggested that in sandy soils, leaching of urea-N could be an important part of total N loss from urea-based slow-release fertilizers, especially with the first precipitation events. Paramasivam and Alva (1997) found leaching amounts of total N (sum of urea NH_4 and NO_3) in 100 days were 59% and 44% applied as PSCU and urea, respectively. The lower N leaching from urea was the result of loss N through volatilization and denitrification. Bundy et al. (1986) suggested that urea-N could be lost by leaching of unhydrolyzed urea, volatilization and greater loss through leaching due to more rapid nitrification compared with an ammonium N source. Zvomuya et al. (2003) found that a single application of PCU improved recovery of N and reduced NO_3 leaching compared with three applications of urea. Similar results were reported by Waddell et al. (2000) when comparing SCU with urea.

Contents of NO_3-N and NH_4-N in the Surface Soil

In 2006, soil NO_3-N content was affected by both N sources and application rates at all sampling events after fertilizing and planting (Figure 3-9). The urea treatment resulted in a significantly higher NO_3-N concentration in the surface soil before harvesting, compared with the PSCU treatment. On the other side, NO_3-N content with application rate of 224 kg N ha^{-1} was higher than with 168 kg N ha^{-1} across three sampling events after fertilizing. Soil NH_4-N content was also influenced by N source and rate at certain sampling events. Generally speaking, soil N content increased more rapidly with urea than with PSCU, especially for soil NO_3-N content. However, more N was retained in surface soil by using PSCU at the last sampling event, which indicated that PSCU released more slowly than urea. This result rendered PSCU a potential in reducing N leaching into the shallow water table. In 2007, both NO_3-N and NH_4-N residues in the surface soil were affected by N sources in the late season (Figure 3-10). High amounts of NO_3-N and NH_4-N remained in the soil with urea at the last two sampling events (64 and 91 DAP). There was no effect of higher N rate on residual soil NO_3-N or NH_4-N during the whole season. Similar results were found in 2008, when N rates failed to influence the content of both N forms in the surface soil (Figure 3-11). A higher NO_3-N content of 27.4 mg kg^{-1}with PSCU was recorded in the third sampling event (54 DAP). After pre-plant sampling, a higher NH_4-N accumulation with PSCU than with urea until harvesting was observed. Averaged across all treatments, the cumulative NO_3-N content of 111.27 mg kg^{-1} in 2007 surpassed the 80.52 mg kg^{-1} amount determined in 2008, while the cumulative residual NH_4-N of 50.49 mg kg^{-1} in 2007 exceeded the residual of 34.63 mg kg^{-1} in 2008. Differences in tuber yields and N uptake by crops were consistent with the differences in available soil N. In regard to the lower N recovery in 2008, the lower N residue in the surface soils indicated a higher N leaching loss in the early season of that year. Low mineral N contents in the top 20 cm of soil at pre-plant were measured as 3.5 mg kg^{-1} and 5.2 mg kg^{-1} in 2007 and 2008, respectively. Meyer and Marcum (1998) concluded that higher N rates were needed to be applied to achieve optimum yields, if low pre-plant soil-N concentrations were observed.

Table 3-1. Mean monthly rainfall and soil temperature (- 10 cm) for three growing seasons.

	2006		2007		2008	
	Soil Temp (°C)	Rainfall (cm)	Soil Temp (°C)	Rainfall (cm)	Soil Temp (°C)	Rainfall (cm)
Feb	14.7	16.3	15.4	14.0	17.3	9.40
Mar	18.3	1.50	18.8	10.4	18.2	11.3
Apr	22.7	2.50	21.1	3.10	21.3	0.30
May	25.3	0.80	23.9	3.20	24.3	1.60
Jun	27.3	11.9	26.7	12.9	27.2	16.7

Table 3-2. Comparison of tuber yield, quality and distributions for various N sources, rates and cultivars during 2006.

N and cultivar treatment	Tuber yield (Mg ha-1)								Specific gravity
	Mkt	Total	Cull	B	A1	A2	A3	A4	
N source									
PSCU	25.88	32.86	3.96	3.02	23.09	2.80	0.00	0.00	1.071
Urea	24.67	30.97	4.05	2.25	19.29	5.32	0.06	0.00	1.072
N rate (kg ha-1)									
168	25.51	32.08	3.92	2.65	21.67	3.84	0.00	0.00	1.071
224	25.05	31.76	4.09	2.62	20.71	4.28	0.06	0.00	1.072
Cultivar									
Atlantic	27.16a	33.20	3.16	2.88	22.45	4.66	0.04	0.00	1.081a
Fabula	23.40b	30.63	4.85	2.39	19.93	3.45	0.01	0.00	1.062b

Note: Marketable yield was calculated by the summation of A1 through A3 tuber grades. Tubers were graded as B=<4.8, A1=4.8-6.4, A2=6.4-8.3, A3=8.3-10.2, A4=>10.2 cm. No interactions were found between either two of the treatments. Treatment means were compared within columns using Tukey's honest significant differences multiple comparison method at the 0.05 probability level. PSCU, polymer sulfur coated urea.

Table 3-3. Comparison of tuber yield, quality and distributions for various N sources, rates and cultivars during 2007.

N and cultivar treatment	Tuber yield (Mg ha^{-1}) Marketable	Total	Culls	B	A1	A2	A3	A4	Specific gravity
N source									
PSCU	29.57	33.35	1.28	2.45	18.07	7.67	3.83	0.05	1.0856
Urea	27.47	30.84	1.00	2.36	17.02	7.01	3.45	0.01	1.0859
N rate (kg ha^{-1})									
168	28.90	32.45	1.15	2.39	17.51	7.69	3.70	0.01	1.0852
224	28.15	31.73	1.12	2.41	17.57	6.99	3.59	0.05	1.0864
Cultivar									
Atlantic	26.56b	30.15b	1.01	2.52	14.03b	7.78	4.75a	0.06	1.0958a
Fabula	30.49a	34.04a	1.27	2.28	21.05a	6.90	2.53b	0.00	1.0759b

Note: Marketable yield was calculated by the summation of A1 through A3 tuber grades. Tubers were graded as B=<4.8, A1=4.8-6.4, A2=6.4-8.3, A3=8.3-10.2, A4=>10.2 cm. No interactions were found between either two of the treatments. Treatment means were compared within columns using Tukey's honest significant differences multiple comparison method at the 0.05 probability level. PSCU, polymer sulfur coated urea.

Table 3-4. Comparison of tuber yield, quality and distributions for various N sources, rates and cultivars during 2008.

N and cultivar treatment	Tuber yield (Mg ha^{-1})								Specific gravity
	Marketable	Total	Culls	B	A1	A2	A3	A4	
N source									
PSCU	17.90a	24.85a	3.74a	3.21a	15.89a	3.06	2.09	0.00	1.0675
Urea	14.98b	20.03b	2.60b	2.38b	12.32b	3.01	1.87	0.01	1.0692
N rate (kg ha^{-1})									
168	16.34	22.50	3.28	2.83	14.36	2.88	1.88	0.01	1.0683
224	16.54	22.38	3.06	2.76	13.85	3.19	2.08	0.00	1.0685
Cultivar									
Atlantic	13.90b	19.78b	3.31	2.57b	12.17b	2.61b	1.90	0.00	1.0737a
Fabula	18.98a	25.11a	3.03	3.02a	16.04a	3.46a	2.07	0.01	1.0630b

Note: Marketable yield was calculated by the summation of A1 through A3 tuber grades. Tubers were graded as B=<4.8, A1=4.8-6.4, A2=6.4-8.3, A3=8.3-10.2, A4=>10.2 cm. No interactions were found between either two of the treatments. Treatment means were compared within columns using Tukey's honest significant differences multiple comparison method at the 0.05 probability level. PSCU, polymer sulfur coated urea.

Table 3-5. Effects of N source, N rate and potato cultivars on N recovery by potato vines and tubers during three growing seasons.

Treatment	2006 N recovery (kg ha^{-1})			2007 N recovery (kg ha^{-1})			2008 N recovery (kg ha^{-1})		
	tuber	vine	Total	tuber	vine	Total	tuber	vine	Total
N source									
PSCU	91.0a	79.6b	170.6b	61.0	67.4	128.4	56.1a	22.0	78.2
Urea	80.8b	103.3a	184.1a	60.5	72.3	132.8	48.3b	26.6	74.9
N rate (kg ha^{-1})									
168	83.8	83.8	167.6	62.2	68.2	130.5	51.8	20.6b	72.4b
224	88.0	99.1	187.1	59.3	71.5	130.8	52.6	28.0a	80.6a
Cultivar									
Atlantic	100.6a	94.0	194.5a	58.6b	51.3b	109.9b	47.7b	23.0	70.7b
Fabula	71.2b	88.9	160.1b	63.0a	88.4a	151.4a	56.7a	25.6	82.4a

Note: No interactions were found between either two of the treatments. Treatment means were compared within columns using Tukey's honest significant differences multiple comparison method at the 0.05 probability level. PSCU, polymer sulfur coated urea.

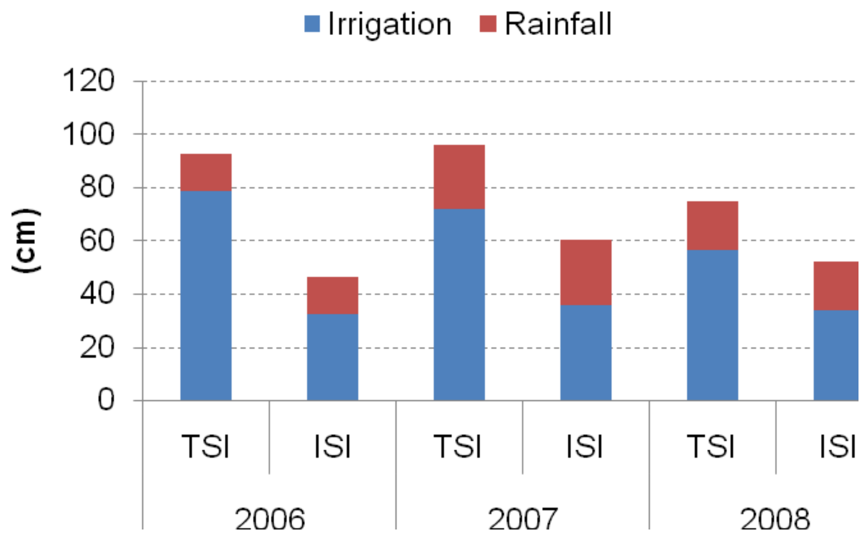


Figure 3-1. Total rainfall and irrigation under traditional and intermittent seepage irrigation systems in 3 years.

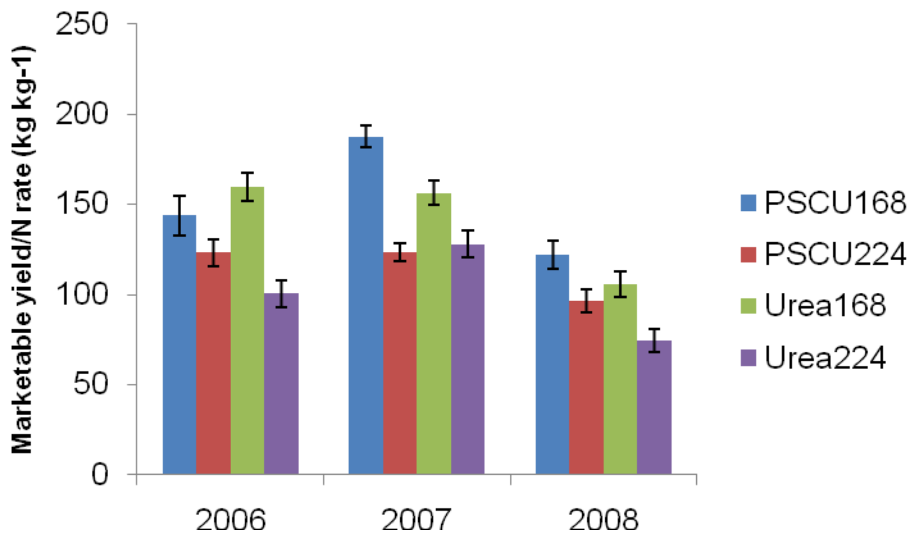


Figure 3-2. Nitrogen use efficiency with different N sources and rates in 3 years.

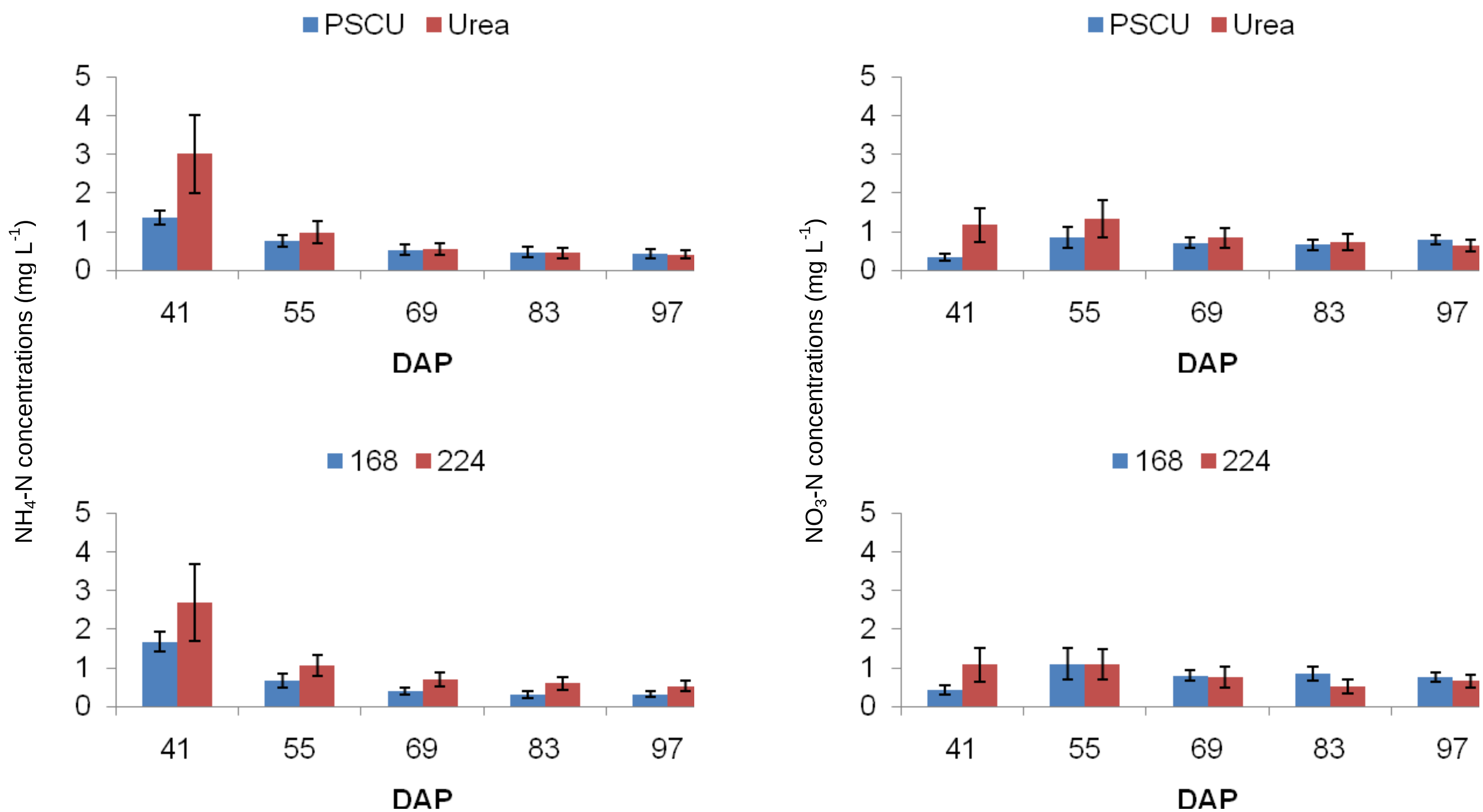


Figure 3-3. NO_3-N and NH_4-N concentrations in the shallow water table separated by N sources and N rates under TSI during 2006. The vertical bars represent the standard error of the mean.

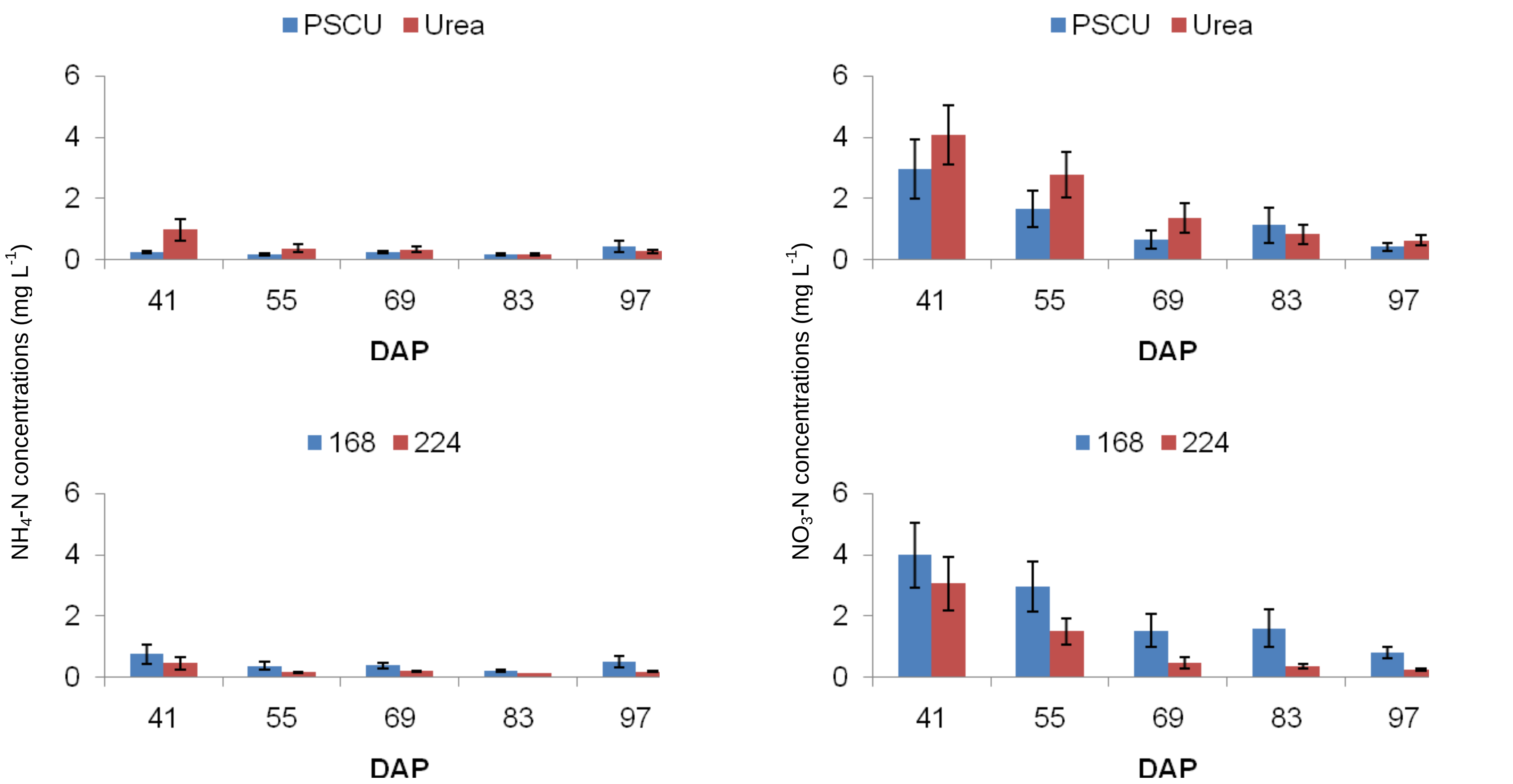


Figure 3-4. NO_3-N and NH_4-N concentrations in the shallow water table separated by N sources and N rates under ISI during 2006. The vertical bars represent the standard error of the mean.

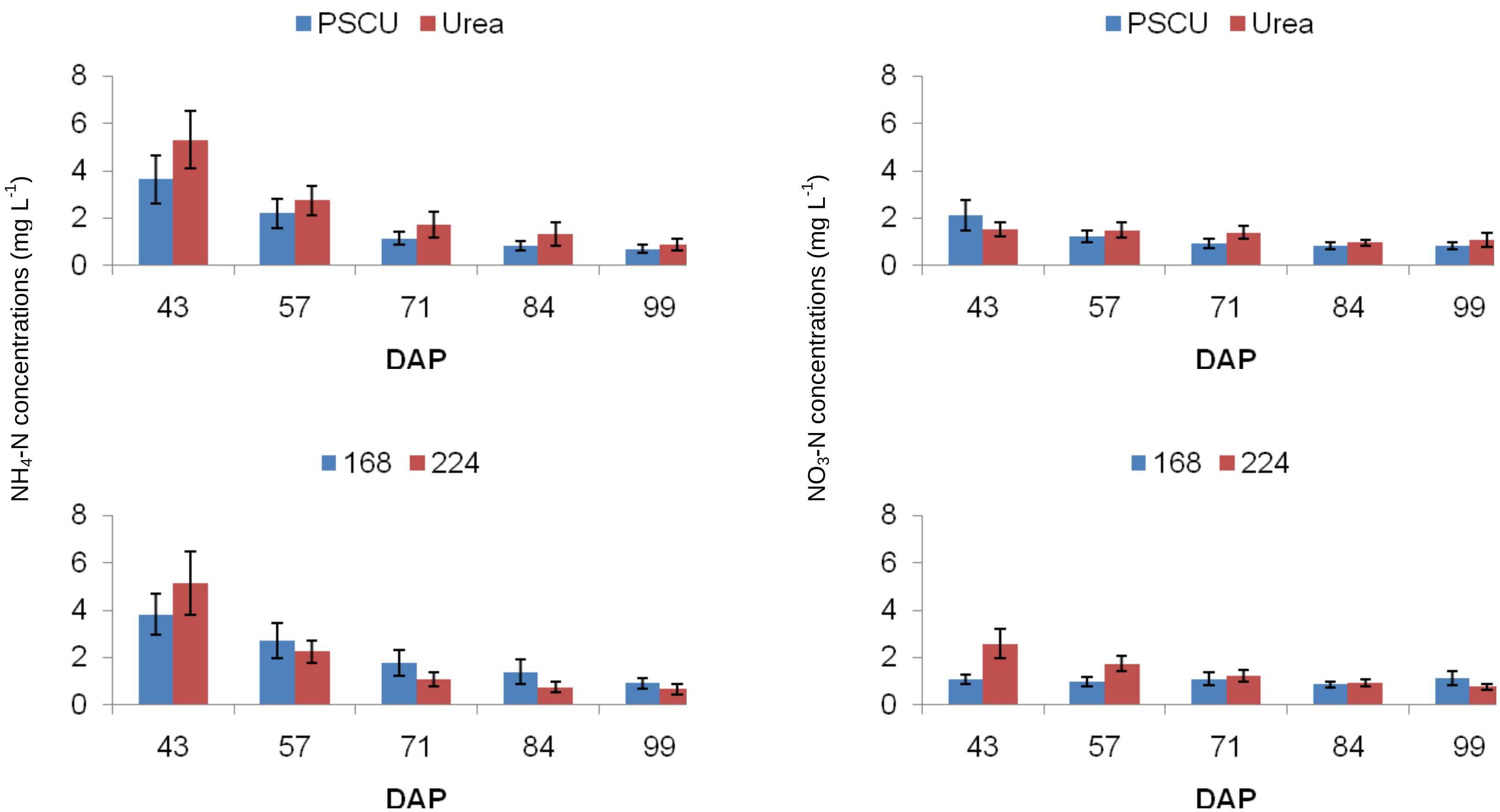


Figure 3-5. NO_3-N and NH_4-N concentrations in the shallow water table separated by N sources and N rates under TSI during 2007. The vertical bars represent the standard error of the mean.

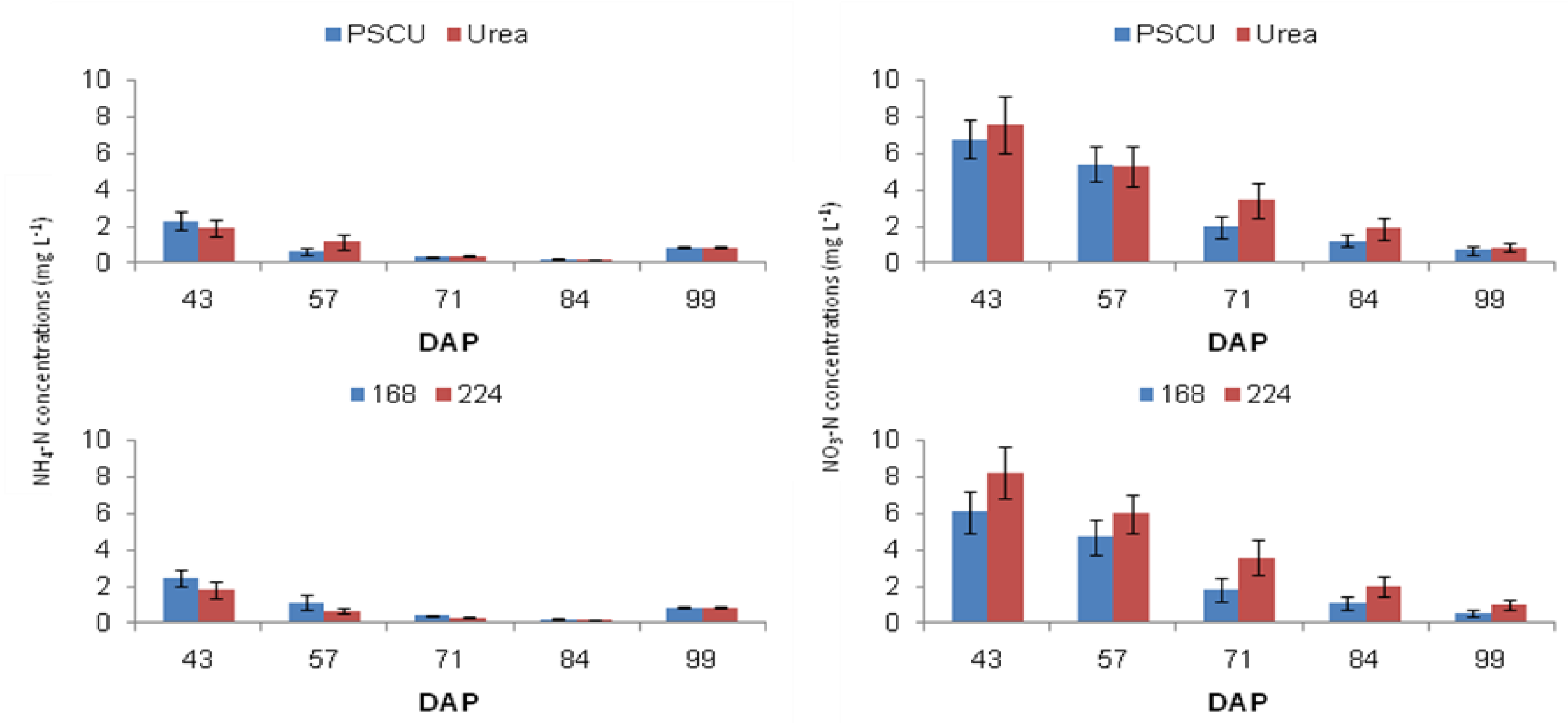


Figure 3-6. NO_3-N and NH_4-N concentrations in the shallow water table separated by N sources and N rates under ISI during 2007. The vertical bars represent the standard error of the mean.

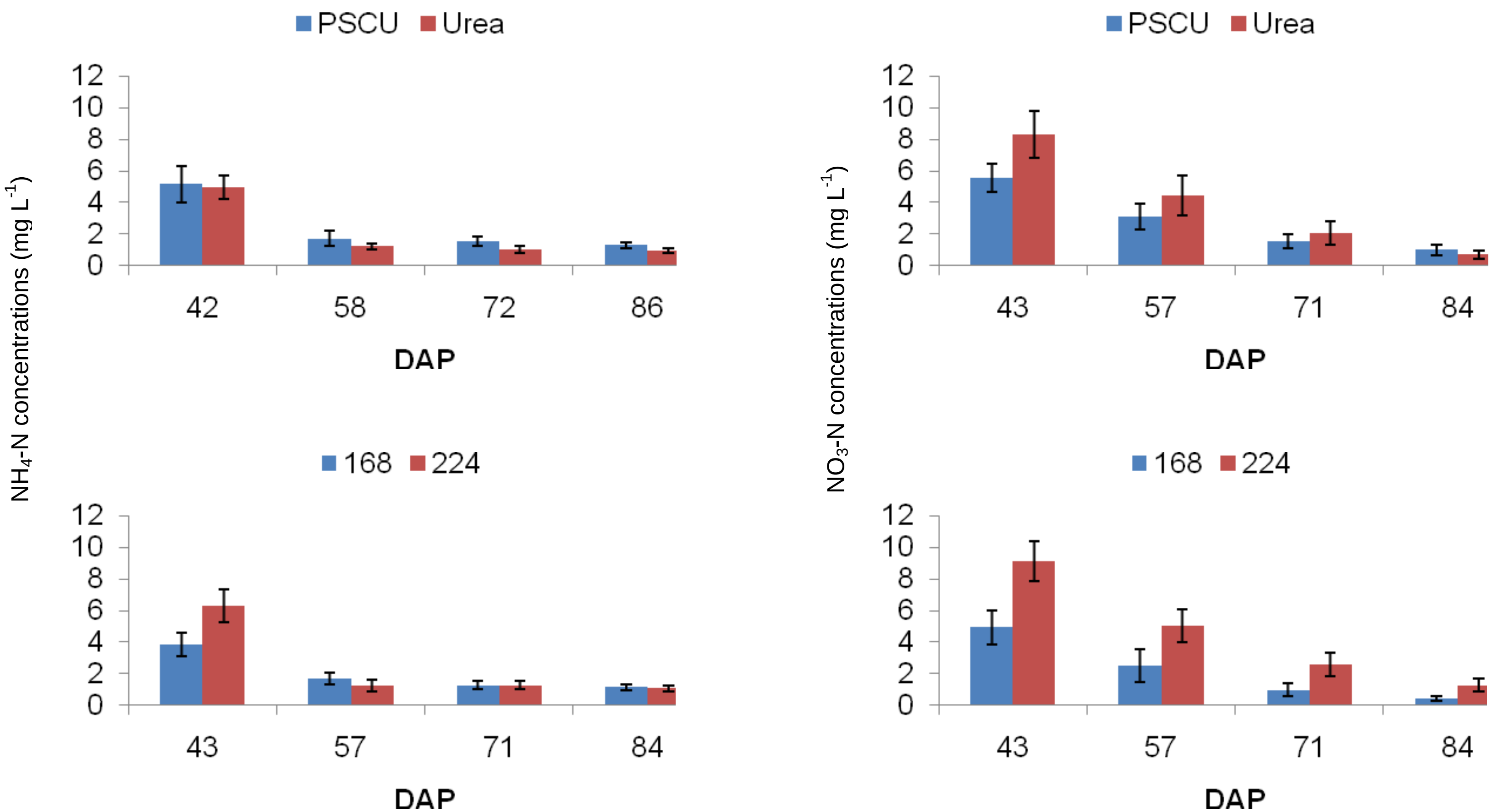


Figure 3-7. NO_3-N and NH_4-N concentrations in the shallow water table separated by N sources and N rates under TSI during 2008. The vertical bars represent the standard error of the mean.

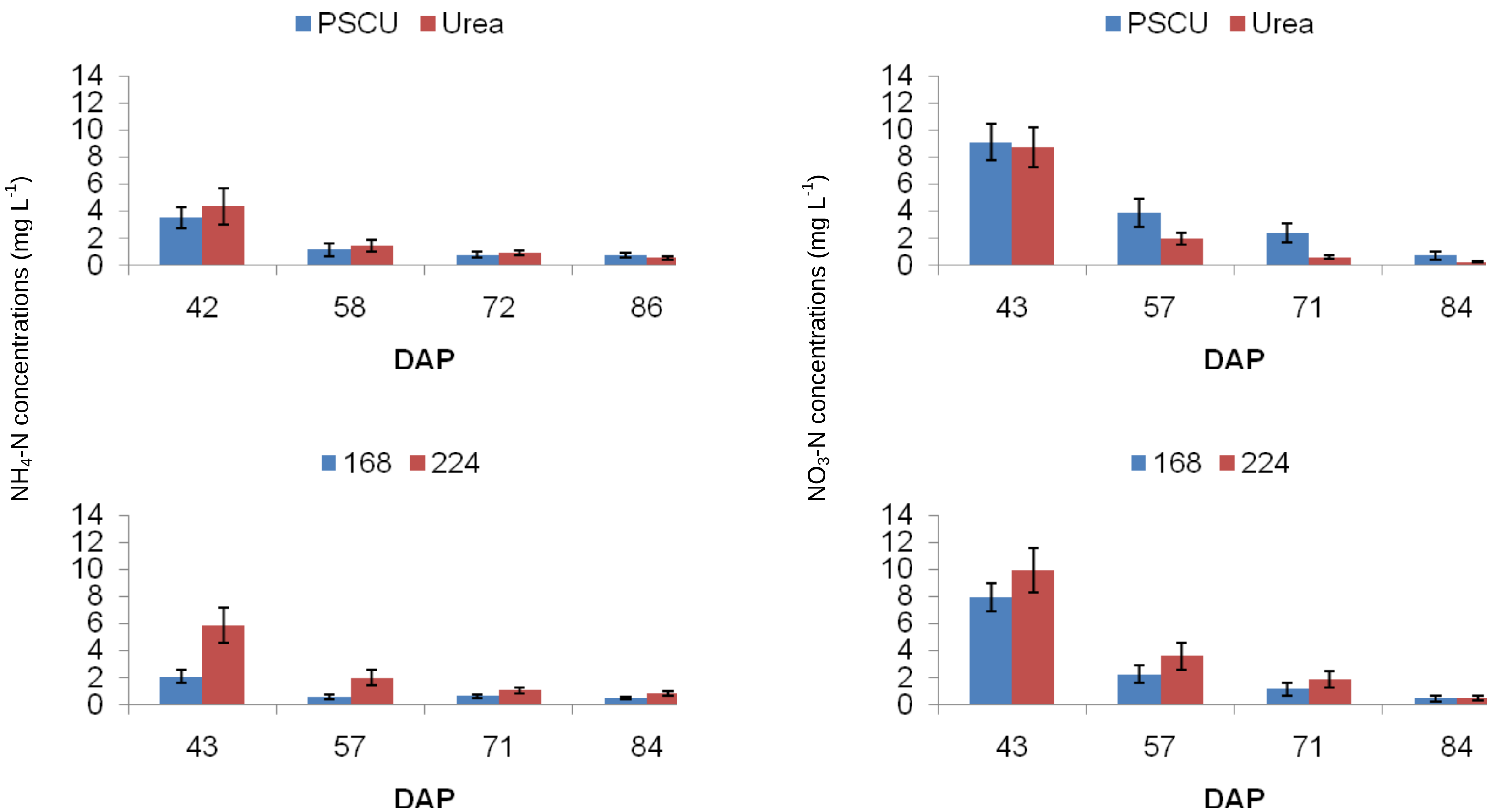


Figure 3-8. NO_3-N and NH_4-N concentrations in the shallow water table separated by N sources and N rates under ISI during 2008. The vertical bars represent the standard error of the mean.

2006

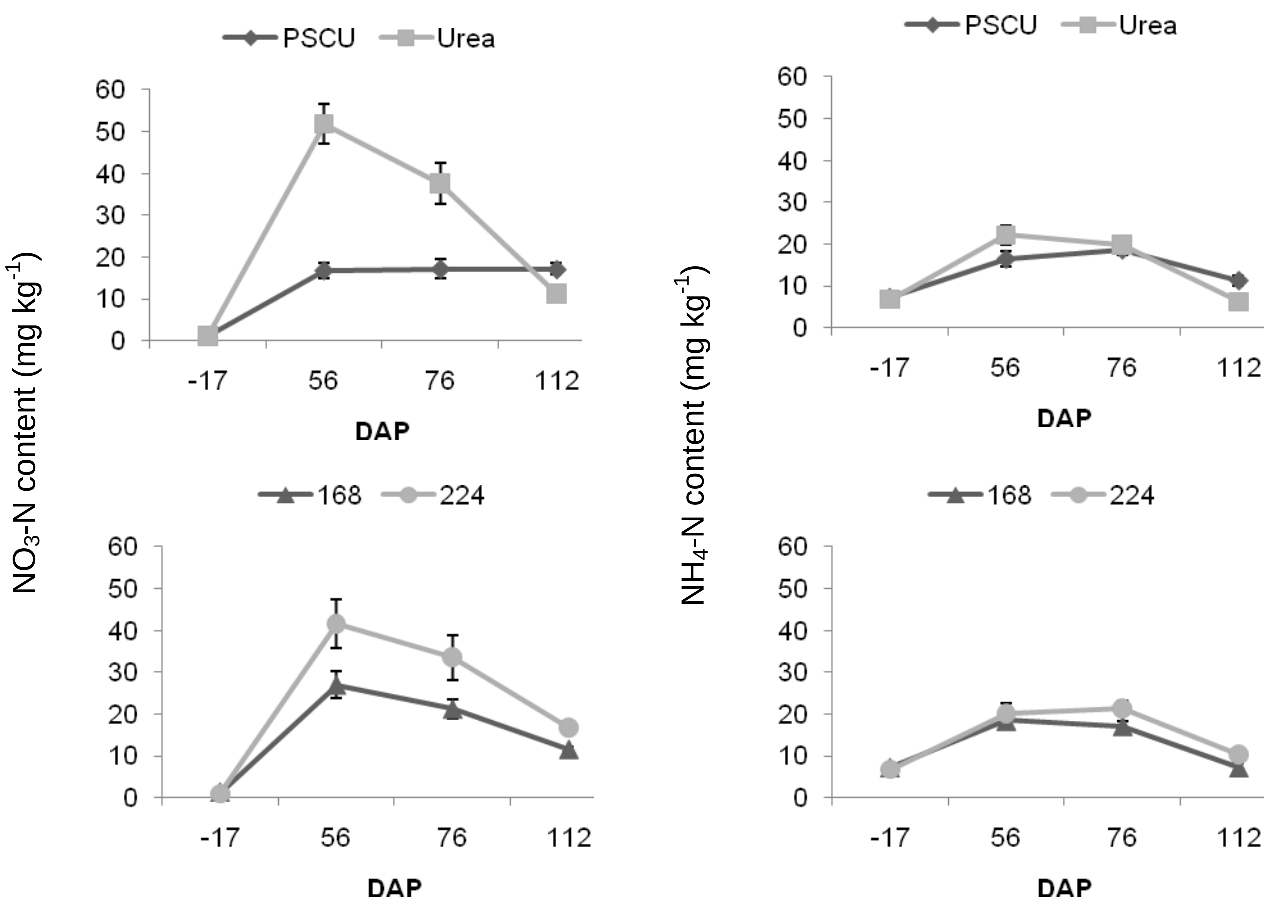


Figure 3-9. NO_3-N and NH_4-N content in the top 20 cm of the soil profile separated by N sources and N rates during 2006. The vertical bar at each data point represents the standard error of the mean.

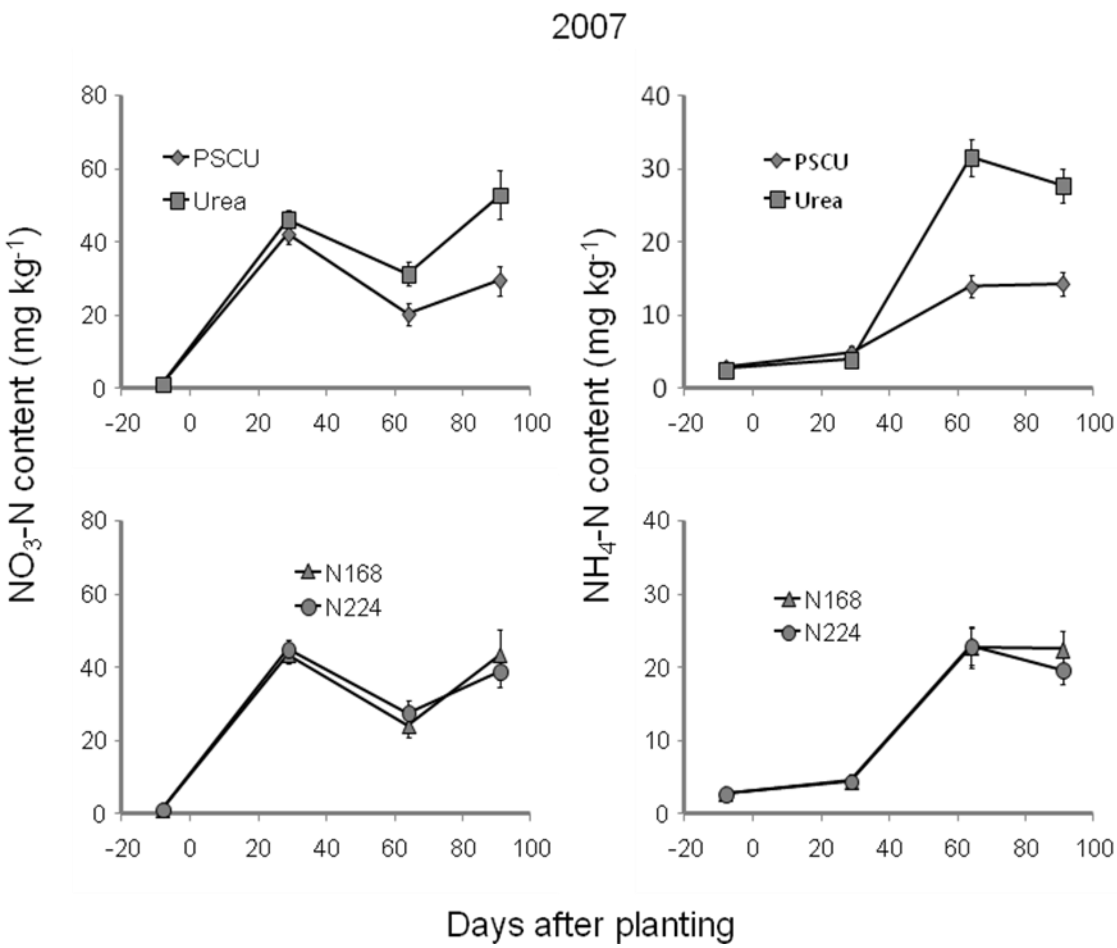


Figure 3-10. NO_3-N and NH_4-N content in the top 20 cm of the soil profile separated by N sources and N rates during 2007. The vertical bar at each data point represents the standard error of the mean.

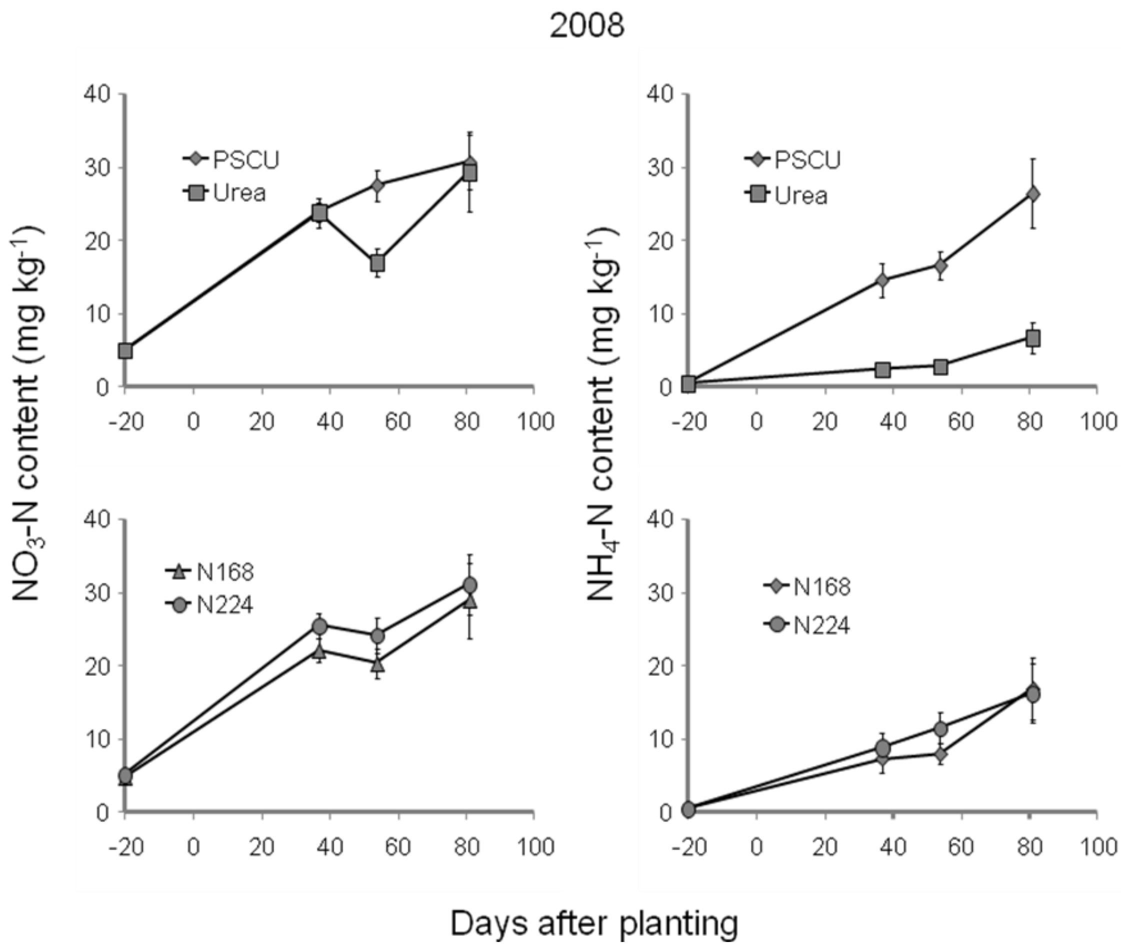


Figure 3-11. NO_3-N and NH_4-N content in the top 20 cm of the soil profile separated by N sources and N rates during 2008. The vertical bar at each data point represents the standard error of the mean.

CHAPTER 4
THE EFFECT OF AN ALTERNATE SEEPAGE IRRIGATION SYSTEM ON POTATO YIELD AND N CONCENTRATIONS IN THE SHALLOW WATER TABLE

Rainfall and Irrigation

Rainfall distribution through the potato seasons in 3 years is presented in Figure 4-1. In 2006, only 13.8 cm of rainfall was recorded during the growing season, which was about 10 cm lower than the 10-yr average (24 cm) for the same period (Table 4-1). This rainfall was supplemented with 79 and 33 cm of irrigation by TSI and ISI, respectively, which resulted in ISI supplying approximately 41% of TSI. In 2007, total rainfall during the potato season was 23.4 cm, which was similar to the 10-yr average. The biggest rainfall event early in the season was 5.9 cm, which occurred from Mar 1st to Mar 3rd, which was 1.7 cm less than a leaching rainfall, followed by a deficit of rainfall (3.7 cm) from Mar 17th through May 13th. Traditional seepage supplied 72 cm of irrigation compared with 36 cm by ISI. In 2008, total rainfall during the growing season was 19 cm, which was approximately 21% below the 10-year average. A leaching rainfall (8.7 cm in 3 days) occurred 2 DAP, which was 7 days after fertilizer application. A severe rainfall deficit occurred from Mar 21st through May 22nd, when only 0.4 cm rain fell in 63 days. Intermittent irrigation delivered 34 cm of water, which was 57% of TSI water use (57 cm). The unfavorable weather condition resulted in a depressed emergence of potato sets in 2008, significantly affecting the tuber yields.

The averaged potato irrigation requirement reported by St. Johns River Water Management District (SJRWMD) is 45.7 to 50.8 cm per year (Smajstrla, 1995). An investigation of potato water use in TCAA reported an average amount of 50 cm irrigation water use for potatoes in 1985 and 1986 (Singleton, 1990). In this study, the range in water use of 23 monitored potato farms was 22 to 100 cm in two years. The author suggested different soil types, farm management practices, and periods of the crop growing season probably resulted in the wide range of water use. In our study, water use varied in years, especially under TSI system, which was mostly due to the different growing periods and weather conditions in three experimental years. Water use was expected to be more when potatoes planted later in a season because evapotranspiration increases as temperature and length of daylight hour increase. In 2006, potato growing season was 110 days, which was longer than 104 and 99 days in 2007 and 2008, respectively. The late harvest resulted in more irrigation water use in 2006 than in other two years. The leaching rainfall which occurred early in 2008 season delayed the beginning of irrigation schedule for both TSI and ISI systems. The late startup of irrigation combined with shortest growing season led to less water use under TSI system compared with the other 2 years. However, the total volume of irrigation under TSI in 2008 (56.5 cm) was closest to the number reported by SJRWMD (45.7 to 50.8 cm). The most possible reason that the amounts of irrigation in 2006 and 2007 were higher than the TCAA average was that the total volumes were over-calculated. Since no flow rate data available in 2006 and 2007, we assumed that the pumping rate generally remained constant throughout all experimental years. The variable pumping rates may occur in the other two years and resulted in different irrigation volumes. The other reason was that duration of irrigation was miscalculated due to manually recording irrigation hours other than using timers.

The crop water requirement (ET) during each season was calculated by multiplying estimated evapotranspiration (ET_0) by crop factors at each growth stage. The total ET of potato plants in three experimental years were 28.4, 24.2 and 25.2 cm, respectively. The efficiency of TSI systems was approximately 30 to 70% (Smajstrla, 1991), which suggested that potatoes under TSI systems needed ranging from 35 to 95 cm of irrigation to meet growth requirement over three seasons. At this point, although irrigation water use in 2006 and 2007 was higher than the average number in TCAA, it was still not over-irrigated due to the variable irrigation efficiency of seepage systems.

Tuber Yield and Quality

In 2006, potato tuber yield was affected by irrigation method (Table 4-2). The marketable yield with TSI (28.5 Mg ha^{-1}) was significantly higher than with ISI (22.1 Mg ha^{-1}). Total yield followed the same trend as marketable yield even though more culls and small size tubers (size B) were recorded with ISI than the TSI. The differences in tuber yield were a result of the different amounts of irrigation applied for the two systems. Potatoes under ISI treatment only received 41% of irrigation water compared with the TSI treatment. Besides, rainfall in that growing season was 10 cm less than the 10-year average, which did not complement the irrigation deficiency. Average specific gravity of potato tubers with ISI treatment was significantly higher than TSI treatment. This result probably revealed that over-irrigating could affect the tuber quality by reducing tuber specific gravity. In 2007, irrigation method did not have an influence on total or marketable tuber yield. However, more middle size tubers (size A1) and less large size tubers (size A2 and A3) were recorded with TSI than ISI. Similar yields were possibly due to sufficient rainfall during this growing season. Also, irrigation supplied by ISI was 50% of that received from TSI, which was 9% higher than in 2006. Increased water supply improved tuber yield under ISI system. Similar specific gravities were also found with two irrigation treatments. In 2008, potatoes did not emerge 100% due to the heavy rainfall right after planting. Reduction of both total and marketable yield was recorded in this year. Leaching rainfall early in the season and poor tuber sets was responsible for the lower yields compared with the yields in the other two years. Compared with TSI, ISI increased marketable tuber yields from 16.9 to 21.4 Mg ha^{-1}. This result was possibly due to more irrigation water applied by ISI treatment compared with the other 2 years. Similar specific gravities were recorded under two irrigation methods; however, both of them were about 0.02 lower than in 2007. The early leaching rainfall was one of the reasons that affected the tuber quality.

Seepage irrigation treatments had different effects on tuber yields in three experimental years. In 2006, the average rainfall during the growing season was 42% lower than the 10-yr average. Intermittent seepage supplied only 41% of irrigation water compared with traditional irrigation, as the system was operated manually. The lower yield was resulted from the deficiency of water application by ISI. In 2007, intermittent seepage supplied more irrigation water than that in 2006. Combined with more rainfall during the growing season, similar tuber yield was observed with ISI compared with TSI. In 2008, irrigation supplied by intermittent seepage was increased to 57% of the TSI, which could be a reason that higher tuber yield was obtained with ISI than TSI. Besides, irrigation schedule was changed from nights to days, which resulted in lesser fluctuation in the water table level in 2008. Therefore, the changing of irrigation timing was another reason that ISI resulted in increased yield in 2008.

The average potato yield in Florida from 1990 to 2009 was 28.3 Mg ha^{-1} (USDA database). In our study, the average total and marketable yields in 3 years were 31.9 and 25.2 Mg ha^{-1}, 32.1 and 28.5 Mg ha^{-1}, and 22.4 and 16.4 Mg ha^{-1}, respectively. The highest potato yield was produced in 2007, which was characterized with the highest precipitation and the lowest soil temperature throughout the season. The highest yield was probably resulted from slow release of PSCU which supplied more N late in the season after soluble N was leached or used. Leaching from the soluble N source was also reduced since the rainfall events occurred more even compared with the other 2 years. Total yields in 2006 and 2007 were similar, however, marketable yield in 2006 was approximately 3 Mg ha^{-1} less than in 2007 and 20-year average in state. The difference was due to more culls produced in 2006, which was probably resulted from dry and warm weather conditions in that year. Both total and marketable yields were low in 2008. The undesirable tuber set and excessive leaching influenced by the unpredictable leaching rainfall contributed to the poor production. Besides, side-dress of urea about 40 DAP usually is required according to typical fertilization practices. However, in our study, in order to compare the impact of CRF and soluble sources with the same field operations, side-dressings were not conducted for urea, which was also resulted in poor potato yields.

N Recovery

The two irrigation systems had different effects on N uptake by potato tubers and vines in 3 years (Table 4-3). In 2006, differences in N uptake were recorded in potato tubers, where TSI resulted in a higher N accumulation than ISI. Consequently, a higher N accumulation in entire potato plants with the TSI treatment was observed since no differences were found in vines. The lower N recovery under ISI system was due to an insufficient irrigation supply. In particular, precipitation in 2006 was quite low compared with the average of the last 10 yrs. In 2007, significantly higher N recovery was found in both tubers and vines by using ISI system. However, the tuber yields under two irrigation systems were similar. In 2008, potato tubers under ISI system recovered more

N than tubers under TSI system, even though no difference in N accumulation by vines was observed. Also, total N recovery under both irrigation systems in 2008 was lower than in other 2 years, which was possibly due to the massive leaching loss of N early in the season after the leaching rainfall. To sum up, ISI system successfully increased tuber N recovery when sufficient irrigation was supplied. Over-irrigating in a normal or a wet season would possibly reduce N accumulations in tubers and vines.

Concentrations of NO_3-N and NH_4-N in the Shallow Water Table

The concentrations of NO_3-N in the shallow water table were significantly affected by irrigation method in 2006 and 2007, when the ISI treatment was scheduled to irrigate overnight. In 2006, minimal fluctuations were observed in NO_3-N concentrations under TSI system across the five sampling events, and all of them were <1.5 mg L^{-1} (Figure 4-2). However, compared with TSI treatment, NO_3-N concentrations under ISI were found to be significantly higher for the first two sampling events. Also, unlike the concentrations with TSI treatment, concentrations of NO_3-N with ISI treatment were significantly decreased across five sampling events. In 2007, NO_3-N concentrations in the well water samples were similar for both the irrigation systems (Figure 4-3). However, average concentrations of NO_3-N under ISI were higher in 2007 than in 2006, which was a result of the differences in rainfall during the 2 years. In 2007, rainfall was more than 40% higher compared with 2006. Rainfall could have easily moved NO_3-N downward into the shallow water table in sandy soils. In 2008, however, no significant differences in NO_3-N concentrations in shallow water table were found between two of the irrigation methods (Figure 4-4). Unlike the first two years, concentrations of NO_3-N under TSI system in 2008 significantly decreased across sampling events and the change of irrigation timing for ISI was the reason for the differences in NO_3-N concentrations. In 2006 and 2007, the schedule for ISI was set up to irrigate potato over-night at 12 hrs per day. However, in 2008, the schedule was changed to supply water during the day at the same 12 hrs per day rate. The change was introduced to minimize water table fluctuation under ISI system, since daytime fluctuations in water table depth due to higher ET compared with night time can be substantial. Such a change in irrigation timing would subsequently reduce NO_3-N leaching into shallow water table. Pack et al. (2005) found no significant difference in NO_3-N concentration between CRF and urea treatments in shallow water table samples. The authors suggested that their result may have been due to a high dilution of nutrients in the large shallow water table below the plots. Besides, wells were not installed in the field until about 40 days after planting, a period during which early leaching probably occurred.

The concentrations of NH_4-N in the shallow water table were significantly higher with TSI method than with ISI method in 2006 and 2007 (Figure 4-2 and 4-3), which showed that the concentrations of NH_4-N in the shallow water table were not affected by the fluctuation in the water table depth. Higher NH_4-N concentrations with TSI treatment was the result of more water being supplied with this treatment. No differences in NH_4-N concentrations were observed between two irrigation methods in 2008 (Figure 4-4), which was also due to the change of ISI schedule to daytime irrigation. In all 3 years, concentrations of NH_4-N in the shallow water table were reduced gradually with sampling events for both of the irrigation systems. The reduction could be the result of nitrification and uptake by the crop.

Contents of NO_3-N and NH_4-N in the Surface Soils

In all years, NO_3-N residues in the surface soil were affected by irrigation treatments (Figure 4-5, 4-6 and 4-7). Residues of NO_3-N were significantly higher with TSI treatment than with ISI treatment all 3 years. However, changes in soil NO_3-N concentrations were different. In 2006, concentration differences between irrigation methods were found at the sampling events at 56 and 76 DAP. However, no difference of NO_3-N concentration was recorded after harvesting. Also, the NO_3-N concentrations in the surface soils decreased following the second sampling event. Crop uptake and leaching were the reasons for the decline in soil nitrate content. However, in 2007 and 2008, the only difference in NO_3-N content between two irrigation treatments was found at the last sampling event. The difference might indicate that TSI and ISI affected nitrate leaching differently. In 2006 and 2007, nitrate leaching with ISI was significantly higher than leaching with TSI, which resulted in the higher nitrate concentrations in surface soil with TSI treatment. The significant higher residue of NO_3-N with TSI treatment in 2008 was a reason for the lower tuber yield with this treatment.

The soil NH_4-N contents under ISI treatment were significantly higher compared with the contents under TSI treatment in 2006 and 2007, but significantly lower in 2008. This result indicated that frequent fluctuations in water table depth under ISI treatment could reduce nitrification in soils in 2008. Therefore, more NH_4-N and less NO_3-N were retained in surface soils with ISI treatment in the first 2 years. In 2008, significantly higher NH_4-N content was found with TSI treatment. Combined with the higher NO_3-N residues with TSI treatment, the higher N concentrations in the surface soil could illustrate lower N uptake by potato plants, since leaching was low due to the low precipitation during the potato growth stages.

Soil Moisture and Water Table Depth

In 2006, the water table depth fluctuated considerably during the growing season under ISI system compared with TSI system (Figure 4-10), due to irrigation timing for ISI and deficient rainfall. While an average water table depth of 49 cm was maintained with TSI treatment, with the ISI method the average depth was 58 cm. The differences in water table depth obviously influenced soil moisture at various soil depths. With TSI treatment, the average of soil moisture at 20 and 30 cm below the surface was 20.1% and 24.8%, respectively, compared with the average of 10.9% and 17.1% with ISI treatment (Figure 4-8). In TCAA production areas, 63% of the potato root system is located between 12 and 24 cm below the soil surface (Munoz, 2004). Therefore, soil moisture differences at 20 and 30 cm depth would greatly affect the crop growth. In 2007, the fluctuation in water table depth under ISI system was not high as it was in 2006. Less fluctuation in water table was due to abundant rainfall during 2007. Average water table depth in 2007 was 50 cm with TSI treatment and 57 cm with ISI treatment during the potato season. In 2008 however, average water table depth was 52 cm with TSI and 56 cm with ISI. The fluctuation in water table depths was minimized by switching the irrigation timings from night-time to day-time for ISI treatment.

Table 4-1. Rainfall and irrigation volumes under traditional and intermittent seepage systems

Year	Treatment	Irrigation area (m^2)	Duration (h)	Flow rate (L/min)	Total irrigation volume (m3)	Total irrigation (cm)	Rainfall (cm)
2006	TSI	2650.7	1711.0	20.4	2094.3	79.0	13.8
	ISI	2650.7	703.80	20.4	861.50	32.5	
2007	TSI	2650.7	1560.0	20.4	1909.4	72.0	24.3
	ISI	2650.7	780.00	20.4	954.70	36.0	
2008	TSI	2650.7	1224.0	20.4	1498.2	56.5	18.5
	ISI	2650.7	732.00	20.4	896.00	33.8	

Table 4-2. Comparison of tuber yield, distribution and specific gravity as related to irrigation management during 2006 to 2008.

Year	Irrigation	Tuber yield (Mg ha^{-1})								Specific
		Mkt	Total	Cull	B	A1	A2	A3	A4	gravity
2006	TSI	28.47a	33.93a	3.22b	2.24b	22.59a	5.82a	0.06	0.00	1.067b
	ISI	22.08b	29.91b	4.80a	3.03a	19.79b	2.29b	0.00	0.00	1.074a
2007	TSI	28.53	32.09	1.19	2.37	19.31a	6.56b	2.66b	0.01	1.0844
	ISI	28.52	32.09	1.09	2.43	15.78b	8.13a	4.62a	0.05	1.0872
2008	TSI	16.90b	21.70b	2.65b	2.15b	12.19b	2.68b	2.03	0.01	1.0696
	ISI	21.35a	28.49a	3.69a	3.44a	16.02a	3.39a	1.94	0.00	1.0671

Note: Treatment means were compared within columns using Tukey's honest significant differences multiple comparison method at the 0.05 probability level. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation.

Table 4-3. Effect of irrigation method on N recovery by potato vines and tubers during the 2006, 2007 and 2008 growing seasons.

Treatment	2006			2007			2008		
	N recovery (kg ha^{-1})			N recovery (kg ha^{-1})			N recovery (kg ha^{-1})		
	Tuber	vine	Total	tuber	vine	Total	tuber	vine	Total
Irrigation									
TSI	95.0a	89.8	184.8a	53.3b	64.5b	117.8b	50.0b	25.2	75.2
ISI	76.8b	93.1	169.9b	68.8a	75.3a	144.0a	53.4a	23.4	76.8

Note: Treatment means were compared within columns using Tukey's honest significant differences multiple comparison method at the 0.05 probability level. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation.

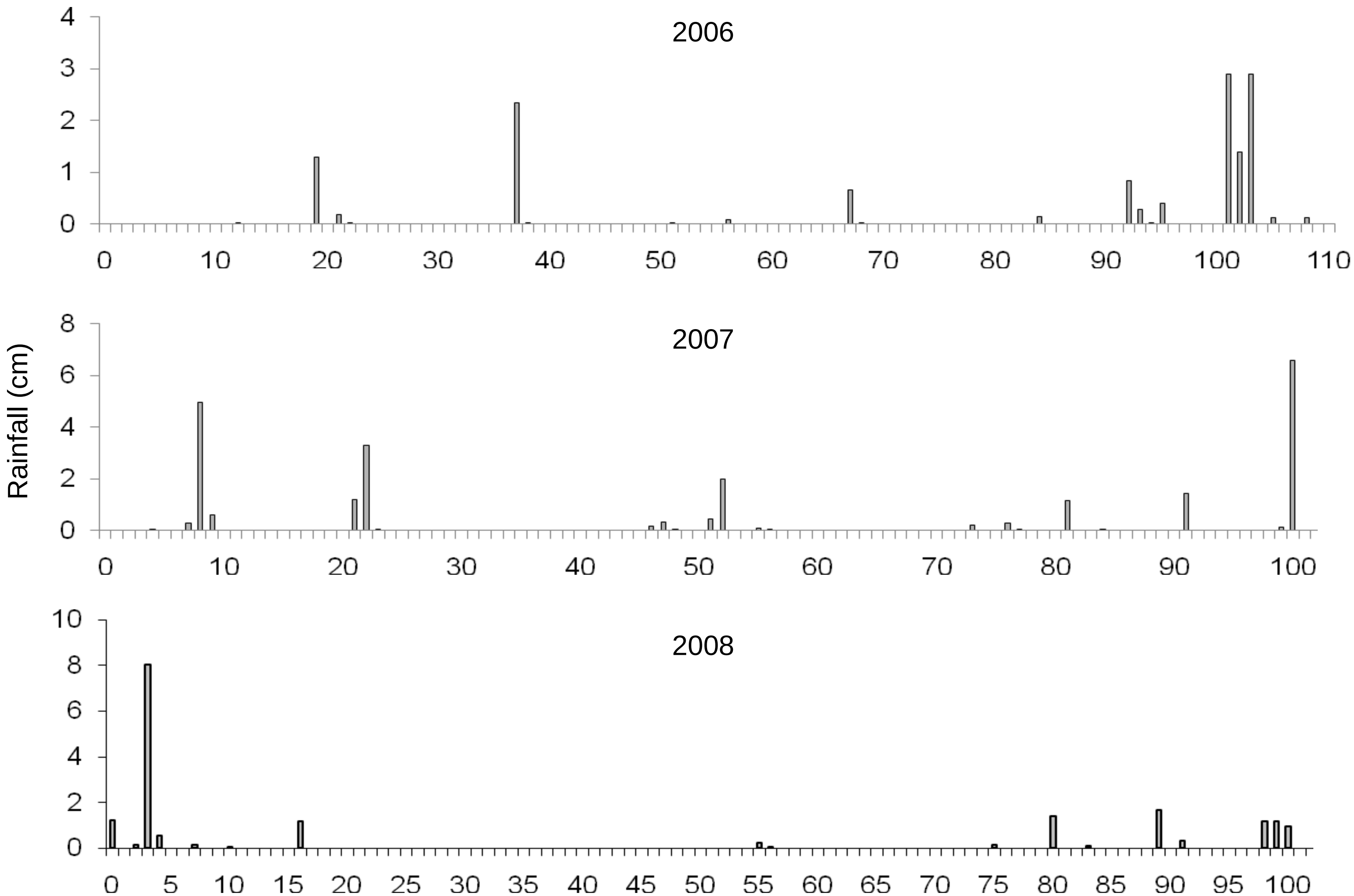


Figure 4-1. Rainfall distribution through potato seasons in 2006, 2007 and 2008. The X-axis shows the sampling days after planting.

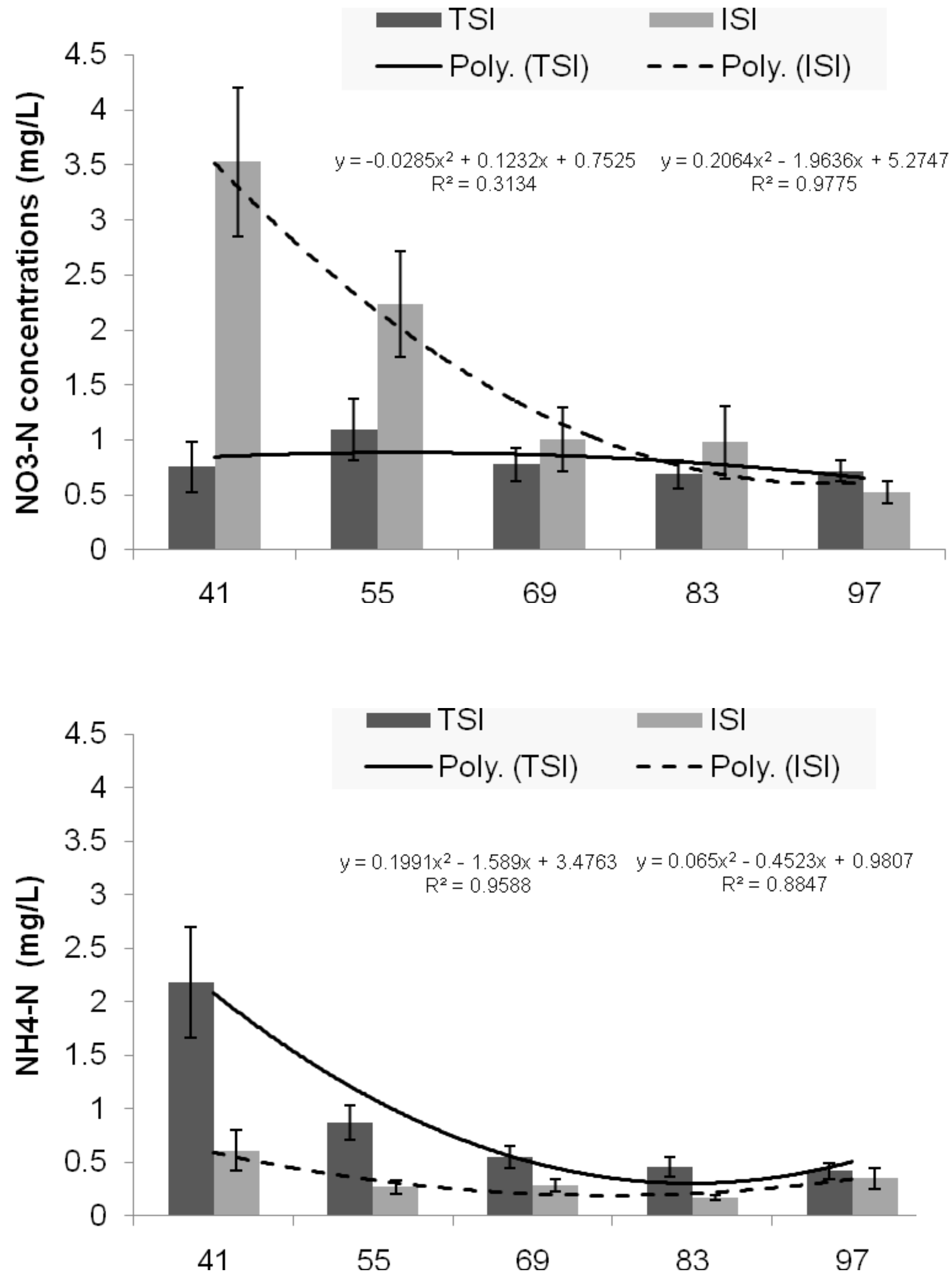


Figure 4-2. Observed and predicted NO_3-N and NH_4-N concentrations in the shallow water table compared between two irrigation methods in 2006. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation. The X-axis shows the sampling days after planting.

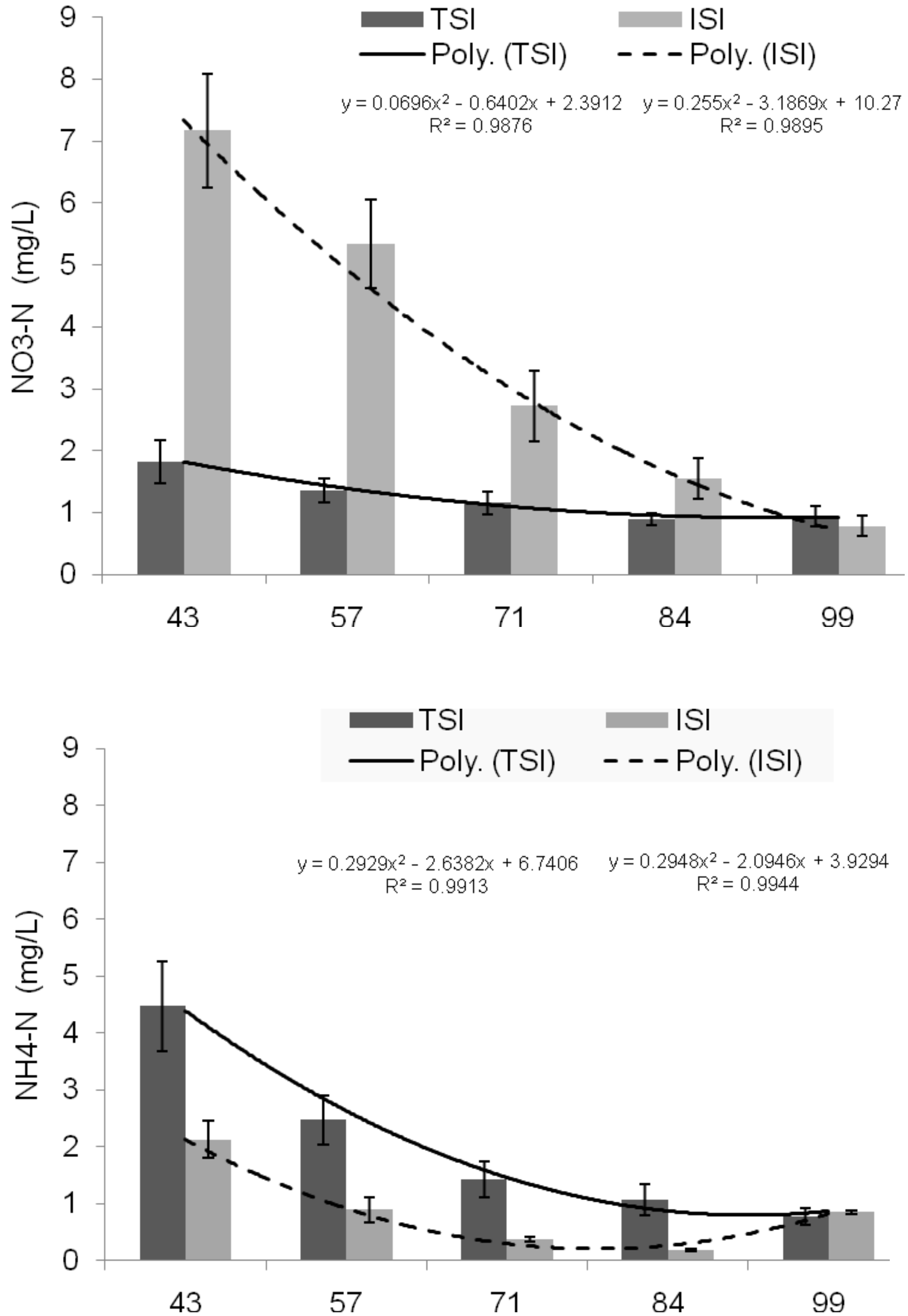


Figure 4-3. Observed and predicted NO_3-N and NH_4-N concentrations in the shallow water table compared between two irrigation methods in 2007. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation. The X-axis shows the sampling days after planting.

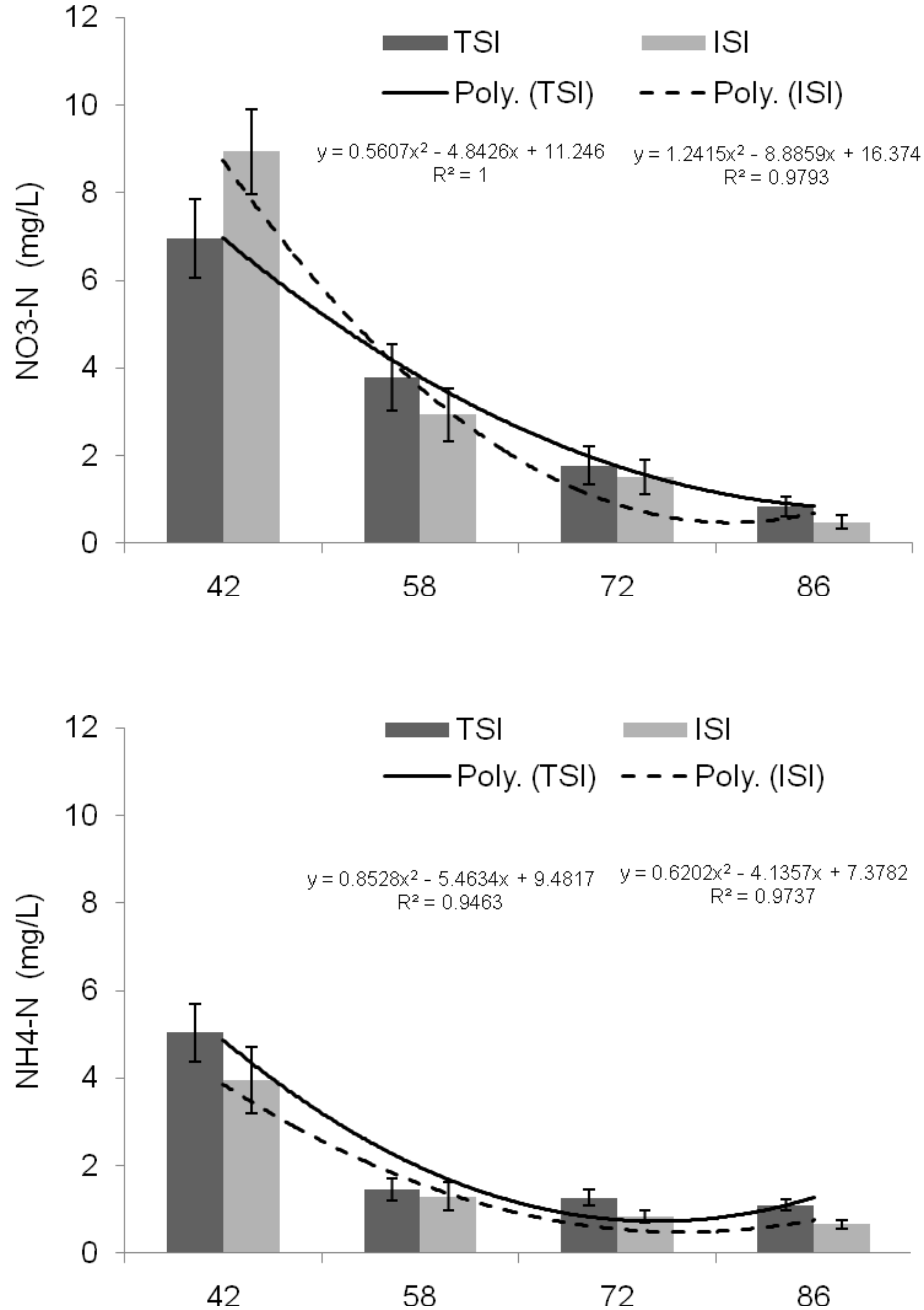


Figure 4-4. Observed and predicted NO_3-N and NH_4-N concentrations in the shallow water table compared between two irrigation methods in 2008. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation. The X-axis shows the sampling days after planting.

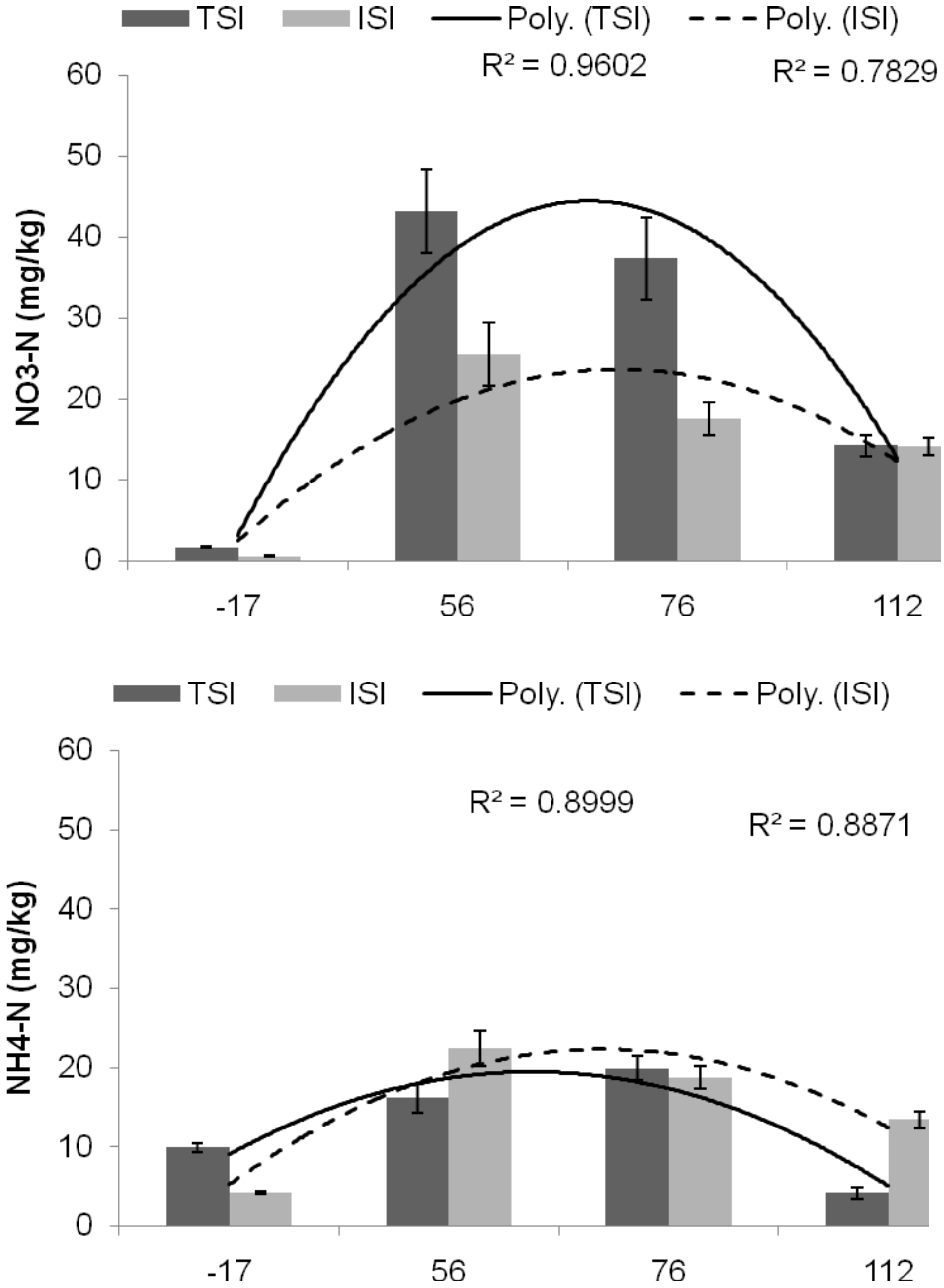


Figure 4-5. Observed and predicted NO_3-N and NH_4-N content in soils under two irrigation methods during 2006. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation. The horizontal axis shows the days after planting where negative number indicates the days before planting.

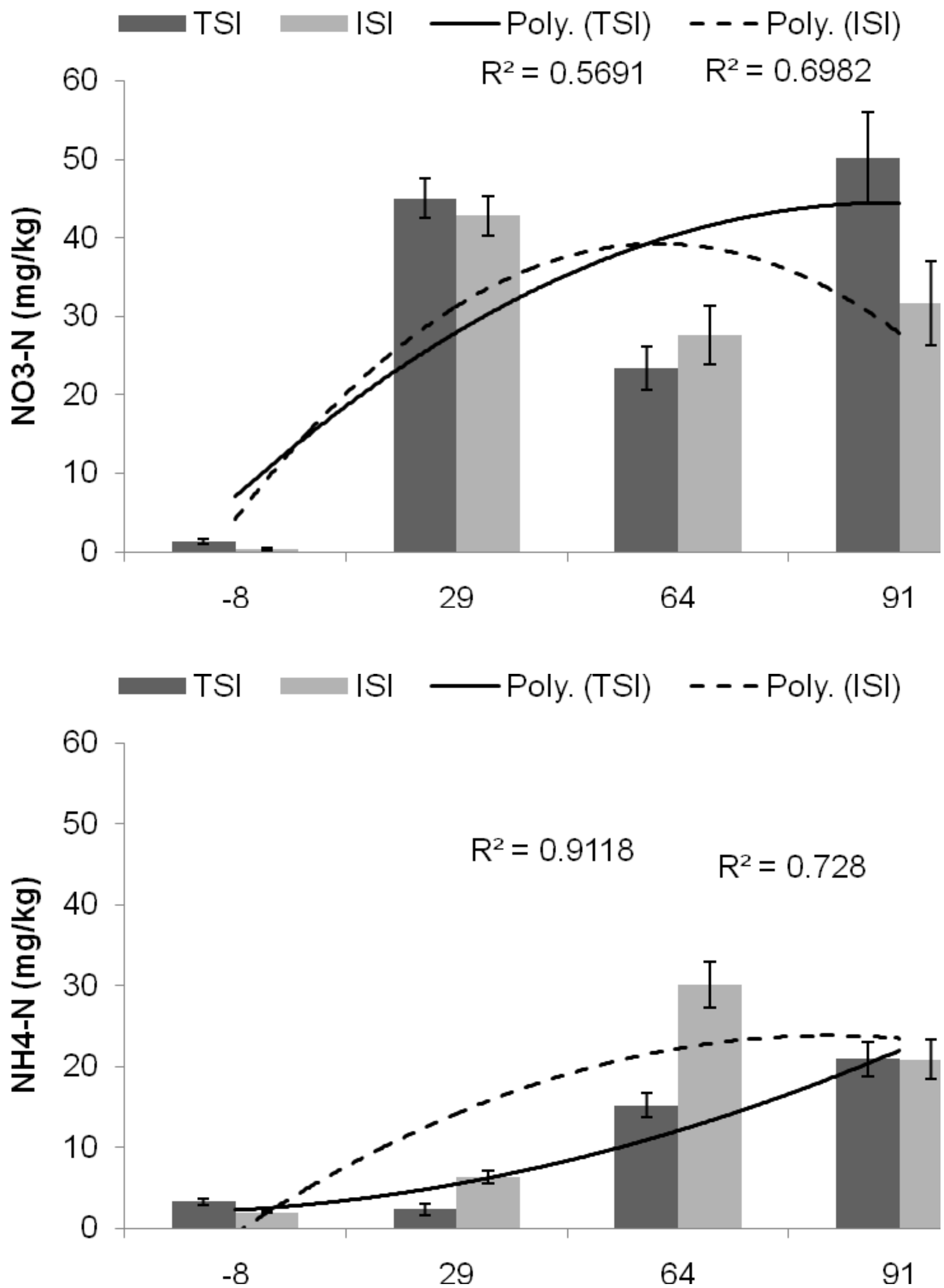


Figure 4-6. Observed and predicted NO_3-N and NH_4-N content in soils under two irrigation methods during 2007. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation. The horizontal axis shows the days after planting where negative number indicates the days before planting.

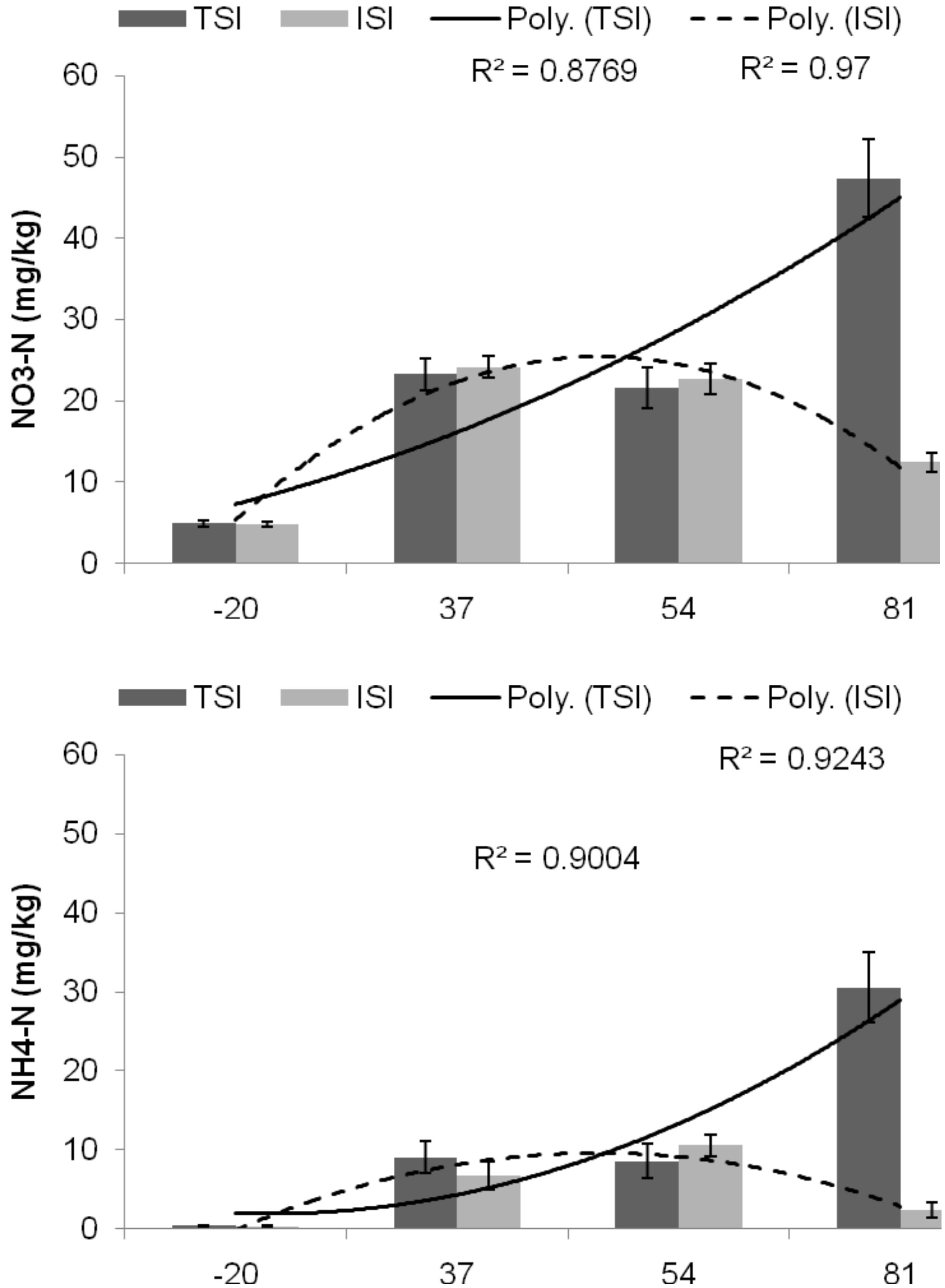
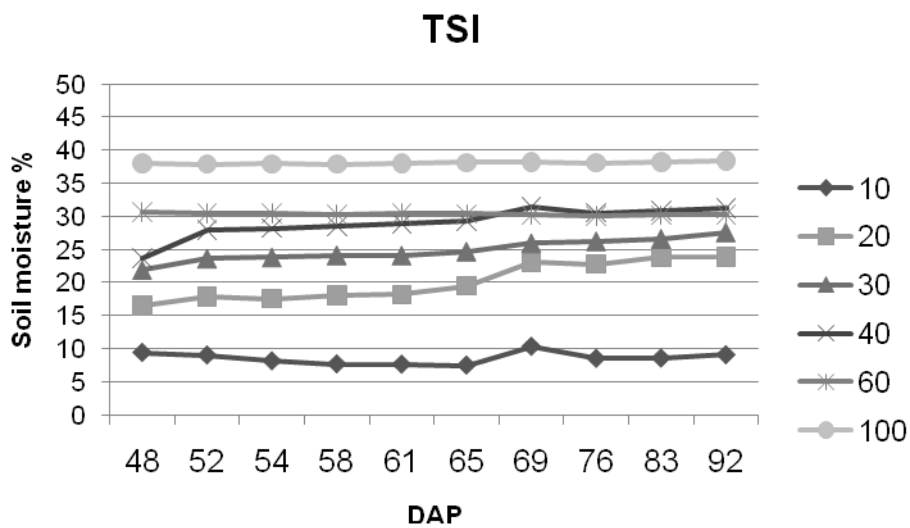


Figure 4-7. Observed and predicted NO_3-N and NH_4-N content in soils under two irrigation methods during 2008. TSI, traditional seepage irrigation; ISI, intermittent seepage irrigation. The horizontal axis shows the days after planting where negative number indicates the days before planting.



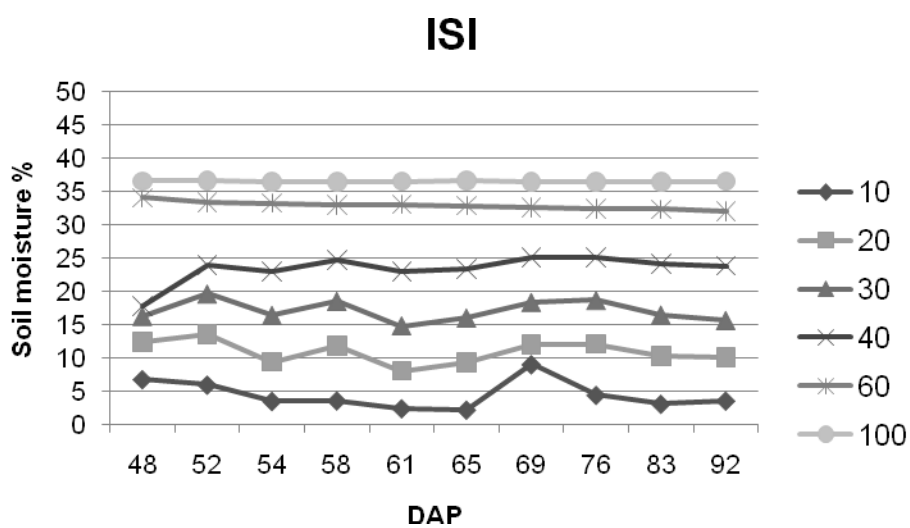


Figure 4-8. The dynamic changing of soil moisture under two irrigation systems during the potato season in 2006. The soil moisture was measured at 10, 20, 30, 40, 60 and 100 cm below the top of the row.

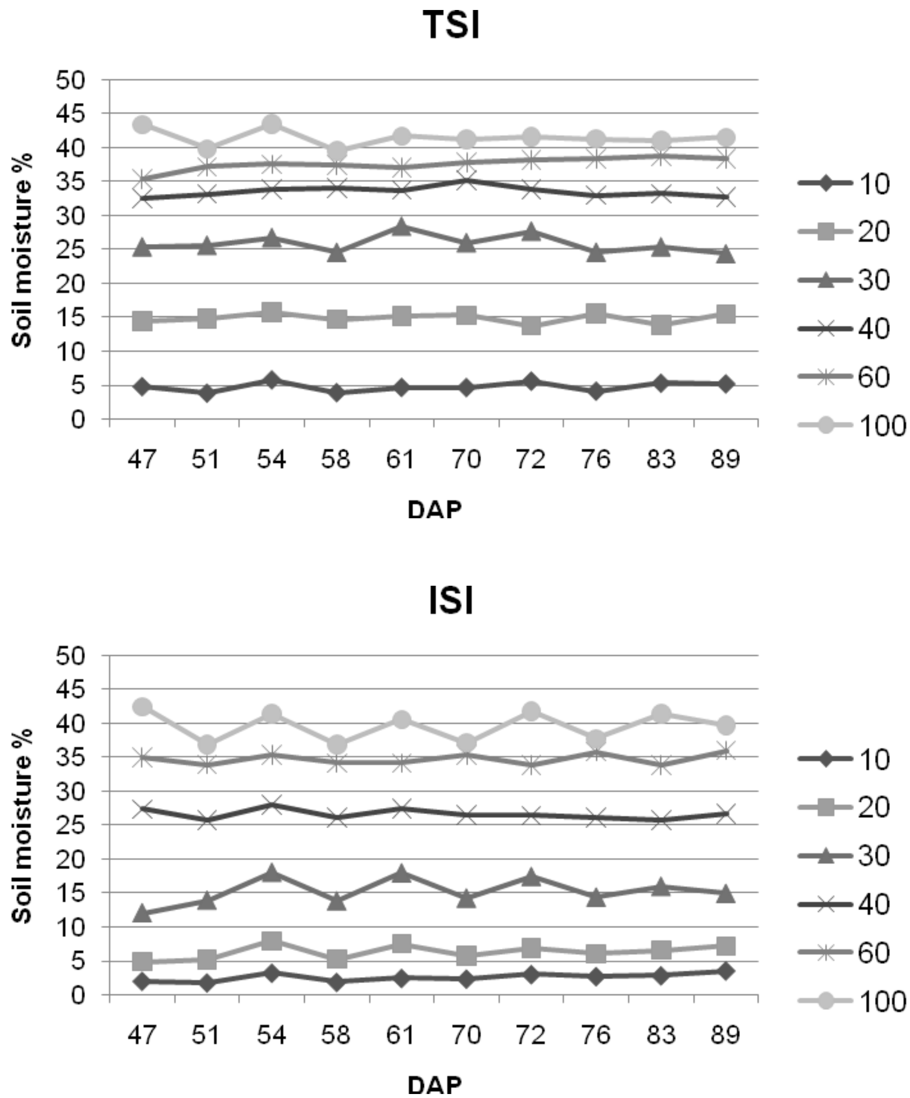


Figure 4-9. The dynamic changing of soil moisture under two irrigation systems during the potato season in 2007. The soil moisture was measured at 10, 20, 30, 40, 60 and 100 cm below the top of the row.

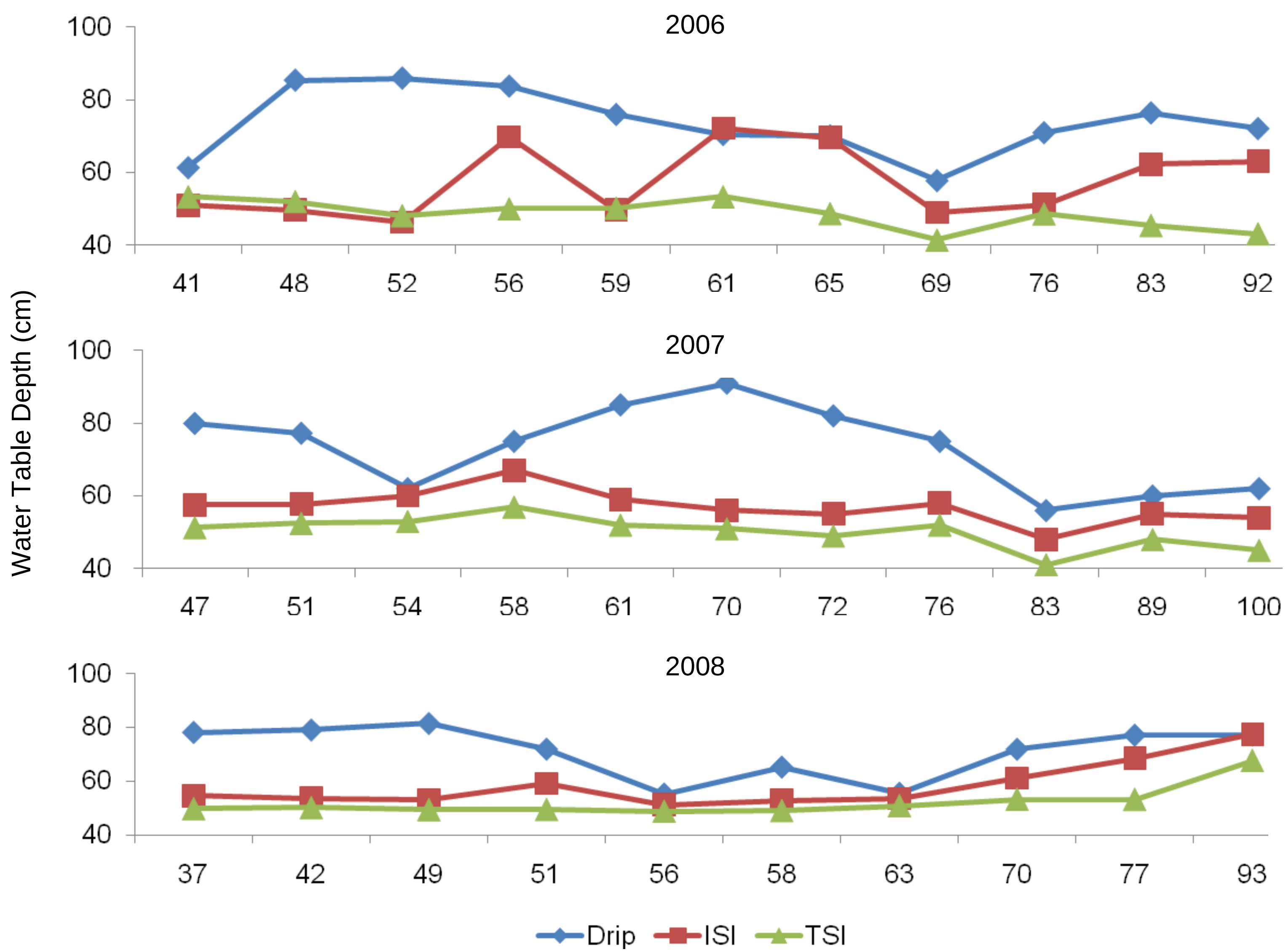


Figure 4-10. Water table depth under seepage irrigation systems and drip irrigation in 2006, 2007 and 2008. The vertical axes represent days after planting.

CHAPTER 5
THE EFFECT OF DRIP IRRIGATION SYSTEM ON POTATO YIELD AND THE FEASIBLILITY OF FERTIGATION METHOD ON POTATO PRODUCTION

Irrigation Volumes and Weather Conditions

The system we used has several innate benefits. First, no shallow water table was maintained, which allowed the field to “absorb” more rainfall before surface water drained from the field and entered the watershed. Smajstrla et al. (2000) found that the water table responded more quickly to irrigation with subsurface drip irrigation than with seepage irrigation. Secondly, irrigation rate was based on evapotranspiration rate, i.e., less when the plant was small and more when the plant matured. With seepage irrigation, the irrigation rate usually remains the same during the entire season. Thirdly, soil moisture can be maintained at reduced levels during late bulking to improve tuber quality. Excess water during the bulking period can suffocate tubers causing a disorder called “black heart”. Shae et al. (1999) compared subsurface drip irrigation (SDI) to above-ground drip irrigation for potato production and water use efficiency in North Dakota. The SDI was found to be the most water use efficient while also maintaining potato yield and quality.

With drip irrigation, 27.3 cm of water was applied during 2006, supplemented by 14.0 cm of rainfall (Figure 5-1). In 2007, the water applied through drip irrigation was 28.0 cm. In 2008, the total irrigation amount through the drip system (31.0 cm) was similar to the previous two experimental years. The average potato irrigation requirement reported by St. Johns River Water Management District (SJRWMD) is 45.7 to 50.8 cm per year (Smajstrla, 1995). Compared with the averaged potato irrigation amounts, drip irrigation in our study reduced 35 to 42% of irrigation water use. One of the reasons for the reduction in water use with drip irrigation was that no runoff occurred, whereas runoff occurred under both seepage irrigation systems since water furrows with small slopes are used to distribute water, particularly for drainage after heavy rain.

Crop water requirements (ET) and water applied at each potato growth stage are shown in Table 1. In 2006, the amount of irrigation water applied through drip system was less than the crop water requirements at stage 2 and 3, which are the critical growth stages for plant water requirement. This occurrence was possibly the reason for lower tuber yields with drip irrigation compared with the seepage irrigation systems. In 2007, the water applied with drip was similar to the ET requirement at stage 2 and more than the ET at stage 3 and 4, which resulted in the higher tuber yields compared with the yields in the other 2 years. In 2008, even though the total water applied with drip system was higher than the other two years, potato crops were under-irrigated at stage 2 and over-irrigated at stage 3. Combined with the leaching rainfall in the early season, the tuber yields were severely low under both drip and seepage irrigation in this year. Our study was not set up to determine the effects of adjustment of the amounts of water delivered during different physiological stages using drip irrigation based on the ET requirement for crop growth and yield. A separate experiment designed with specific objectives for gathering such information could possibly help gain better understanding.

Tuber Yield

The drip irrigation system did not perform well in both total and marketable yields except for the second experimental year compared with the seepage irrigation systems (Figure 5-2, 5-3, 5-4). The heaviest rainfall occurred in 2007, which was similar to the 10-year average, resulting in the highest total and marketable potato yields compared with the yield in the other two years. Both total and marketable yields, when fitted with linear regression models relating to the different N rates, resulted in R^2s ranging from 0.67 to 0.97 during the three experimental years. In 2006, no significant differences in marketable yield with any N rate were found except for the control. However, marketable yields with all N rates were below 10 Mg ha^{-1}, which were lower than marketable yields under the traditional seepage systems. One of the reasons was that there were no fertilizers applied to the field until after the drip tapes were set up for fertigation. The potato crops need N at planting and in the early season for shoot growth and tuber initialization, which is critical for tuber yields. The other reason was the lower irrigation amount supplied through the drip system, especially during growth stages 2 and 3. Total yields with each N rate were much higher than the marketable yields in 2006, which indicated that a lot of small-sized tubers were produced with drip irrigation due to the inefficient water and N fertilizer management.

In 2007, the marketable yields with N rates of 168 and 280 kg ha^{-1} were significantly higher than the yields with other N rates. Also, average marketable and total yields in this year were higher than the yields in the other 2 years. Adequate rainfall was one of the reasons for higher yields. In addition, improved efficiency in managing the drip system during 2007 could be another reason for higher yields.

In 2008, total and marketable yields increased significantly with the N rates. The average marketable yield during this year was similar to the yield in 2006 and lower than the yield in 2007. Even though total rainfall in 2008 was more than the total rainfall in 2006, the distribution through the growing season was extremely uneven. More than 83% of rainfall occurred within 10 DAP and after 80 DAP, which was not effective in sustaining or improving optimum tuber yields. Therefore, the drip system did not produce more yields in 2008 compared with 2006.

Fabeiro et al. (2001) concluded that tuber bulking and ripening stages were found to be the most sensitive stages to water stress with drip irrigation. Water deficit occurring at these two growth stages could result in yield reductions.

The two potato cultivars had remarkably different marketable and total tuber yields during the 3 study years (Figure 5-5). In 2006, significantly higher marketable and total tuber yields of var. *Atlantic* were produced than var. *Fabula*, whereas, in 2007 and 2008, var. *Fabula* harvested more marketable and total tubers than var. *Atlantic*. The differences in irrigation rates along with precipitation during 3 years contributed to the yield variances. The data further suggested that var. *Atlantic* would have higher tuber yields during a dry season, whereas var. *Fabula* would produce more tubers if there was normal rainfall combined with adequate irrigation.

Nitrogen Recovery

Nitrogen recovery by plants under drip irrigation was generally low, irrespective of the N rates in all experimental years (Table 5-2). Compared with N recovery at the corresponding equivalent N application rates under seepage irrigation systems, N recovery by both potato tubers and vines was lower all 3 years.

In 2006, N recovery by potato tubers and vines with control N treatment, which was the treatment with no fertilizer applied, was significantly lower than the recovery with other N treatments. No differences in N uptake by tubers were found except at the highest N application rate (280 kg N ha^{-1}). Nitrogen uptake by vines was significantly highest at 224 kg ha^{-1} N compared with 112 kg ha^{-1} N and control. The highest N application rate contributed to the highest total N recovery, which was significantly higher than the other N treatments except for the N rate of 224 kg ha^{-1}.

In 2007, no significant differences in N recovery by potato tubers were found at any N application rate. The variance in total N recovery among control and other N treatments could not be compared during this year as the data on N uptake by potato vines were not available for the control. However, no significant differences in vine and total N uptake were found at any of the N application rates. The potato tuber and total N recovery was consistent with the trend of potato tuber yields, where also no differences were found among all N application rates.

In 2008, similar to the N recovery under seepage irrigation systems, N uptake by tubers and vines at all N application rates was lower compared with the uptake at corresponding equivalent rates in the other 2 years. Nitrogen recovery by potato tubers was highest with the 280 kg ha^{-1} N rate treatment, which was significantly higher than the other N treatments except for the 224 kg ha^{-1} N treatment. Differences in N uptake by vines were only recorded between control treatment and the 224 and 280 kg ha^{-1} N treatments. Total N uptake with control treatment was significantly lower than the other N treatments, and the 280 kg ha^{-1} treatment had a higher total N recovery than the other N treatments except for the 224 kg ha^{-1} treatment. The lower N recovery of both tubers and vines in 2008 was a result of the deficient irrigation at the early growth stage, which also contributed to the lower tuber yields in this experimental year.

NH_4-N and NO_3-N Contents in Surface Soil

The highest NH_4-N and NO_3-N contents in surface soil across sampling events after planting in three experimental years were found in 2006 (Figure 5-6). At the second sampling event in 2006, the NO_3-N contents in surface soil exceeded 30 mg kg^{-1}

with 168 and 280 kg ha^{-1} N treatments, which were significantly higher than the contents with other two N treatments. At the third sampling event (76 DAP), the nitrate residues in surface soil were highest in the 280 kg ha^{-1} N treatment, which was significantly higher than the residual soil N in other treatments. No differences in soil NO_3-N and NH_4-N residues among all N treatments were found after harvesting (112 DAP). In 2007, the NH_4-N and NO_3-N contents in surface soil barely varied with each N treatment across sampling events, including the event before planting (Figure 5-7). Significantly lower NO_3-N contents were measured with the 112 kg ha^{-1} treatment at the last two sampling events. No differences in NH_4-N contents at any N rate were found across sampling events except for the lower contents at 112 kg ha^{-1} treatment at the last event. In 2008, both NO_3-N and NH_4-N residues in soil were relatively lower than the residues across sampling events in the other 2 years (Figure 5-8). Also, relatively higher soil NO_3-N contents were found before planting during this year. At the second sampling event, both NH_4-N and NO_3-N contents with each N treatment were significantly lower compared with contents in the corresponding samples in the other 2 years. The low soil N content at this sampling event resulted from the late N fertilizer application with drip irrigation, which also contributed to low potato tuber yields that year. The soil TKN contents were tested in 2008, but no differences among N treatments were found over the sampling events.

NH_4-N and NO_3-N Concentrations in Observation Wells

The NH_4-N and NO_3-N concentrations in the observation wells showed marked variation during the three experimental years. In 2006, no differences in the well water NO_3-N concentrations among N application rates were observed at the first two sampling events (Figure 5-9), and the concentrations were extremely low (less than 1.0

mg L^{-1}) for the first three events. At the last two sampling events, lower NO_3-N concentrations were observed with 112 kg ha^{-1} N compared with the other N rates except with 224 kg ha^{-1} N rate. High standard deviations were also observed between replications within each N treatment at the last two sampling events. Unlike the NO_3-N concentrations across sampling events, NH_4-N concentrations in the wells decreased from the first to the fourth sampling. At the first two sampling events, higher NH_4-N concentrations with high standard deviations were found with 112 kg ha^{-1} N. At the third and fourth sampling events, no differences in NH_4-N concentrations were measured among all N treatments, and all concentrations were less than 0.5 mg L^{-1}. At the last event, the only difference observed was that between 112 and 280 kg ha^{-1} N treatments.

In 2007, higher NO_3-N concentrations were measured acrss sampling events (Figure 5-10) compared with the concentrations in 2006. Since the amount of water delivered through the drip system in both the years was the same, higher precipitation in 2007 should be the only reason for the differences in the nitrate concentrations in the observation wells. The nitrate concentrations also increased with N application rates except for the last sampling event. High standard deviations were also measured within each N treatment, especially with the 224 and 280 kg ha^{-1} N rates. Similar patterns of NH_4-N concentrations were observed across sampling events in 2006 and 2007. The NH_4-N concentrations decreased from the first event to the fourth event in all N treatments. However, the highest N application rate contributed to the lower NH_4-N concentrations in wells, especially for last three sampling events.

In 2008, NO_3-N concentrations increased with N application rates except for the first sampling event (Figure 5-11). There were no differences in nitrate concentrations measured among N treatments at the first event, including the control. Compared with the nitrate concentrations in 2007, the concentrations in 2008 were lower through all sampling events, which were similar to the concentrations in 2006. The precipitation differences were the reason for the variances of nitrate concentrations in wells. The NH_4-N concentrations with all N treatments were less than 1.0 mg L^{-1} across sampling events, and the highest concentrations with each N treatment were found at the first sampling event, which were similar to the patterns of NH_4-N concentrations in the other 2 years.

Table 5-1. Irrigation water for drip irrigation and ET at each potato growth stage measured during 2006, 2007 and 2008.

Year	Growth Stage	ET0 (cm/d)	Kc	ET (cm/d)	Irrigation water (cm/d)
	1	0.34	0.4	0.13	0.14
2006	2	0.36	0.7	0.25	0.14
	3	0.41	1.1	0.45	0.35
	4	0.43	0.7	0.30	0.36
	2	0.33	0.7	0.23	0.22
2007	3	0.38	1.1	0.42	0.53
	4	0.41	0.7	0.28	0.46
	2	0.35	0.7	0.24	0.15
2008	3	0.41	1.1	0.45	0.65
	4	0.45	0.7	0.32	0.33

Table 5-2. Effect of N rate on N uptake by potato vines and tubers compared among N rates during 2006, 2007 and 2008.

	2006			2007			2008		
N rate	N recovery (kg ha^{-1})			N recovery (kg ha^{-1})			N recovery (kg ha^{-1})		
	Tuber	Vine	Total	Tuber	Vine	Total	Tuber	Vine	Total
0	11.49c	9.02c	20.51c	30.96	ns	ns	6.69c	3.15b	9.84c
112	49.31b	58.70b	108.02b	44.01	24.19	68.21	13.22bc	23.03ab	36.25b
168	41.52b	75.04ab	116.56b	64.49	27.10	91.59	16.85b	23.34ab	40.19b
224	39.43b	97.18a	136.60ab	46.70	30.36	77.07	28.26a	35.15a	63.41ab
280	69.57a	80.42ab	149.99a	63.62	32.53	96.15	35.41a	37.30a	72.72a

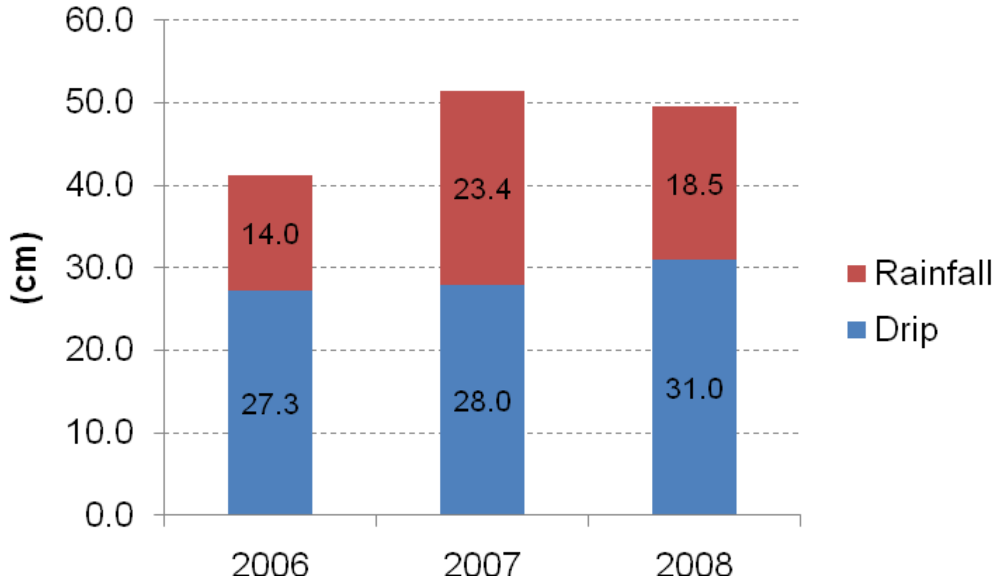


Figure 5-1. Total rainfall and drip irrigation volumes in 3 years.

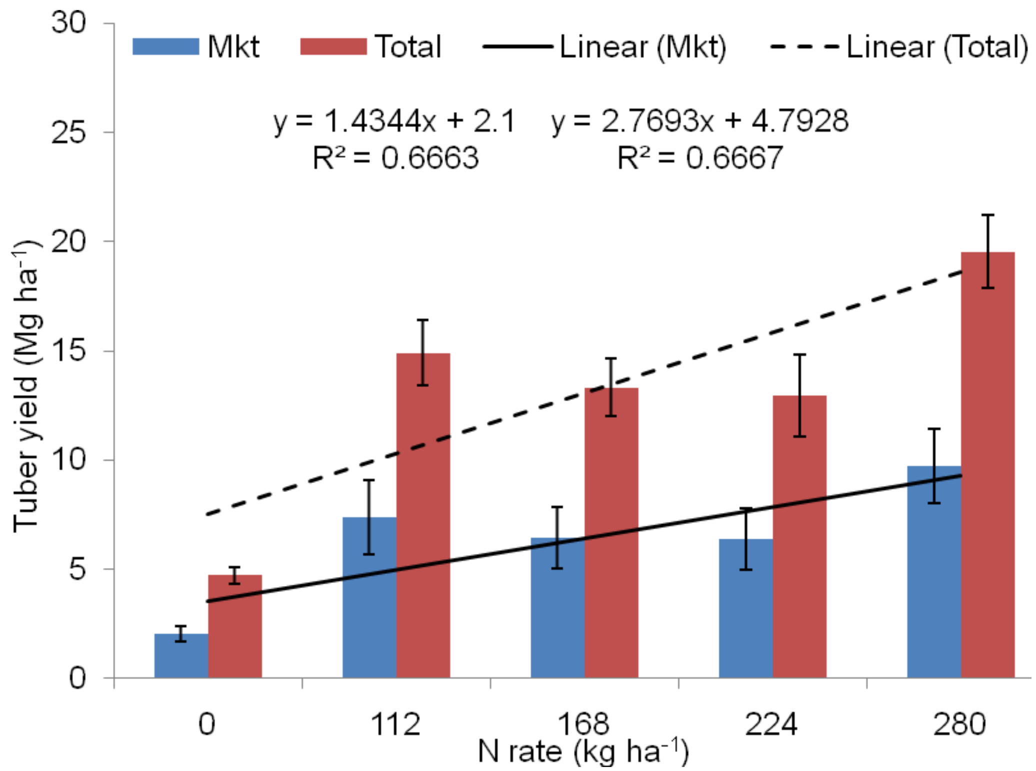


Figure 5-2. Total and marketable yields compared among N rates under drip irrigation system in 2006.

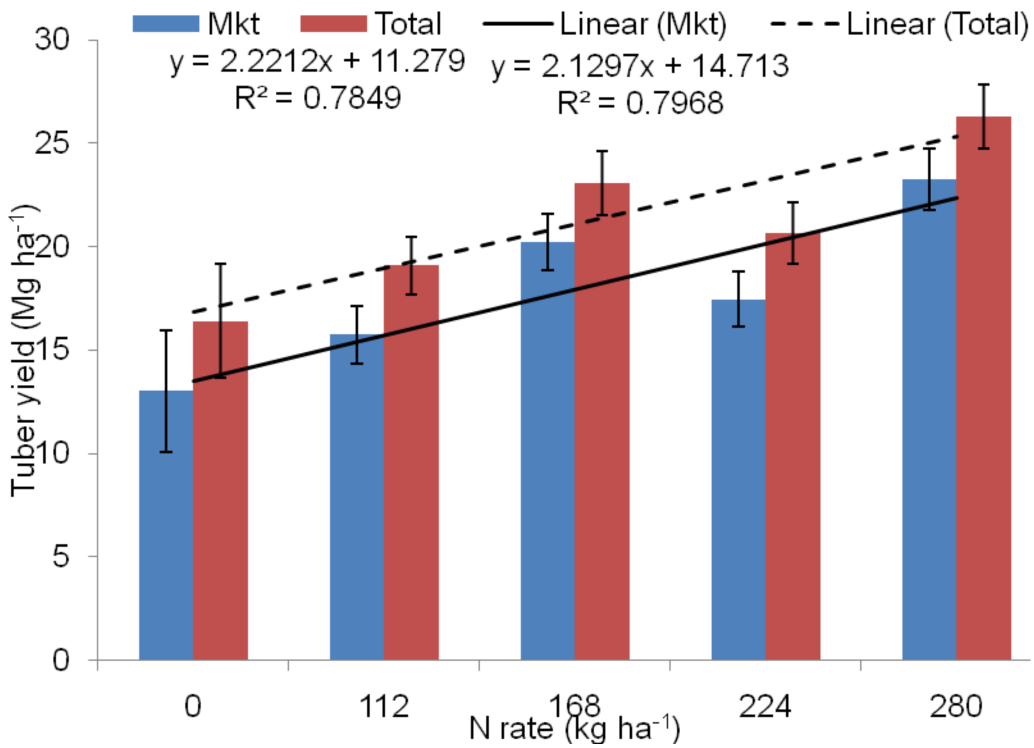


Figure 5-3. Total and marketable yields compared among N rates under drip irrigation system in 2007.

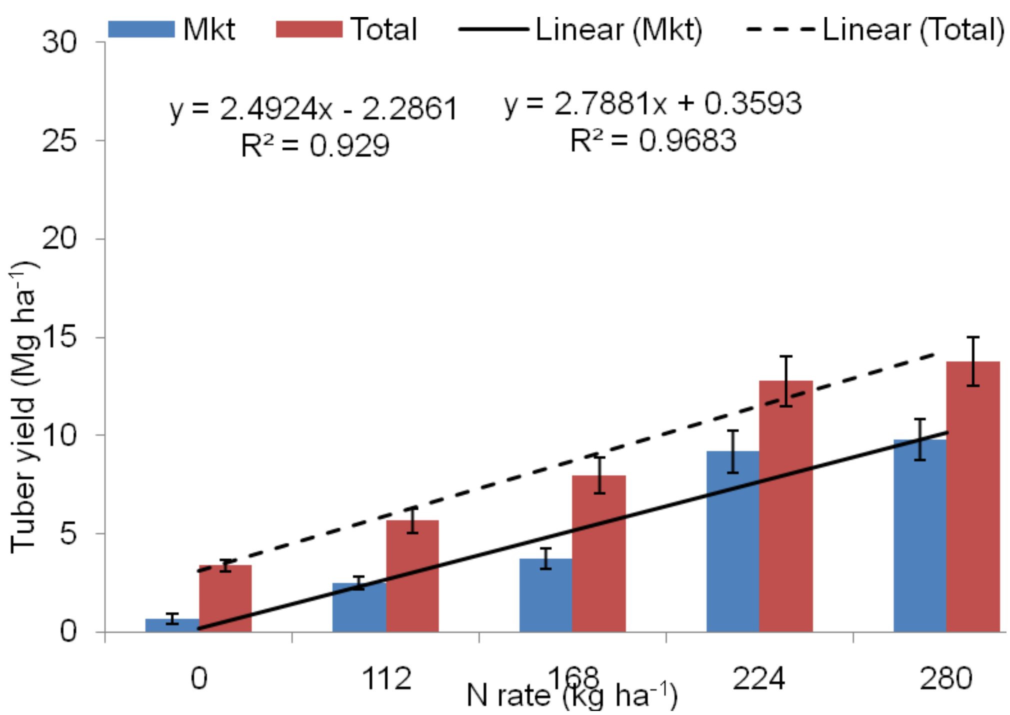


Figure 5-4. Total and marketable yields compared among N rates under drip irrigation system in 2008

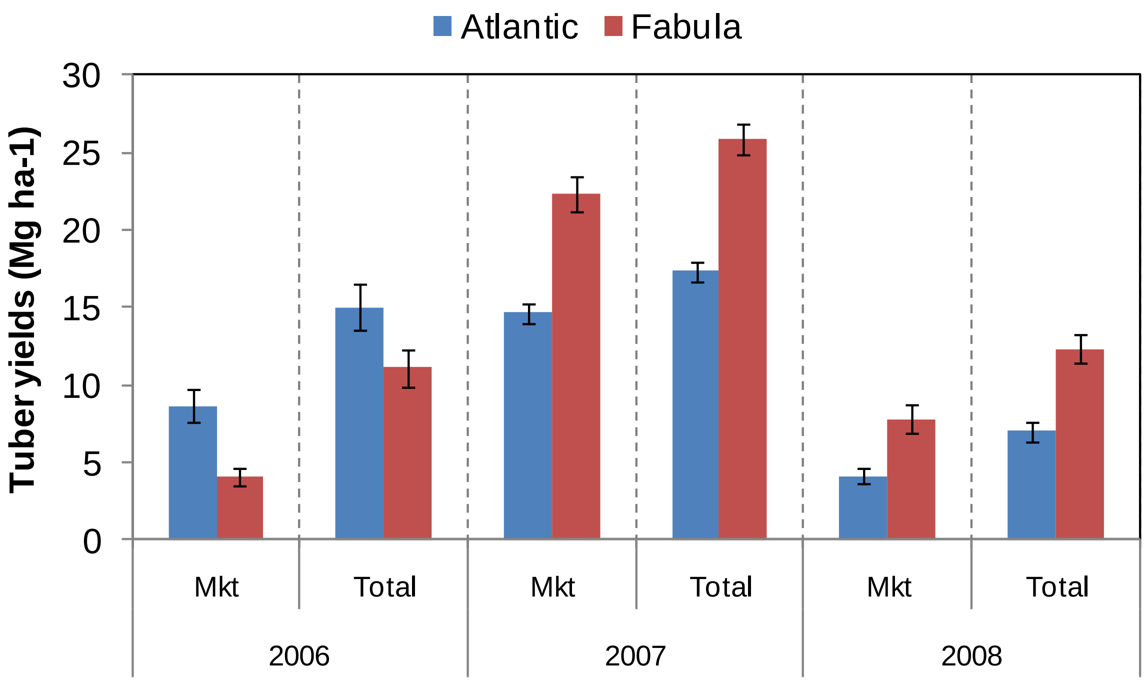


Figure 5-5. Total and marketable yields compared between two potato cultivars under drip irrigation in 2006, 2007 and 2008

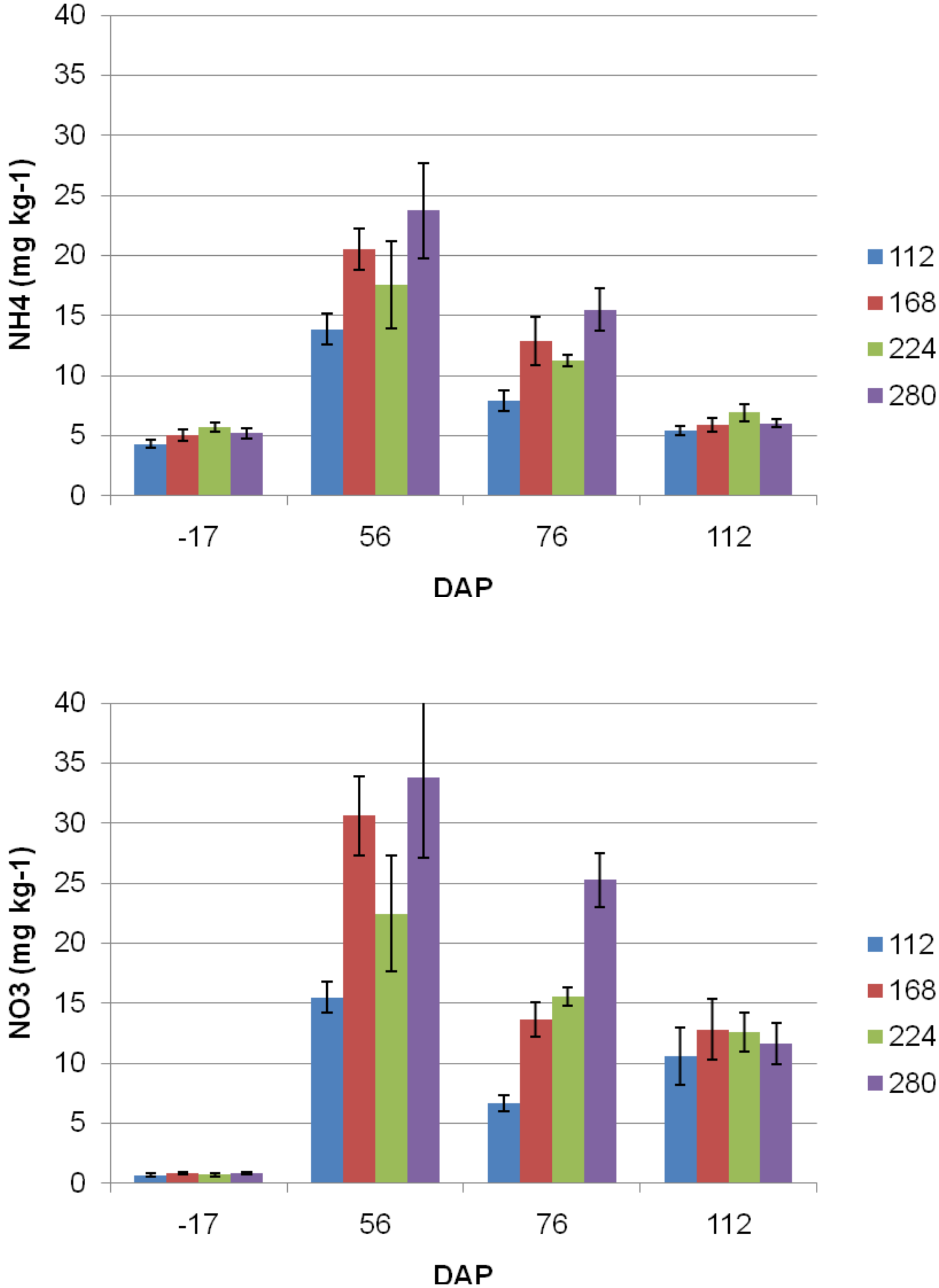
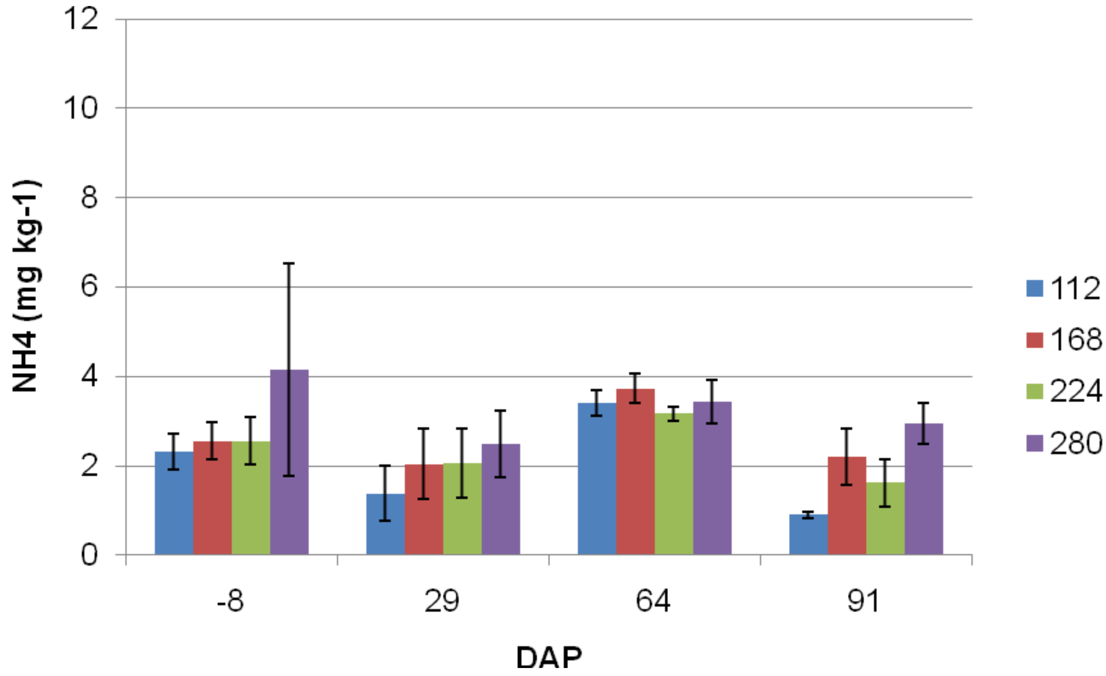


Figure 5-6. Soil NH_4-N and NO_3-N contents under drip irrigation system compared among N rates during 2006.



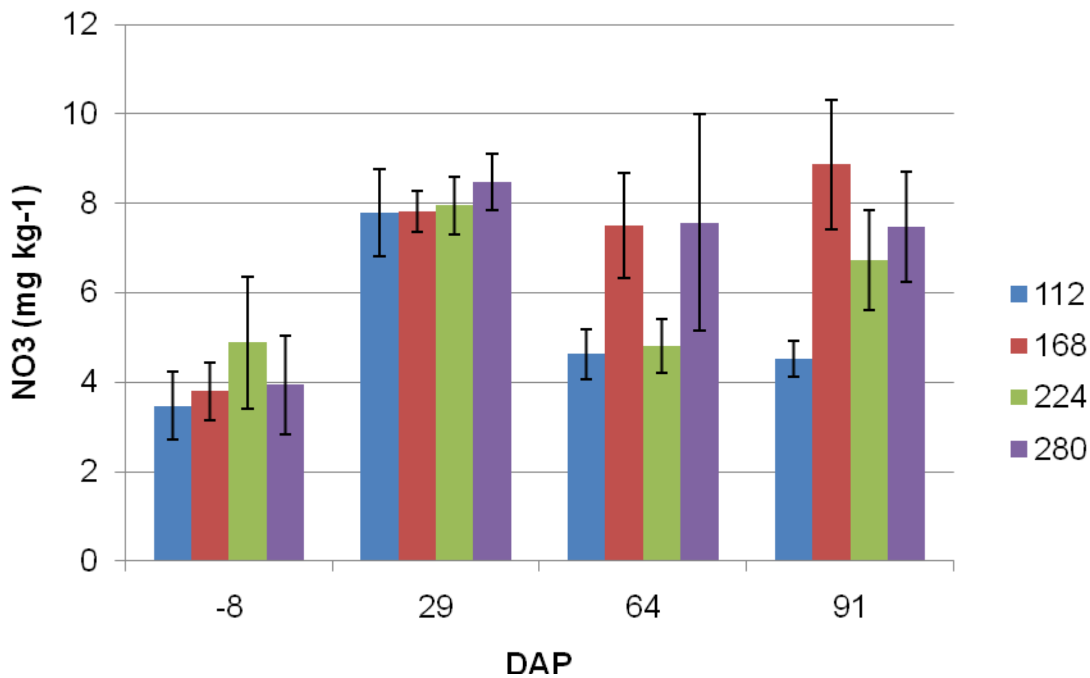


Figure 5-7. Soil NH_4-N and NO_3-N contents under drip irrigation system compared among N rates during 2007.

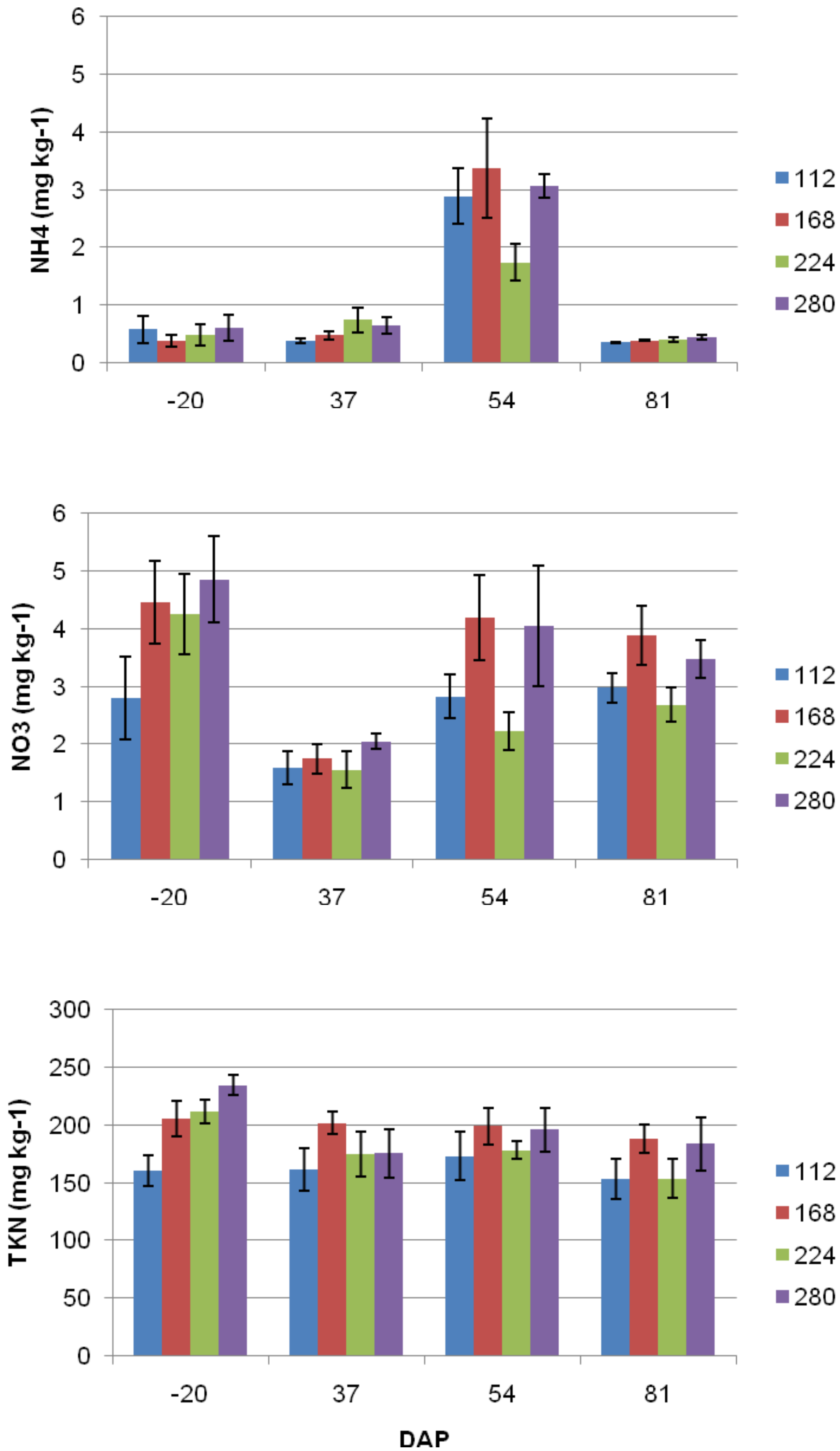


Figure 5-8. Soil NH_4-N, NO_3-N and TKN contents under drip irrigation system compared among N rates during 2008.

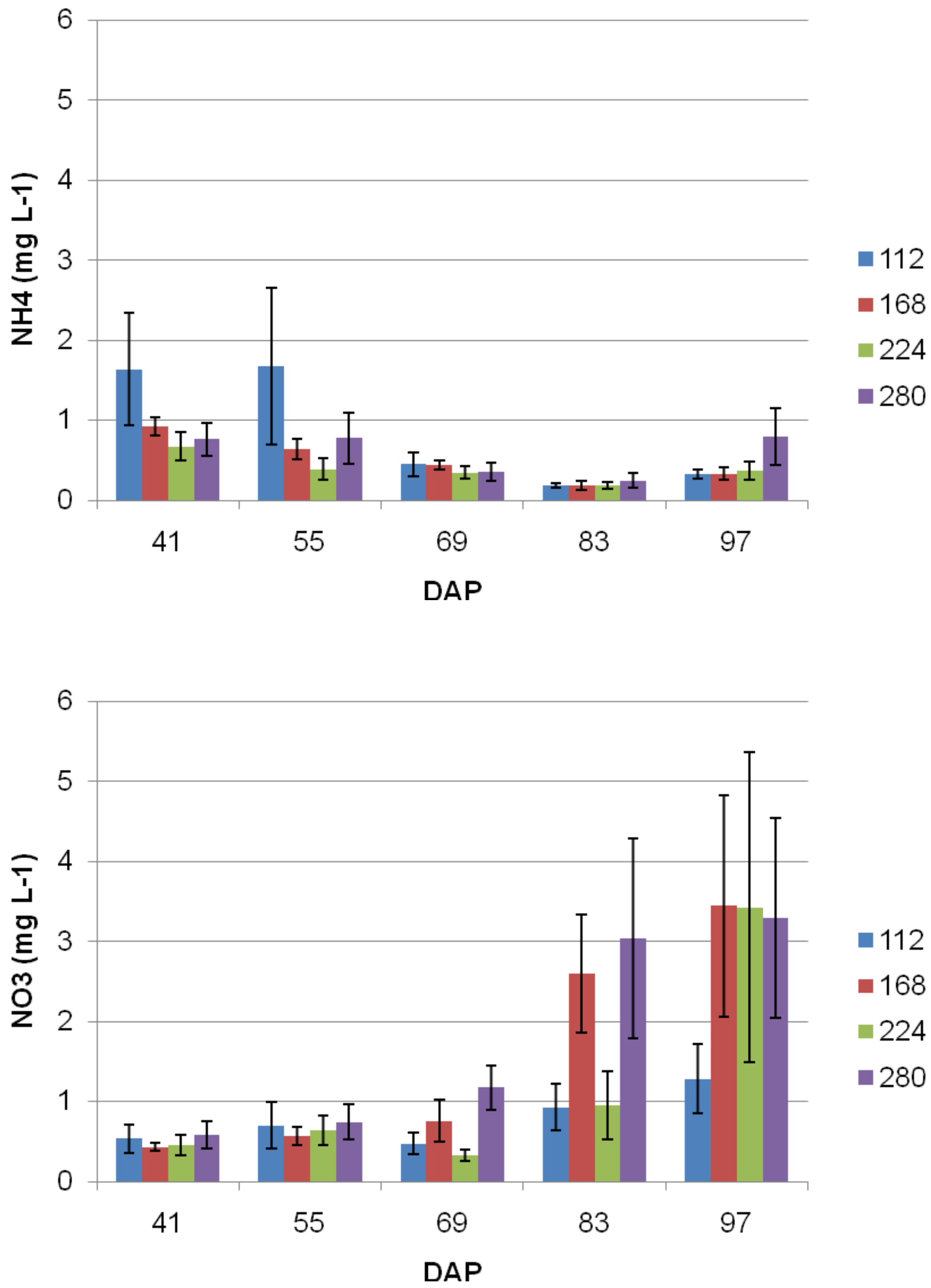


Figure 5-9. NH_4-N and NO_3-N concentrations compared among N rates in the observation wells under drip irrigation system during 2006.

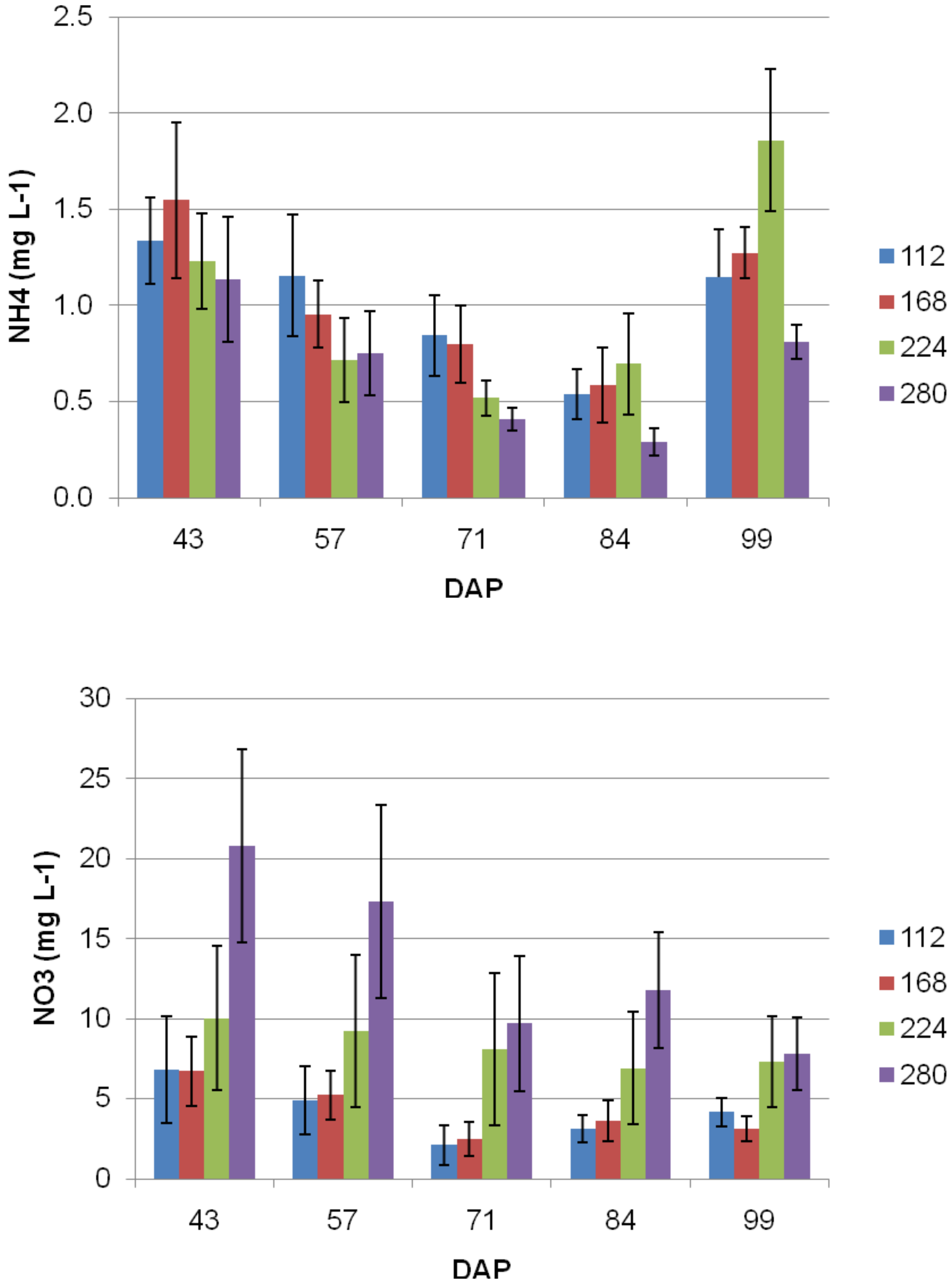
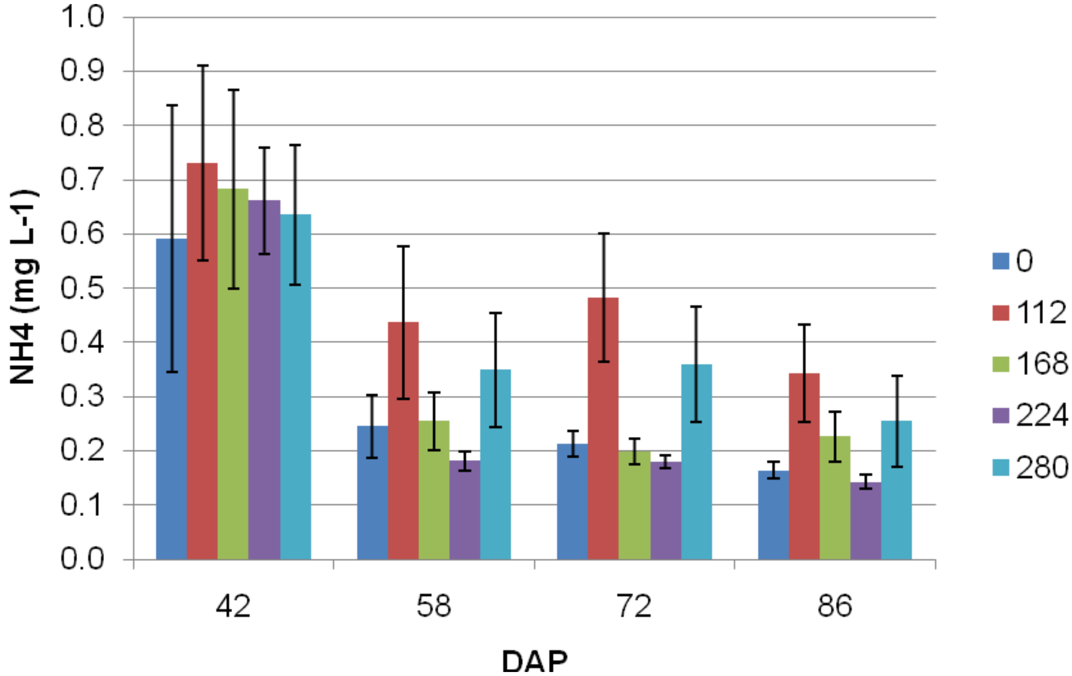


Figure 5-10. NH_4-N and NO_3-N concentrations compared among N rates in the observation wells under drip irrigation system during 2007.



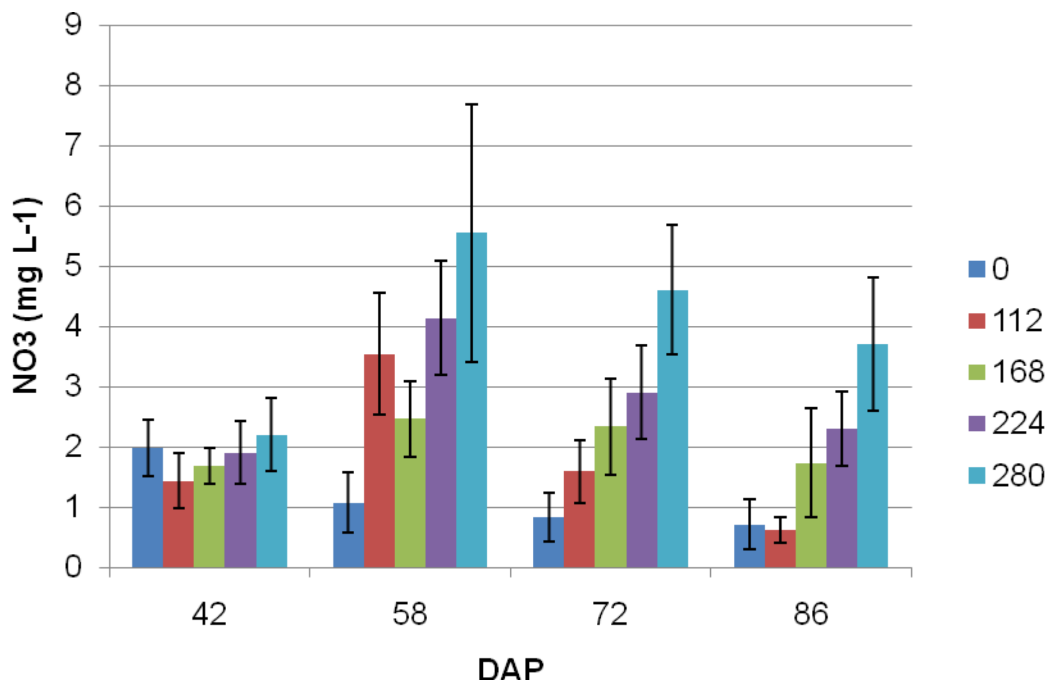


Figure 5-11. NH_4-N and NO_3-N concentrations compared among N rates in the observation wells under drip irrigation system during 2008.

CHAPTER 6
CONCLUSIONS

In this study, potato yields in 2006 and 2007 were similar to the 20-year average in Florida. However, yield in 2008 was lower than the average number. The weather conditions, especially uneven rainfall distribution, had important impacts on potato production. Particularly, the distribution of rainfall events throughout the growing season was more important than the total precipitation on potato production. In 2008, a leaching rainfall event occurred 3 DAP which greatly damaged the potato tuber sets and maximized N leaching early in the season. The unpredictable rainfall events reduced tuber yields and increased the potential of nitrate leaching as well. In order to avoid yield reduction, certain amount of fertilizers should be applied after big rainfall events. Planting time also influenced nitrogen uptake and leaching potentials by determining the release rate of CRFs. From our study, potatoes planted in the middle of February produced higher yields than those planted in the early March.

Intermittent seepage irrigation reduced water use by approximately 50% compared with TSI throughout 3 study years, and maintained potato yield in 2007, when the tuber yield was the highest in 3 years and very similar to the 20-yr average in State. Even though tuber yield with ISI was higher than the yield with TSI in 2008, the total and marketable yields were much lower than long-term average yield. Therefore, further studies are required to investigate whether ISI could increase tuber yields as well as significantly reduce water use. Compared with the TSI, the ISI also had the potential to reduce nitrate leaching if appropriate irrigation timing and scheduling are used. Applying irrigation water from 6am to 6pm during a day successfully reduced the fluctuation of the shallow water table, which subsequently minimized nitrate leaching under ISI.

As a controlled release N source, PSCU has the potential to increase total and marketable tuber yields compared with urea with a single pre-plant application. However, there may be still a risk of leaching of urea-N from PSCU, particularly after the first few leaching events in sandy soils. Heavy early-season rainfall can deplete available soil N; thus, side-dress fertilizers may still be required to produce optimum tuber yields for both PSCU and urea treatments. Besides leaching loss, urea and urea-based controlled-release fertilizers can also be lost through volatilization and denitrification, which can result in lower N uptake and poorer tuber yields. Increase of N rate from 168 to 224 kg ha^{-1} barely benefitted tuber yields, but increased the potential of N leaching losses.

Fertigation in this study was unsuccessful in maintaining potato yields as fertilizer application was delayed, as a delay in laying down drip tapes could not be avoided for the potato crop. A booster dose of fertilizer at planting to meet the nutrient requirement for germination and establishment of potato plants may help overcome the delayed fertigation problem. Besides, in this study, fertigation schedule was changed weekly, which could not match the daily ET sometimes. Therefore, daily schedules are probably needed to obtain the optimum potato yield.

This study was not set up to determine the effects of adjustment of the amounts of water delivered during different physiological stages using drip irrigation based on the ET requirement for sufficient crop growth and yield. A separate experiment designed with specific objectives for gathering such information could possibly help gain better understanding.

APPENDIX A
ANOVA TABLE FOR POTATO YIELD UNDER SEEPAGE IRRIGATION

Table A-1. ANOVA table for potato total yield under seepage irrigation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
rep	3	968.11	322.70	5.28	0.1026
year	2	3704.73	1852.36	39.94	<.0001
irri	1	61.07	61.07	1.02	0.3759
N	3	886.01	295.34	4.26	0.0171
year*irri	2	1437.05	718.52	15.49	<.0001
year*N	6	975.21	162.54	3.50	0.0024
irri*N	3	570.73	190.24	2.74	0.0692
year*irri*N	6	210.96	35.16	0.76	0.6035
var	1	327.23	327.23	7.06	0.0084
year*var	2	659.32	329.66	7.11	0.001
irri*var	1	58.01	58.01	1.25	0.2645
var*N	3	186.33	62.11	1.34	0.2622
year*var*N	6	234.06	39.01	0.84	0.5392
year*irri*var	2	232.09	116.05	2.50	0.084
irri*var*N	3	22.74	7.58	0.16	0.9209
year*irri*var*N	6	104.08	17.35	0.37	0.8951
rep(irri)	3	183.36	61.12	0.85	0.4845
N*rep(irri)	18	1294.14	71.90	1.55	0.0738
Residual	248	11502.00	46.38	.	.

Table A-2. ANOVA table for potato marketable yield under seepage irrigation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
rep	3	1062.36	354.12	7.01	0.0721
year	2	5767.00	2883.50	78.06	<.0001
irri	1	29.80	29.80	0.61	0.4855
N	3	447.55	149.18	1.85	0.1705
year*irri	2	1268.73	634.37	17.17	<.0001
year*N	6	687.05	114.51	3.10	0.006
irri*N	3	400.21	133.40	1.66	0.2086
year*irri*N	6	160.16	26.69	0.72	0.6317
var	1	204.63	204.63	5.54	0.0194
year*var	2	869.23	434.61	11.77	<.0001
irri*var	1	86.08	86.08	2.33	0.1281
var*N	3	102.09	34.03	0.92	0.4311
year*var*N	6	149.74	24.96	0.68	0.6694
year*irri*var	2	159.12	79.56	2.15	0.1182
irri*var*N	3	34.26	11.42	0.31	0.8188
year*irri*var*N	6	76.33	12.72	0.34	0.9127
rep(irri)	3	151.64	50.55	0.59	0.6281
N*rep(irri)	18	1536.25	85.35	2.31	0.0023
Residual	248	9160.63	36.94	.	.

APPENDIX B
ANOVA TABLES FOR POTATO YIELD UNDER DRIP IRRIGATION

Table B-1. ANOVA table for potato total yield under drip irrigation

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
rep	3	313.43	104.48	6.88	0.0002
year	2	8931.28	4465.64	294.26	<.0001
N	4	1995.22	498.81	32.87	<.0001
year*N	8	430.62	53.83	3.55	0.0009
var	1	465.67	465.67	30.69	<.0001
year*var	2	1195.98	597.99	39.40	<.0001
N*var	4	46.73	11.68	0.77	0.5465
year*N*var	8	164.16	20.52	1.35	0.2224
Residual	147	2230.85	15.18	.	.

Table B-2. ANOVA table for potato marketable yield under drip irrigation

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
rep	3	267.60	89.20	6.13	0.0006
year	2	9892.65	4946.32	340.06	<.0001
N	4	1378.06	344.51	23.69	<.0001
year*N	8	362.60	45.33	3.12	0.0028
var	1	218.33	218.33	15.01	0.0002
year*var	2	1122.55	561.27	38.59	<.0001
N*var	4	67.47	16.87	1.16	0.3311
year*N*var	8	204.27	25.53	1.76	0.0904
Residual	147	2138.19	14.55	.	.

APPENDIX C
IRRIGATION SCHEDULE FOR DRIP IRRIGATION

Table C-1. Irrigation schedule for drip system in 2006

Date	Activity	Stage	Gallons		Duration	comments
			Initial	final	(min)	
27-Mar	Irrigation	1	4074	4207	28	
28-Mar	Irrigation	1	4234	4512	50	
28-Mar	Irrigation	1	4512	4701	50	Filter clogged
28-Mar	Irrigation	1	4701	4818	50	Filter clogged
29-Mar	Irrigation	1	4824	5184	50	Filter cleaned (10 am)
29-Mar	Irrigation	1	5184	5494	50	
29-Mar	Irrigation	1	5494	5732	50	
30-Mar	Irrigation	1	5732	6634	50	
31-Mar	Irrigation	1	6634			weekend
2-Apr	Irrigation	1		8916		weekend
3-Apr	Fertigation	1	8927	9336	80	First injection fertilizers (10-0-11)
3-Apr	Fertigation	1	9336	9734	80	Afternoon
3-Apr	Fertigation	1	9734	10176	80	
3-Apr	Fertigation	1	10176			
3-Apr	Fertigation	1		10952		
4-Apr	Fertigation	1	10952			
5-Apr	Fertigation	1&2		13064		Overlapping stage 1 and 2
7-Apr	Fertigation	2	13108	13429	65	
7-Apr	Fertigation	2	13429	13752	65	
8-Apr	Fertigation	2	13407	14407	130	10am and 2pm
9-Apr	Fertigation	2				Valve closed for rain
10-Apr	Fertigation	2	14407	14743	65	Morning
10-Apr	Fertigation	2	14743		65	Noon
10-Apr	Fertigation	2		15622	65	Afternoon
11-Apr	Fertigation	2	15622	15956	52	
11-Apr	Fertigation	2	15956		65	Additional applic at 5:00pm
12-Apr	Fertigation	2		16467	65	Additional applic at 8:00am
12-Apr	Fertigation	2	16467	17246	65	applic at 10am & 2pm
13-Apr	Fertigation	2	17246	17530	65	
13-Apr	Fertigation	2	17530	17831	65	
13-Apr	Fertigation	2	17831	18259	90	Applic morning
14-Apr	Fertigation	2	18259	18673	90	Applic afternoon
15-Apr	Fertigation	3	18741			16 min each period

Irrigation schedule for drip system in 2006. Continued.						
Date	Activity	Stage	Gallons		Duration	comments
			Initial	final	(min)	
16-Apr	Fertigation	3		20133		16 min each period
17-Apr	Fertigation	3	20133			Applic K to control (1.76 lb)
17-Apr	Irrigation	3				
17-Apr	Fertigation	3		20790		
18-Apr	Fertigation	3	20790		60	morning
18-Apr	Fertigation	3		22084	50	Afternoon
19-Apr	Fertigation	3	22084	22370	50	Morning
19-Apr	Fertigation	3	22370	22674	50	Afternoon
20-Apr	Fertigation	3	22674	23156	100	
20-Apr	Irrigation	3	23156	23460	50	Additional applic (3:30pm)
21-Apr	Fertigation	3	23460	23774	50	
21-Apr	Fertigation	3	23774			
22-Apr	Fertigation	3		25194		
23-Apr	Fertigation	3	25194	25765		
24-Apr	Fertigation	3	25765			
25-Apr	Fertigation	3		30873		
26-Apr	Fertigation	3	30873	34200		
3-May	Fertigation	3	34200	55583		Additional applic at 4:00 am
3-May	Fertigation	3	55583	55770		
3-May	Fertigation	3	55770			
9-May	Fertigation	3		78396		
15-May	Fertigation	3				
17-May	Fertigation	4		102732		
18-May	Irrigation	4	102732			
16-Jun	Irrigation	4		149731		

Table C-2. Irrigation schedule for drip system in 2007

Date	Activity	Stage	Gallons		Duration	comments
			Initial	final	(min)	
30-Mar	Irrigation	2	153721	153967	30	
31-Mar	Irrigation	2				Weekend
1-Apr	Irrigation	2				Weekend
2-Apr	Fertigation	2	154456	158042	95	Calibrated injectors
3-Apr	Irrigation	2			30	
4-Apr	Fertigation	2	158835	161489	60	Calibrated injectors
5-Apr	Fertigation	2				
6-Apr	Fertigation	2	162545	165671	60	
7-Apr	Fertigation	2				Weekend
8-Apr	Fertigation	2				Weekend
9-Apr	Fertigation	2	166882	167438		
10-Apr	Fertigation	2				
11-Apr	Fertigation	2	168042	168796	30	
12-Apr	Fertigation	2				
13-Apr	Fertigation	2		170175		
14-Apr	Fertigation	2				Weekend
15-Apr	Fertigation	2				Weekend
16-Apr	Fertigation	2			60	
17-Apr	Fertigation	2				
18-Apr	Fertigation	2			60	
19-Apr	Fertigation	2				
20-Apr	Fertigation	2				
21-Apr	Fertigation	2				Weekend
22-Apr	Fertigation	2				Weekend
23-Apr	Fertigation	2	178409			
24-Apr	Fertigation	2				
25-Apr	Fertigation	2			90	
26-Apr	Fertigation	2				
2-May	Fertigation	3	188721		240	
11-May	Irrigation	3	214264			
15-May	Irrigation	3	224702			
17-May	Irrigation	3		231057	300	
21-May	Irrigation	4	258934			
4-Jun	Irrigation	4		303423		

Table C-3. Irrigation schedule for drip system in 2008

Date	Activity	Stage	Gallons		Duration	comments
			Initial	final	(min)	
1-Apr	Irrigation	2	329258			
2-Apr	Irrigation	2				
3-Apr	Irrigation	2				
4-Apr	Irrigation	2		330758		
5-Apr	Irrigation	2				weekend
6-Apr	Irrigation	2				weekend
7-Apr	Irrigation	2				
8-Apr	Irrigation	2		332725		Injection of N
9-Apr	Irrigation	2				
10-Apr	Irrigation	2			60	
11-Apr	Irrigation	2				
12-Apr	Irrigation	2				weekend
13-Apr	Irrigation	2				weekend
14-Apr	Irrigation	2				
15-Apr	Irrigation	2	339500	340837		Injection of N
16-Apr	Irrigation	2	340837	342237		
17-Apr	Irrigation	3	342242		120	
18-Apr	Irrigation	3				
19-Apr	Irrigation	3				weekend
20-Apr	Irrigation	3				weekend
21-Apr	Irrigation	3				
22-Apr	Irrigation	3	346394	348320		Injection of N
23-Apr	Irrigation	3				
24-Apr	Irrigation	3		354838		
25-Apr	Irrigation	3				
26-Apr	Irrigation	3				weekend
27-Apr	Irrigation	3				weekend
28-Apr	Irrigation	3				
29-Apr	Irrigation	3	378678	383159		Injection of N
30-Apr	Irrigation	3				
1-May	Irrigation	3	387723			
2-May	Irrigation	3				
3-May	Irrigation	3				weekend
4-May	Irrigation	3				weekend
5-May	Irrigation	3				
6-May	Irrigation	3	414557			Injection of N

Irrigation schedule for drip system in 2008. continued.						
Date	Activity	Stage	Gallons		Duration	comments
			Initial	final	(min)	
7-May	Irrigation	3				
8-May	Irrigation	3	423438			
9-May	Irrigation	3				
10-May	Irrigation	3				weekend
11-May	Irrigation	3				weekend
12-May	Irrigation	3				
13-May	Irrigation	3	436400	437886		Injection of N
14-May	Irrigation	3				
15-May	Irrigation	3	446415			
16-May	Irrigation	4				
17-May	Irrigation	4				weekend
18-May	Irrigation	4				weekend
19-May	Irrigation	4				
20-May	Irrigation	4	459034			Injection of N
5-Jun	Irrigation	4	490299			
10-Jun	Irrigation	4	494847			

APPENDIX D
FLOW METER RECORD FOR SEEPAGE IRRIGATION

Table D. The record of the flow meter under TSI in 2008

Date	Flow meter			
	Initial record time	Volumes (gal)	Final record time	Volumes (gal)
15-Apr	10:00 AM	433	2:00 PM	1271
16-Apr				
17-Apr	9:30 AM	10560	1:00 PM	11238
18-Apr				
19-Apr				
20-Apr				
21-Apr				
22-Apr	11:00 AM	37006	2:30 PM	37748
23-Apr				
24-Apr	8:45 AM	46654	1:00 PM	47361
25-Apr				
26-Apr				
27-Apr				
28-Apr				
29-Apr	9:00 AM	69372	12:30 PM	70107
30-Apr				
1-May	9:15 AM	79756	12:30 PM	80583
2-May				
3-May				
4-May				
5-May				
6-May	10:00 AM	107282	1:00 PM	107923
7-May				
8-May	10:00 AM	118113	12:30 PM	118681
9-May				
10-May				
11-May				
12-May				
13-May	11:00 AM	143003	1:00 PM	143431
14-May				
15-May	10:00 AM	152831	1:30 PM	153535
16-May				
20-May	10:00 AM	177293	1:00 PM	177885
22-May	10:30 AM	187427		
10-Jun	10:00 AM	227712		

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