Annual Report # 3
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Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems

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Supporting Staff

Rick A. Schoneman Agricultural Engineer, USDA-ARS, coordinated installation and maintenance of the irrigation system and student support.

Rebecca C. Phene, Staff Research Associate II, UC Davis, coordinated UC orchard maintenance, developed computer software for the lysimeter and the irrigation control systems, developed the lysimeter KARE website and measured various crop variables.

Objectives:

The overall objective of this project is to optimize water-nitrogen interactionsto improve FUE of young and maturing pomegranate and to minimize leaching losses of nitrogen. Specific objectives are:

1. Determine the real time seasonal nitrogen requirements (N) of DI- and SDI- irrigated maturing pomegranate that improve FUE without yield reduction.
2. Determine the effectiveness of three nitrogen injection rates with DI and SDI on maintaining adequate N levels in maturing pomegranates.
3. Determine the effect of real time seasonal nitrogen injections (N) with DI- and SDI-irrigated maturing pomegranate on N leaching losses.
4. Develop fertigation management tools that will allow the growers to achieve objective 1 and present these results to interested parties at yearly held field days and seminars.
5. Determine if concentrations of macronutrients (P, K, Ca, Mg) and micronutrients (Zn, Cu, Mn, Fe, B, Se) and eventually healthy bioactive compounds in soil,

peel and fruit are influenced by precise irrigation/fertigation management with DI and SDI.

Abstract:

Pomegranate has been identified as a promising specialty crop in California because of its
potential nutritive value, drought and salinity tolerance. The acreage has doubled within the past few years. However, even though this is an ancient crop very little is known about the water and fertilization requirements of the crop. This project is designed to determine the nitrogen requirements of a developing pomegranate crop and follow it until full production. A replicated field experiment is being used with 2 irrigation treatments (surface and subsurface drip) and 3 nitrogen levels,(50%, 100% and 150% of the crop requirement.

In 2011 the installation of the fertigation system was completed and the trees were fertilized uniformly to ensure uniform plant development. The irrigation system was operated in a semi automatic mode with a total of 8.5 inches (216 mm) of water being applied. The total evapotranspiration was 9.8 inches (249 mm) and the additional water use over applied irrigation was taken from stored soil water. Soil analysis determined that the nitrate levels were uniform throughout the first 4.5 feet (1.4 m) of the soil profile. Plant tissue analyses demonstrated that the pomegranate responded well to nitrogen fertilization. Soil suction samplers demonstrated that there was very little percolation loss towards the end of the summer.

In 2012 the irrigation systems were operated in a full automatic mode with the irrigation application being determined and operated by the weighing lysimeter. The mean yearly cumulative applied irrigation water for the DI and SDI treatments were respectively 18.0 in. (456 mm) and 17.4 in. (441 mm). A small amount of stored soil water from precipitation (P<6.0 in.) may have been used by the trees early in the season. All N was automatically applied by continuous injection of N-PHURIC (46 lb N/ac) for all treatments and additionally as AN-20 for N-2 (102 lb N/ac) and N-3 (203 lb N/ac) treatments, starting on 5/12/2012 and ending on 8/18/2012. Phosphorus (47 lb P/ac) was injected at a rate of P=15 ppm to maintain adequate P level in the SDI treatment. Potassium (K2T) was also injected at a rate of K=23- 35 ppm (67 lb K/ac) to maintain adequate K level in both SDI and DI treatments.

Total N analysis was used to characterize the long term N response to the N treatments. The total % nitrogen in leaf tissue in the DI and SDI irrigation treatments was averaged for the three N treatments from May 1 and May 15 prior to any significant fertigation and thereafter until August 15 when the N injection stopped. A large drop in tissue total N levels from 5/1 to 5/15 happened as plants were leafing out and starting to flower rapidly even though a large amount of N was being injected. Thereafter, the tissue N started to recover slowly and slightly faster for the DI than for the SDI treatment.

Introduction:

The California Department of Water Resources (DWR) Bulletin 160-05 states: “In the future,
water management challenges will be more complex as population increases, demand patterns shift, and environmental needs are better understood…”. The competition for water will increase as the population of California increases to nearly 50 million people by 2050 and the environmental flows increase to meet the demands in the Sacramento San Joaquin Delta. California agriculture is facing severe, recurring water availability shortages, groundwater quality deterioration, and accumulation of salts in the shallow, perched water table. To compensate for the lack of sufficient surface water, growers on the west side of the SJV are pumping from deep saline aquifers, bringing salts to the surface that are causing drainage issues and irrigated acreage to be drastically reduced. Senate Bill (SBX 7-7) was enacted

in January 2012 and will require irrigation districts to measure delivery of water to growers by July 2012. A recent UCD report on groundwater quality released on March 13, 2012 and entitled: "Nitrate in Drinking Water Raises Health Concerns for Rural Californian" indicated that "one in ten people living in California's most productive agricultural area is at risk of exposure to harmful levels of nitrates contamination in their drinking water" (Harter, Lund, Kostyrko and Kerlin, 2012). Laws on groundwater quality will soon be enacted controlling leaching of agricultural NO_3-N to the groundwater.

Research and demonstration have demonstrated that well managed surface drip (DI) and subsurface drip irrigation (SDI) systems can eliminate runoff, deep drainage, minimize surface soil and plant evaporation and reduce transpiration of drought tolerant crops. Reduction of runoff and deep drainage can also significantly reduce soluble fertilizer losses and improve groundwater quality. The success of DI and SDI methods depends on the knowledge and management of fertigation, especially for deep SDI. Reductions in wetted root volume, particularly if combined with deficit irrigation practices, restrict available nutrients and impose nutrient-based limits on growth or yield. This is particularly important with an immobile nutrient such as P. Avoiding nutrient deficiency or excess is critical to maintaining high water and fertilizer use efficiencies (WUE & FUE). This interaction has been demonstrated for field and vegetable crops but no similar research has been conducted for permanent crops (Phene et al., 1989).

During droughts, water deliveries are reduced or even stopped and if water stress is severe enough to limit plant growth, fertilizer application should be reduced proportionally. This can only be accomplished if fertilizers are applied frequently and only as needed by the crop as part of the irrigation supply.

Pomegranate acreage in California is now about 11,700 ha and Kevin Day noted that "from 2006 to 2009 the area planted with pomegranate trees has increased from approximately 11,800 ac to 14,800 ac (4800 to 6000 ha) in 2006 to 28,900 ac (11,700 ha) in 2009" (Personal communication K. Day 2009). The rising demand for juices, e.g. pomegranate, blueberry, with healthy bioactive compounds, mineral nutrients and high antioxidant contents are partially contributing to this growth in acreage. Pomegranate is thought to be both a drought and salt tolerant crop that can be grown on saline soils and is thus ideally suited for the Westside of the San Joaquin Valley as a replacement for lower value crops.

There have been no studies that evaluated the fertilization requirements of developing pomegranate orchard using either surface drip or subsurface drip irrigation. This project will initially determine the fertilizer requirements for a developing pomegranate orchard.

Work Description:
This project is using a 1.4 ha Pomegranate orchard (var. Wonderful) located on the Kearney Agricultural Center (KARE) that contains a large weighing lysimeter (Phene et al., 1991). This lysimeter will be used to manage the irrigation scheduling on the site and determine the crop water use for the 100% SDI treatment, 100% N-sub treatment. The trees in the 50% N and 150% N sub-treatments will be irrigated at 100% of crop water measured by the lysimeter until feedback from the soil matric potential measurements indicate a need for up and/or down adjustments. The lysimeter tree will be irrigated using subsurface drip irrigation. Trees were planted with rows spaced 4.9 m apart and trees in the harvest rows spaced at 3.6 m along the row. There are 2 border rows with trees spaced at 3.6 m apart. Figure 1 is a schematic of the plot layout (Randomized Complete Block Design with sub-treatments) showing main irrigation treatments and N-fertility sub-treatments. The

main irrigation treatments are DI and SDI (50 to 60 cm. depth) systems with dual drip irrigation laterals, each

0.9 m. from the trees. The fertility sub treatments are 3 N treatments (50% of adequate N, adequate N, based on biweekly tissue analysis and 150% of adequate N, all applied by continuous injection of AN-20). Potassium (K2T) and phosphorus (PO4-P) will be supplied by continuous injection of P=15 ppm and K=50 ppm to maintain adequate levels. The pH of the irrigation water will be automatically maintained at 6.5+/-0.5. Tree and fruit responses will be determined by trunk and canopy measurements, pruned plant biomass, bimonthly plant tissue analyses and fruit yield and quality. When appropriate, flowers, fruit yields and quality will be measured and statistically analysed. Analysis of variance (ANOVA) for the Randomized Complete Block design (RBCD) with sub-samples will be used to determine the treatment significance.

Task and sub-tasks to achieve objectives for year #3

a. Determine the real time seasonal nitrogen requirements (N) of DI- and SDI-irrigated maturing pomegranate that improve FUE without yield reduction. Bi-weekly tissue analyses will be used to provide N-uptake rates under three N application levels and will be used to fertilize the 100% N level accordingly. Nitrogen concentration levels will require knowledge of accurate hourly ETc and associated irrigation application rates.

b. Determine the effectiveness of three nitrogen injection rates with DI and SDI on maintaining adequate N levels in maturing pomegranates. Yearly whole tree harvesting and analyses for total nitrogen (and other nutrients) will provide total N-uptake under three N application levels.

c. Determine the effect of real time seasonal nitrogen injections (N) with DI- and SDI- irrigated maturing pomegranate on N leaching losses. Soil samples will be collected down to two meters and analyzed for soluble N concentration and to determine the treatment effects on N-leaching losses.

d. Develop fertigation management tools that will allow the growers to achieve objective 1 and present these results to interested parties at yearly held field days and seminars.

e. Determine if concentrations of macronutrients (P, K, Ca, Mg) and micronutrients (Zn, Cu, Mn, Fe, B, Se) and eventually healthy bioactive compounds in soil, peel and fruit are influenced by precise N-fertigation management with DI and SDI.

f. Soil matric potential measurements will be used to determine the direction of the hydraulic gradient and the N-leaching potential.

g. Development of fertigation management tools will be initiated. These tools will eventually allow the growers to achieve the objectives and goals of this project. The obtained results will be presented to interested parties at field days and seminars.

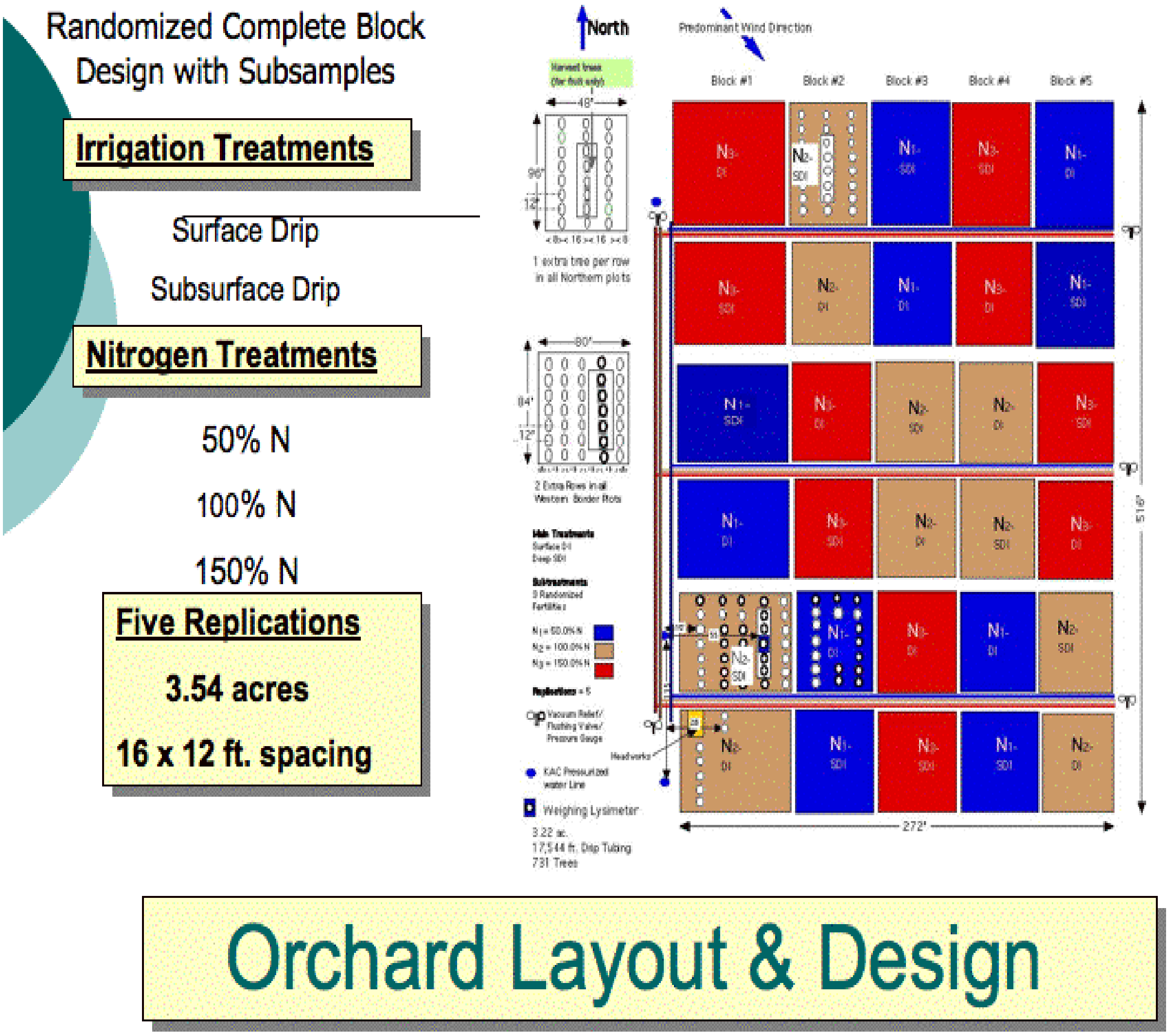


Figure1. Plot layout of pomegranate fertilization project (UCCE Presentation, 11/29/2011).

Importance of Irrigation Scheduling on nitrogen use efficiency (NUE)

Water and nitrogen are the most two important components needed by plants to efficiently achieve plant growth. Unfortunately, if not applied adequately in time and space, significant amounts of water and nitrate can be lost below the root zone and not be available for plant growth. In addition, the transformations and losses of nitrogen as gaseous emission of nitrous oxide (N_2O) under over-irrigation are also significant and detrimental to environmental quality. **Therefore, it is critical to understand the dynamic process involved in the Soil- Plant-Atmosphere Continuum (SPAC) and use this knowledge to manage the water- nitrogen application in order to maintain them in the root zone and minimize losses.**

Factors Affecting Irrigation Scheduling

Factors that affect irrigation scheduling are listed in Table 1. Most of these factors are interdependent and variable, both spatially and temporally. Many crops are good integrator; however, accurate scheduling of irrigation, and especially drip irrigation and more specifically subsurface drip irrigation, can minimize the adverse effects of some of these factors and maximize crop productivity without causing detrimental effects to the environment. Assuming that water, fertilizers, and management factors are not limiting and that growers are planning to use automated feedback control systems to schedule high frequency drip irrigation, there are basic closed loop feedback methods that are commercially

available and accessible on the internet: (1) soil water content and potential, (2) plant water status, (3) reference evapotranspiration on the internet (CIMIS) and with own equipment, and
(4) combination of 1, 2 and 3. Details of these methods will not be discussed here.

Table 1. General factors affecting irrigation water requirements and scheduling.

Factors affecting irrigation water requirement (Phene, 1986a)

Water factors	*Soil factors*
water availability (amount and time)	soil structure
water quality	soil texture
	soil depth
Climatic/weather factors	mechanical impedance
ambient temperature (day/night)	infiltration rate
solar radiation	drainage rate
wind speed	soil aeration
rainfall	water retention characteristics
humidity	hydraulic conductivity
day length	water table
length of growing season	soil salinity
	soil fertility
Plant factors	soil temperature
crop variety	soil borne organisms
rooting characteristic	
drought tolerance	*Management factors*
growth stage	dates of planting/harvesting
harvestable constituent	plant population
yield and quality	irrigation system
length of growing season	critical growth stages
salt tolerance	fertilization
nutrient requirement	crop protection
stomatal mechanism	cultivation
canopy architecture	

The Soil-Plant Atmosphere Continuum (SPAC)

In the evapotranspiration (ET) process, meteorological factors control the strength of the "sink" (a SPAC term referring to the atmospheric affinity for water), soil factors control the source of water available to plants and plant factors control the transmission of water from the source to the sink (Phene et al, 1990). Therefore, to understand and be able to accurately predict irrigation water requirements, the SPAC must be considered as a physically integrated dynamic system in which water inputs and outputs, transport processes and meteorological factors occur interactively and simultaneously (see Figure 2). **Hence the objective for an ideal irrigation monitoring and control system should be to develop a system based on feedback from the plant and soil components and real time measurements of meteorological variables.** This system could be used to maximize water use efficiency (WUE) and agricultural productivity. The field water balance is defined as:

$$(\Delta S+\Delta V) = (P+I+U)-(R+D+E+T) \quad (1)$$

Where ($\Delta S+\Delta V$) represents the changes in soil ΔS and plant ΔV water content, P is the precipitation, I is the irrigation water applied and U is the upward water movement from the capillary fringe of a shallow water table; these three variables, (P+I+U) represent the water input to the system. The four variables (R+D+E+T) represent the output from the system where R is the runoff from the field, D is the deep percolation below the root zone, E is the evaporation at the soil and plant surfaces and T is the plant transpiration. In addition, when the water quality is affected by salinity, it may be necessary to calculate a leaching requirement (LR) to maintain the soil root zone within a range adequate for plant growth. Also, I should be increased by a percentage equivalent to the difference between the design emission uniformity (EU) and 100% (a uniform EU is usually 95%). Figure 2 shows a schematic representation of this extremely dynamic and intricate SPAC process.

Soil nitrogen processes

Figure 3 shows the many factors involved in the dynamic nitrogen inputs, outputs and transformations in the soil. In agriculture, it is recognized that besides water management, fertility management is the next most limiting factor in maximizing yields and WUE (Bar- Yosef et al., 1989; Bar-Yosef, 1999). Plants take up nitrogen mostly as nitrate. Nitrogen losses, such as nitrite and nitrate leaching and N_2 and N_2O gaseous emissions from denitrification of nitrate, often result from over-irrigation and precipitation. Hence, **adequate irrigation scheduling and frequent low fertilizer-N applications are critical to maintaining water and nutrients, and nitrate-N in particular, within the root zone.** The major objectives of this project are to maximize WUE and NUE of a maturing pomegranate orchard by using computerized lysimetric high frequency irrigation and fertigation techniques with DI and SDI.

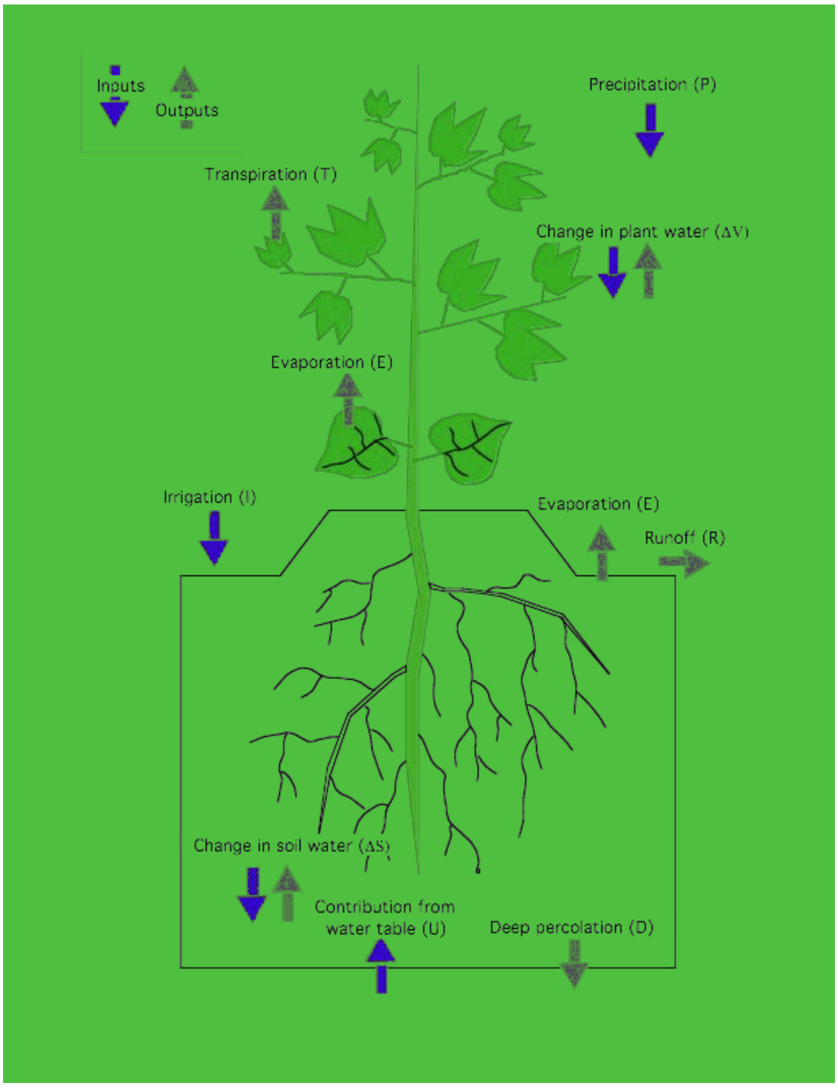


Figure 2. Dynamic representation of the interactive soil plant atmosphere continuum (SPAC) as it affects irrigation scheduling.

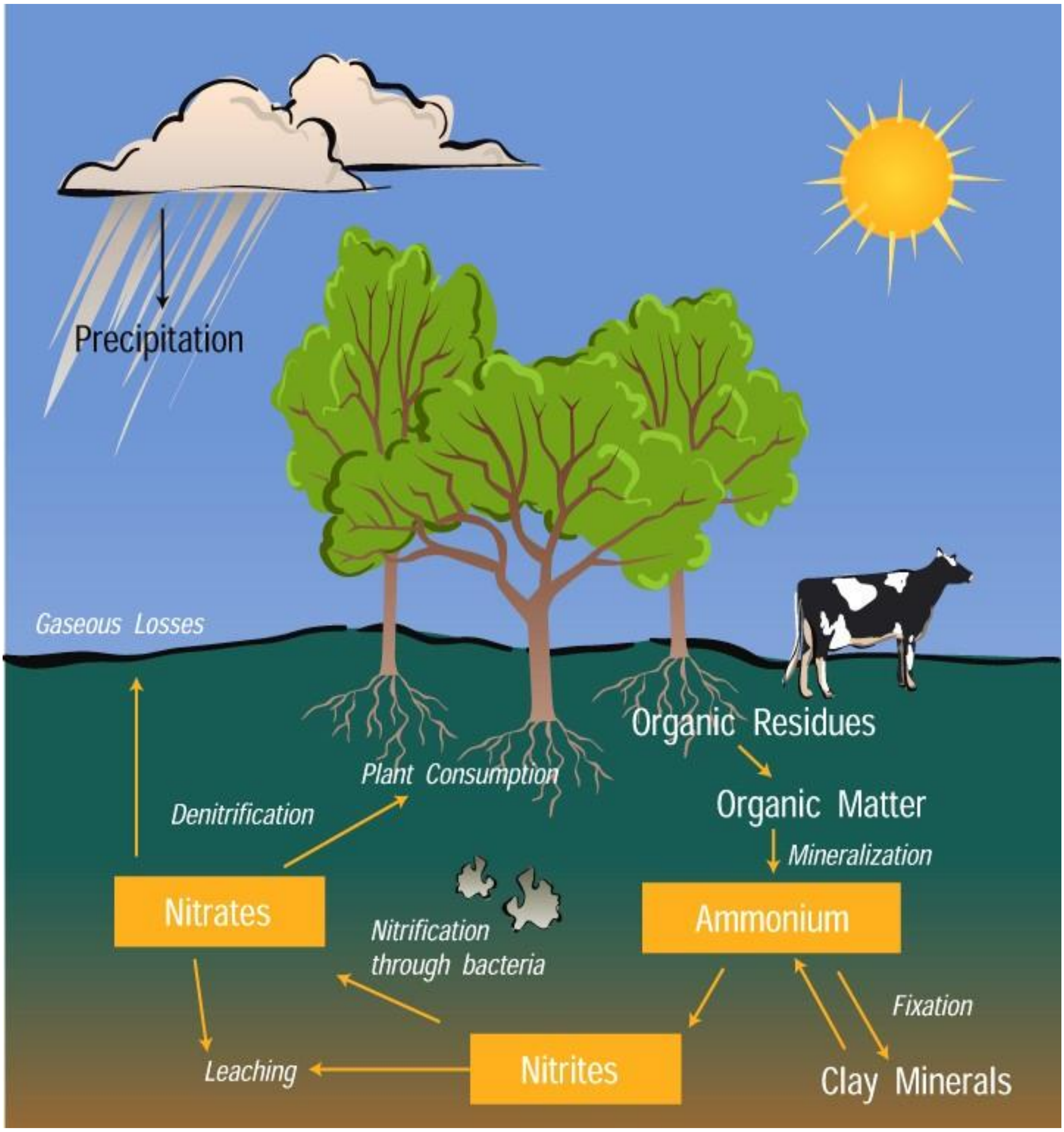


Figure 3. Schematic representation of the nitrogen cycle.

Results

1. Water Use: Figure 4 shows the yearly cumulative grass reference ET (CIMIS ETo), cumulative precipitation (P) and the cumulative orchard evapotranspiration (ETc). The cumulative orchard evapotranspiration is calculated by multiplying the lysimeter ETc by a ratio equal to the lysimeter surface area (8 m^2) divided by the surface area of one orchard tree (17.6 m^2). In 2012, these respective values were: ETo=1381 mm, P=221 mm and ETc=462 mm.

Figure 5 shows the mean yearly cumulative applied irrigation water for the SDI and DI treatments, the 7-day averaged crop coefficient (Kc) and the 4^{th} order polynomial regression of the 7-day averaged Kc. The mean yearly cumulative applied irrigation water for the SDI and DI treatments were respectively 456 mm (18.0 in.) and 441 mm (17.4 in.). The Kc is defined as the ratio of the orchard ETc to the CIMIS ETo from January 1st, 2012 to Dec31st 2012. The 7-day averaged Kc reached a maximum of 0.6 on October 7th 2012 (October was extremely hot in 2012).

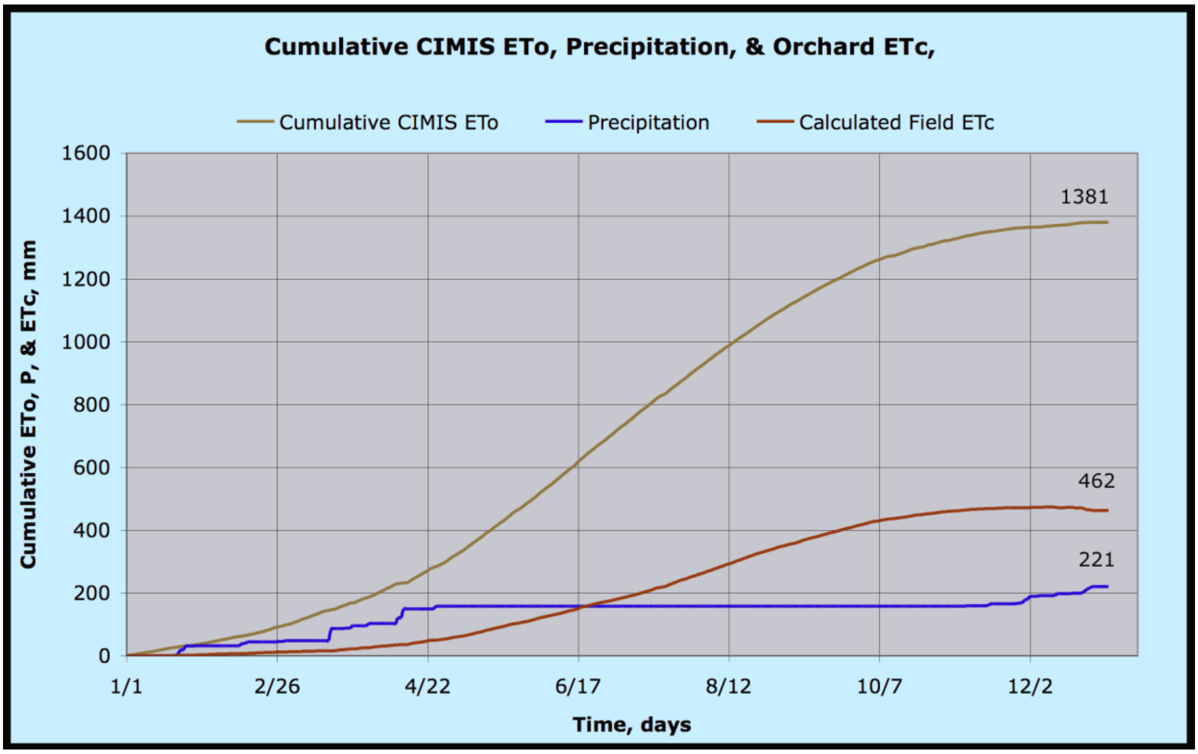


Figure 4. The yearly cumulative grass reference ET (CIMIS ETo), cumulative precipitation (P) and the cumulative orchard evapotranspiration (ETc).

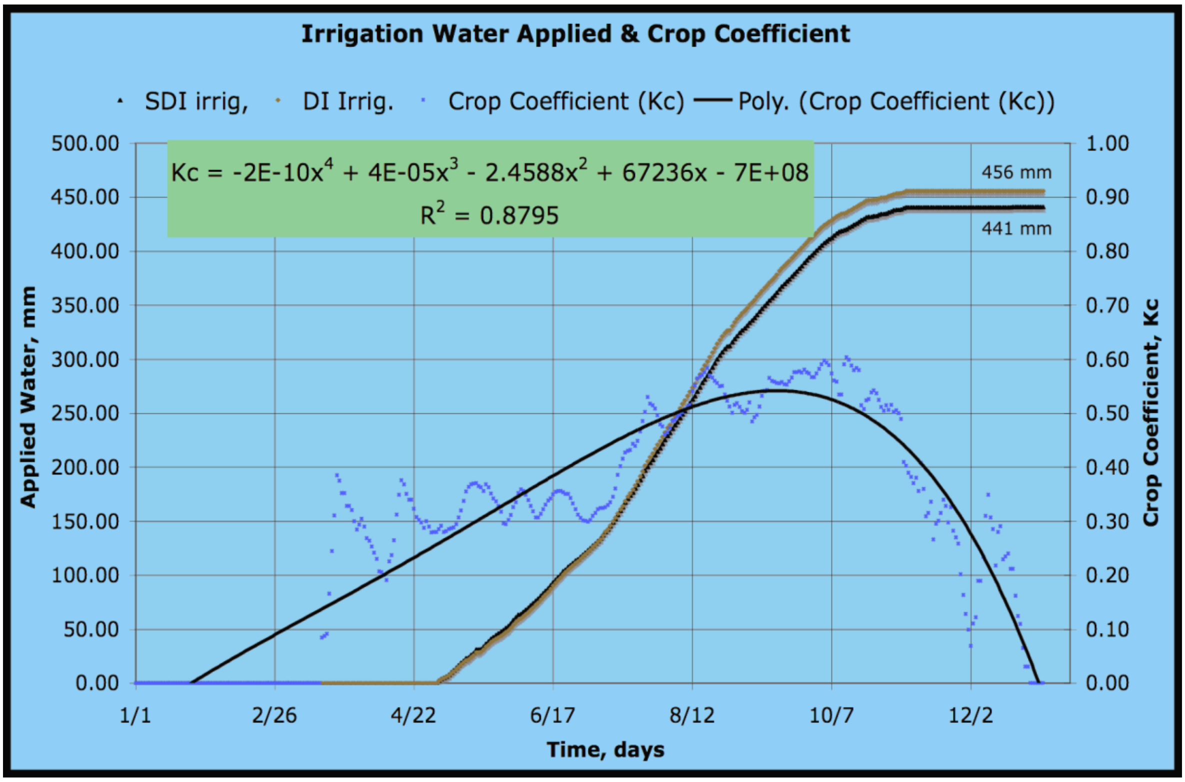


Figure 5. The mean yearly cumulative applied irrigation water for the SDI and DI treatments, the 7-day averaged crop coefficient (Kc) and the 4th order polynomial regression of the Kc.

Figure 6 shows the mean yearly cumulative applied irrigation water for the SDI and DI treatments in gallon/tree (left vertical axis) and in mm (right vertical axis). This figure is included for facilitating irrigation scheduling by grower's using drip irrigation on a 3-year old pomegranate orchard.

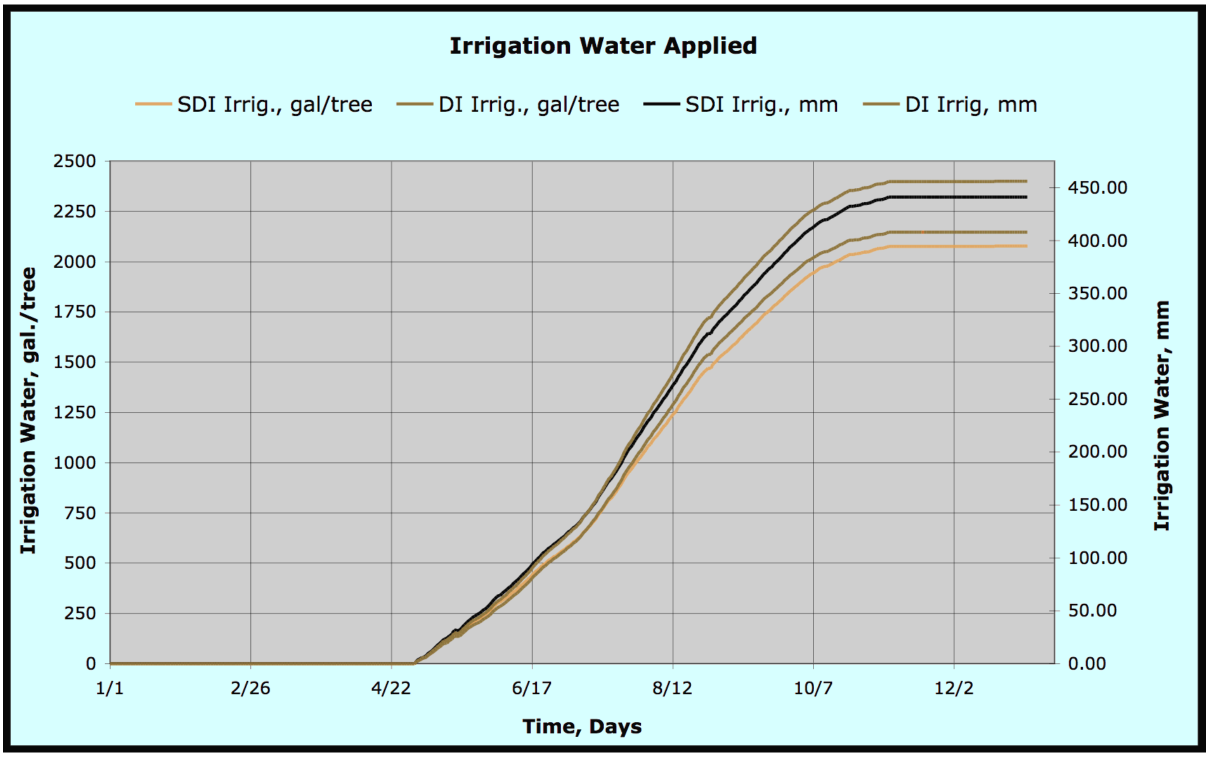


Figure 6. The mean yearly cumulative applied irrigation water for the SDI and DI treatments in gallon/tree (left vertical axis) and in mm (right vertical axis).

2. Automated fertigation management

a.Nitrogen--The three nitrogen fertility sub-treatments are 50, 100 and 150% of adequate N. They were determined from biweekly tissue analyses. All N was automatically applied by continuous injection of N-pHURIC (46 lb N/ac) for all treatments and additionally as AN-20 for N-2 (and N-3 treatments, starting on 5/12/2012 and ending on 8/18/2012. Figure 7 shows the cumulative injected nitrogen (lb N/ac), as N-pHURIC for all treatments and additionally as AN-20, respectively: (102 lb N/ac) for N-2 and N-3 (203 lb N/ac) treatments. Figure 8 shows the injected nitrogen concentration (ppm N), as N-pHURIC for all treatments and additionally as AN-20 for N-2 and N-3 treatments. The various growth stages of the pomegranate are shown at the top of each injection graph.

b.Phosphorus—Phosphoric acid (H3PO4) was continuously injected at a rate of P=15 ppm to maintain adequate P level in the SDI treatment. Previous research has shown that phosphorus becomes deficient as soil depths are greater than 0.2 m. The pH of the irrigation water was automatically maintained at 6.5+/-0.5 with the N-pHURIC to avoid precipitation of phosphates that typically start occurring at pH in excess of 7.2. Figure 9 shows the cumulative injected phosphorus (left axis, lb P/ac) and as phosphoric acid (right axis, gal. H3PO4/ac) for all treatments. Total of applied P was 47 lb P/ac for all treatments from 5/31/2012 to 9/6/2012.

c.Potassium—Potassium (K2T) was continuously injected at a rate of K=23-35 ppm to maintain adequate K level in both SDI and DI treatments. Previous research has shown that potassium may become deficient in sandy loam soil, especially as soil depths increase.

Figure 10 shows the cumulative injected potassium (left axis, lb. K/ac) and as potassium thiosulfate (right axis, gal K2T/ac) for all treatments Total of applied K was 67 lb K/ac for all treatments from 6/14/2012 to 9/6/2012.

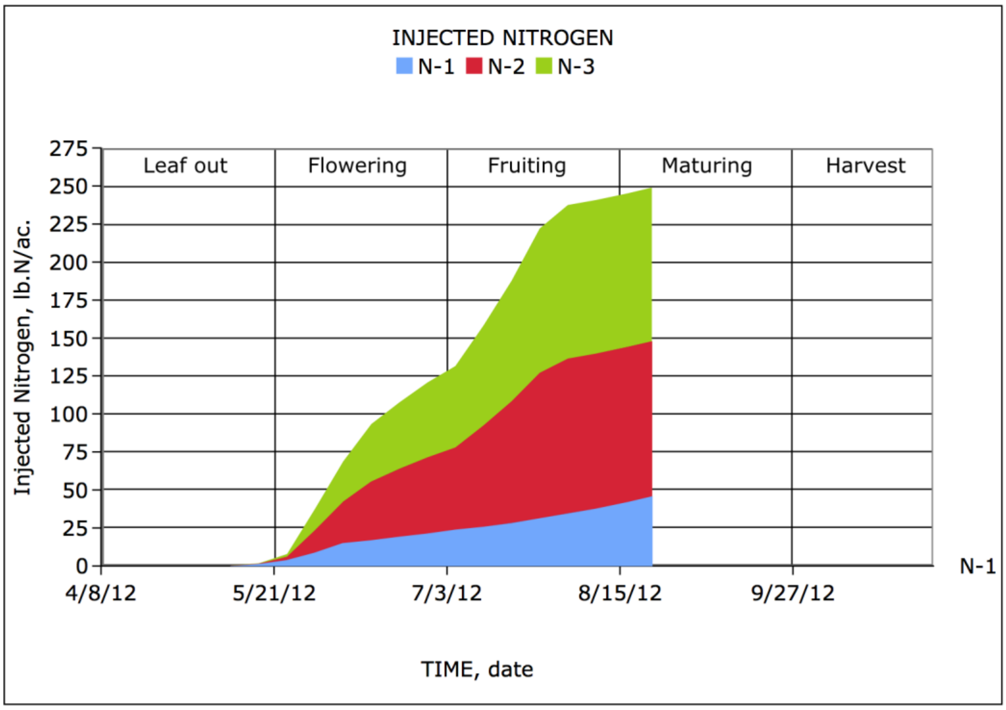


Figure 7. Cumulative injected nitrogen (lb. N/ac), as N-pHURIC for all treatments and additionally as AN-20 for N-2 and N-3 treatments.

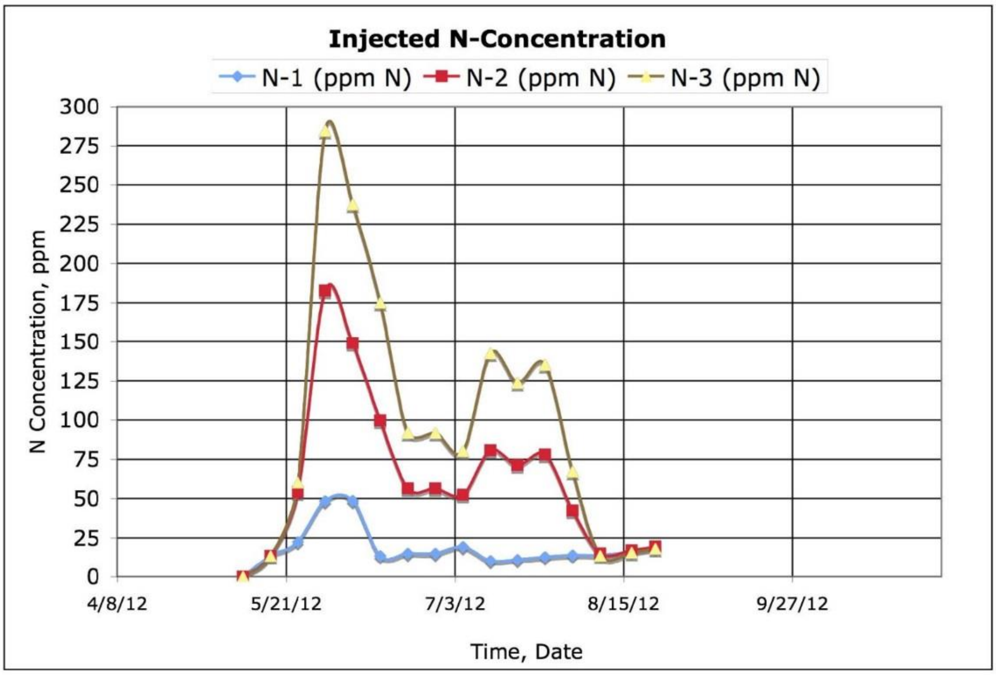


Figure 8. Injected nitrogen concentration (ppm N), as N-pHURIC for all treatments and additionally as AN-20 for N-2 and N-3 treatments.

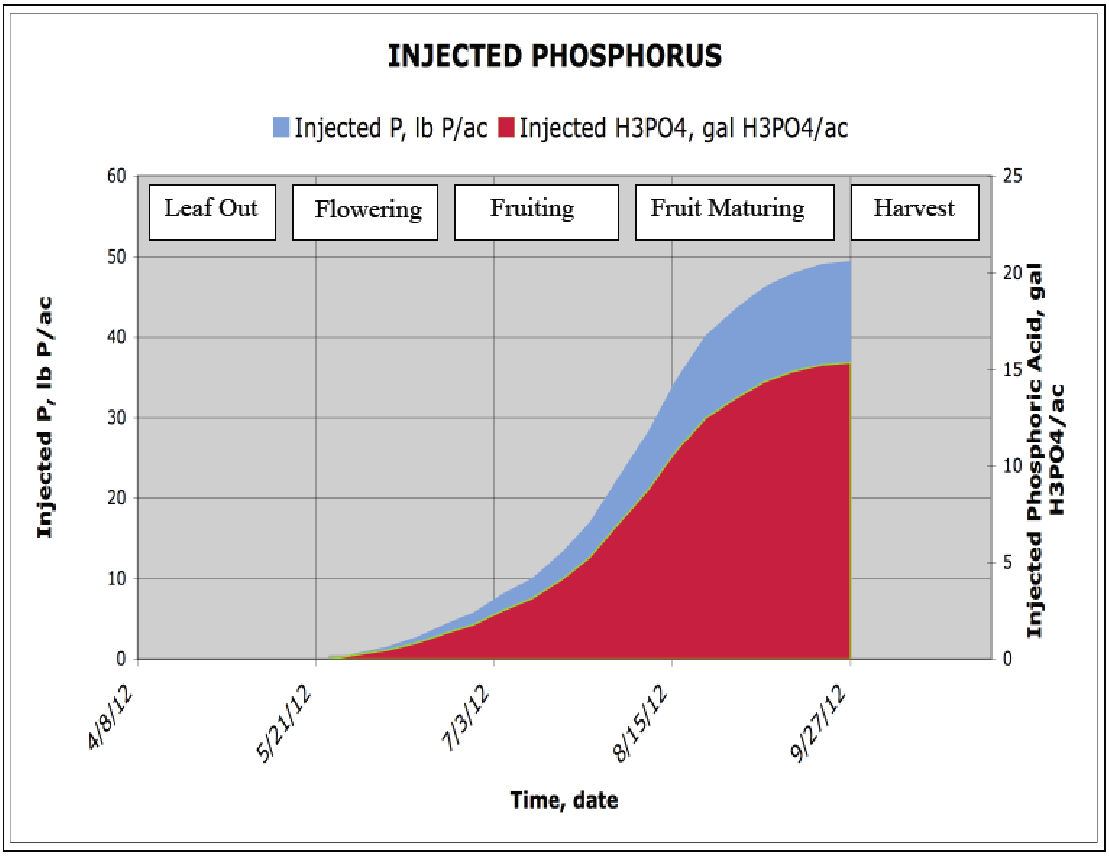


Figure 9. Cumulative injected phosphorus (lb. P/ac) and as phosphoric acid (gal. H_3PO_4/ac) for all treatments.

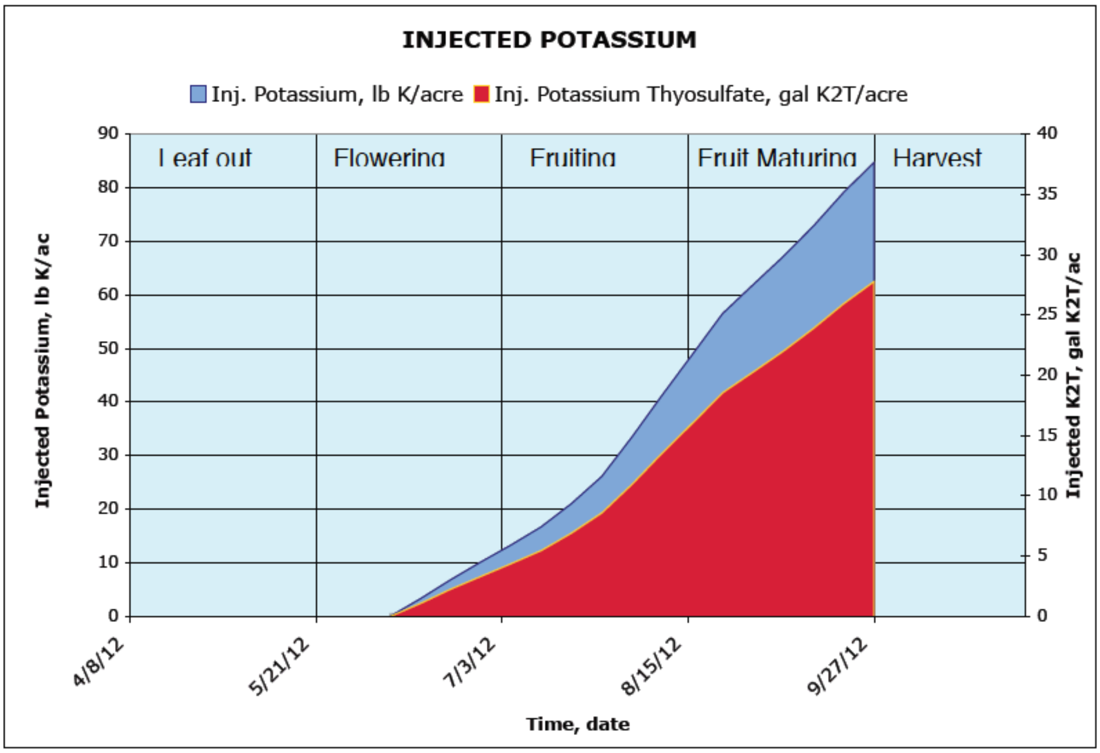


Figure 10. Cumulative injected potassium (lb. K/ac) as potassium thyosulfate (gal. K_2T/ac) for all treatments.

3. Leaf Tissue Nitrogen and Carbon

Most of the N-uptake by plants is in the NO3-N form because of its solubility and mobility with water from the soil to the plant. Total N analysis was used to characterize the long term

N response to the N treatments. Plant samples were collected every two weeks from 5/1 to 10/1/2012 . Plant samples were washed, oven dried at 65°C and ground. Triplicate samples were used to measure major, minor and trace elements by ashing 1gram of plant sample at 500

°C in a muffle furnace and acidifying the sample with 5 ml, 6 M hydrochloric acid and dilute it up to 50 ml and were determined by using ICP-OES (Varian, Palo Alto, CA). Plant Total N and C contents were determined by dry combustion with a Flash 2000 N & C Soil Analyzer (Thermo Scientific®, Pittsburgh, PA).

Results in Figure 11 show the total nitrogen in leaf tissue (%), in the DI and SDI irrigation treatments, averaged for the three N treatments from May 1 until October 1, 2012 (nn May 1 and May 15 prior to any significant fertigation and thereafter until August 18 when the N injection stopped). The large drop in tissue total N levels from 5/1 to 5/15 happened as plants were leafing out and started to flower rapidly even though a large amount of N was being injected (Figs. 7 and 8). Thereafter the tissue N started to recover slowly and slightly faster for the DI than for the SDI treatment.

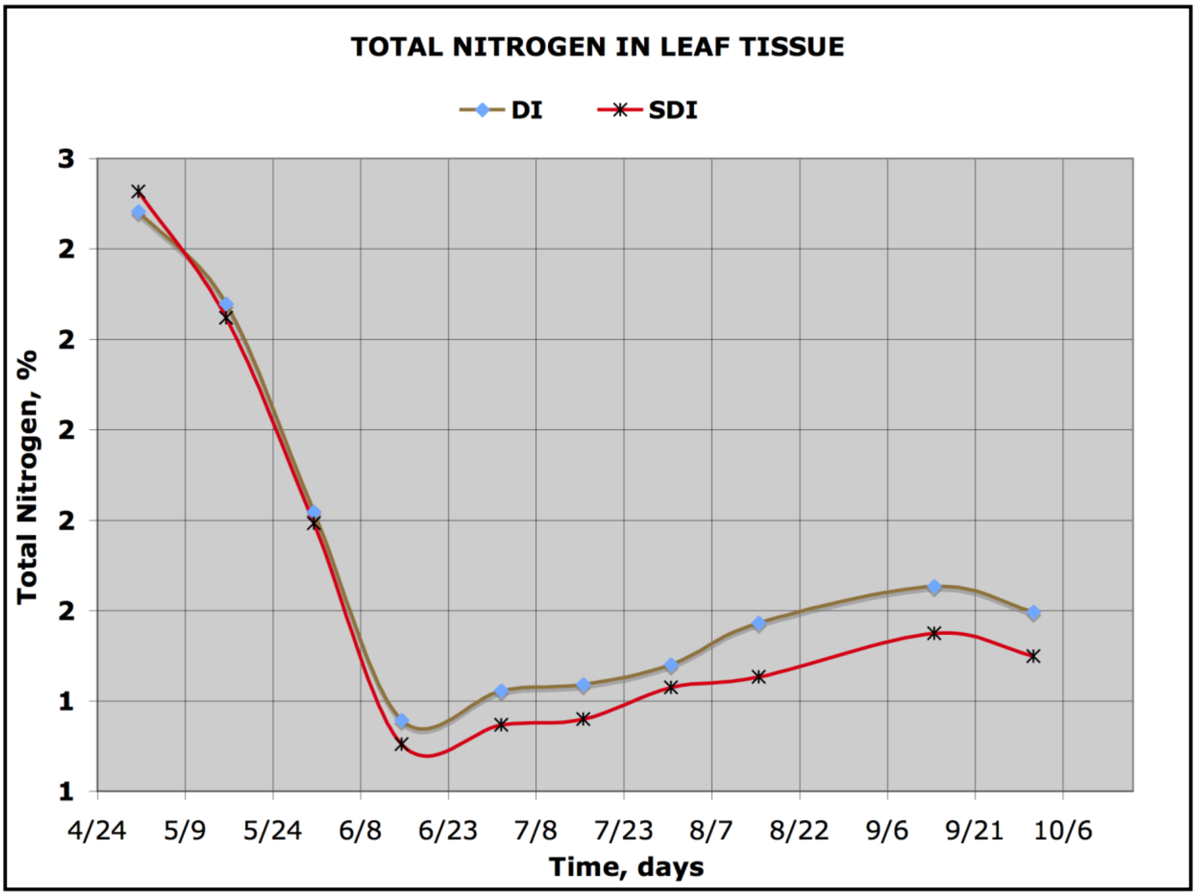


Figure 11. Total nitrogen in leaf tissue (%), in the DI and SDI irrigation treatments, averaged for the three N treatments from 5/1/2012 to 10/1/2012.

Data in Figure 12 show the total nitrogen in leaf tissue (%), for the three nitrogen treatments averaged for the DI and SDI irrigation treatments. On June 30th, the tissue in the N-1 treatment was 0.2% below that of the N-2 and N-3 treatment but seemed to have partially recovered by Aug. 30th although still lower than that of the N-2 and N-3. The carbon response is shown in figures 13 and 14. There is no difference in total levels between the irrigation system types and very little difference between the N levels. Apparently the fertilizer treatments have not impacted the C/N significantly.

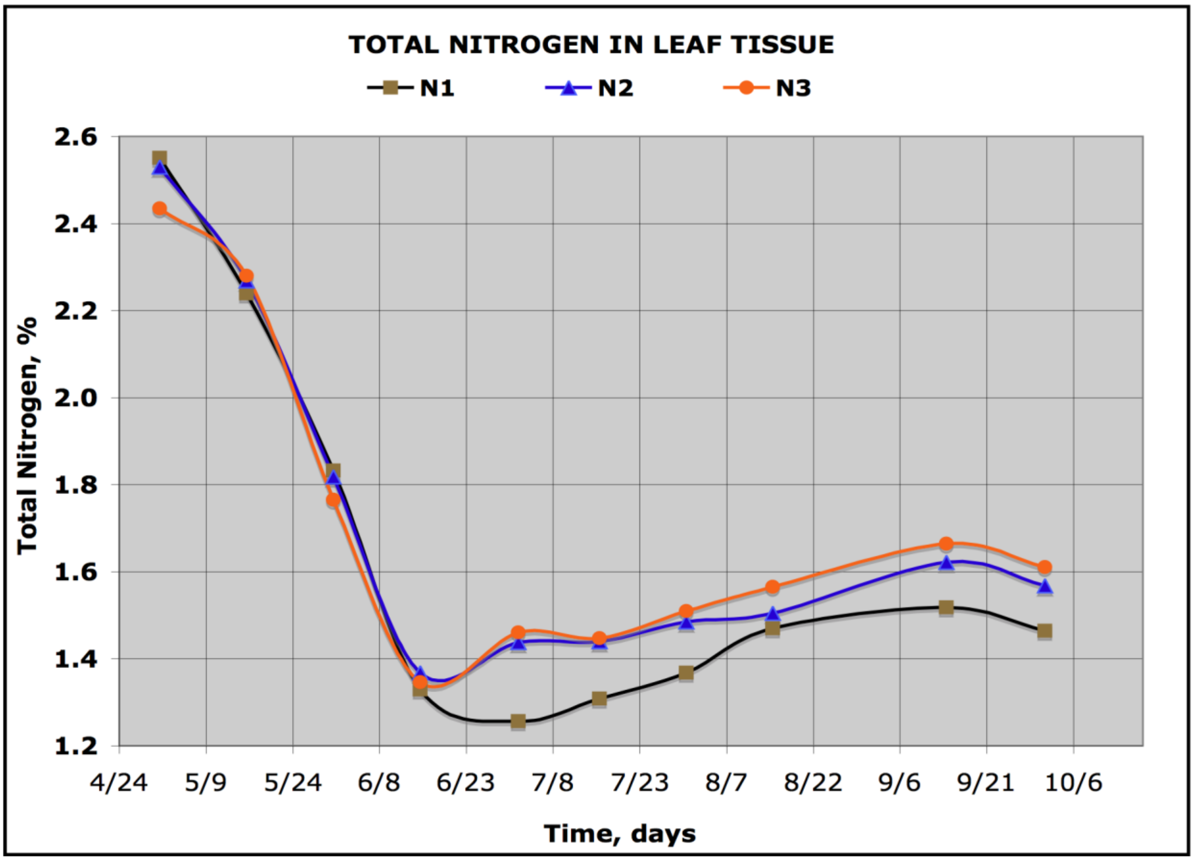


Figure 12. Total nitrogen in leaf tissue (%), in the three nitrogen treatments averaged for the DI and SDI irrigation treatments from 5/1/2012 to 10/1/2012.

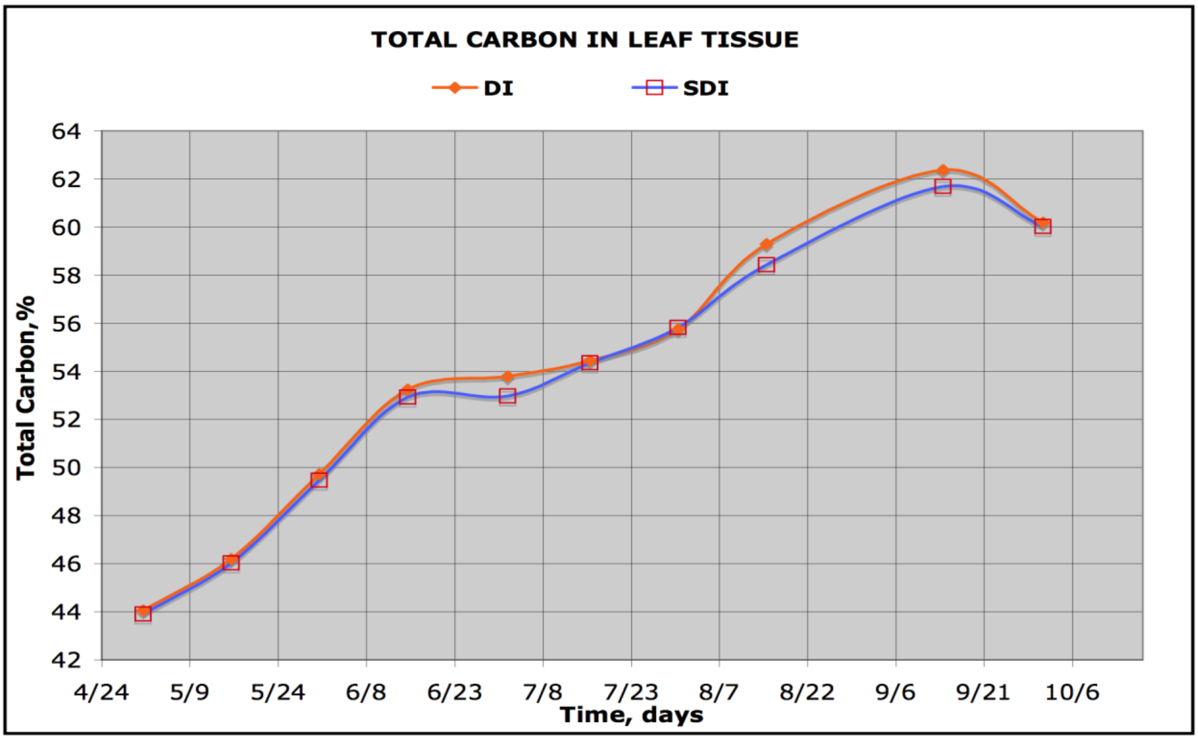


Figure 13. Total carbon in leaf tissue (%), in the DI and SDI irrigation treatments, averaged for the three N treatments from 5/1/2012 to 10/1/2012.

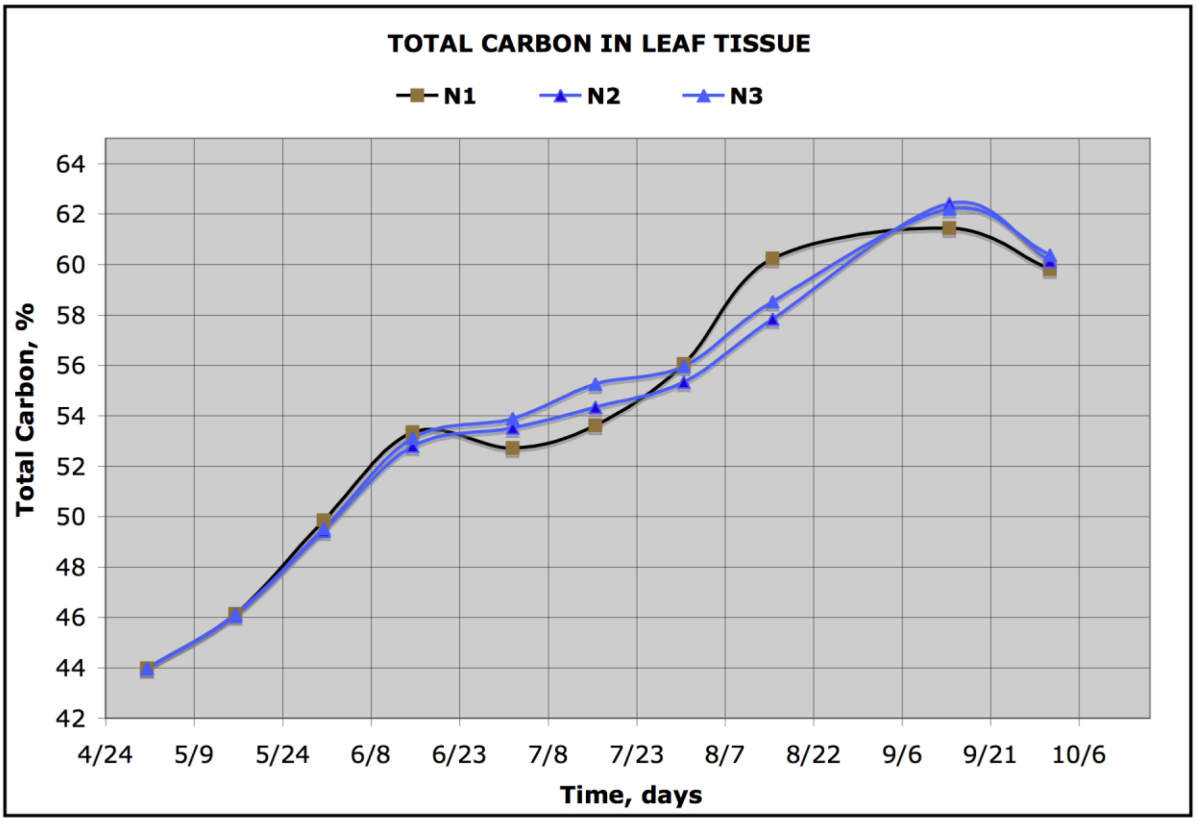


Figure 14. Total carbon in leaf tissue (%), in the three nitrogen treatments averaged for the DI and SDI irrigation treatments from 5/1/2012 to 10/1/2012.

4. Soil Nutrients

In 2012, soil samples were collected in April, August and December 2012, from eight soil depths at 0-6, 6-12, 12-18, 18-24, 24-30, 30-36, 36-42, 42-48 in. from the soil surface (sampling at deeper depths was prevented by the presence of extremely compacted hardpan).

A three-inch diameter soil auger was used to collect a 6-in core at each depth. Soil samples from each of the eight depths were oven dried at 65°C, ground and sieved through 2-mm screen. Triplicate samples were used to measure dissolved organic carbon (DOC) after saturating the soil with DI water (1:1 soil water) for 24 hours, shaken for a one hour on a reciprocal shaker, and filtered through a Whatman, no. 42 filter. Carbon recovered in the water extract was determined using a Fusion Total Organic Carbon Analyzer (Teledyne Tekmar, Mason, OH). Total N and C contents were determined by dry combustion with a Flash 2000 N & C Soil Analyser (Thermo Scientific®, Pittsburgh, PA). Macronutrients (1:1 soil water) such as calcium (Ca), Magnesium (Mg), Sulphur (S), Potassium (K) and Sodium (Na) were determined using ICP-OES (Varian, Palo Alto, CA). Nitrates content (1:1 soil:water) were determined by using Nitrate-Nitrite Astoria Pacific 2.

a. Potassium

The potassium levels (Fig. 15) decreased with depth under both irrigation systems in August
and December but were randomly distributed for the April sample, before any potassium was injected. In general, the soil K levels are slightly higher at a depth of 0-6 inches under both irrigation systems except for the April samples. For the December 2012 samples, the soil K is very low throughout the whole soil profile except in the DI treatment where it is nearly twice that of the SDI treatment at the 0-6 in depth. The low residual soil K at the end of the season might br due to uptake by the pomegranate even though 64 lb K/ac was injected during the season (Fig. 10).

The K response to the three N treatments is given in Fig. 16. The potassium levels decreased uniformly with depth under the three N injection levels in August and December but were randomly distributed for the April sample, before any potassium was injected. In general, the soil K levels are slightly higher at a depth of 0-6 inches under the N-2 and N-3 treatments except for the April samples. For the December 2012 samples, the soil K is overall very low throughout the whole soil profile except for the N-2 and N-3 treatments where it is slightly twice that of the N-1 treatment at the 0-6 in depth. The low and uniform residual soil K at the end of the season might be due to uniform root uptake by the pomegranate even though 64 lb K/ac was injected during the season (Fig. 10).

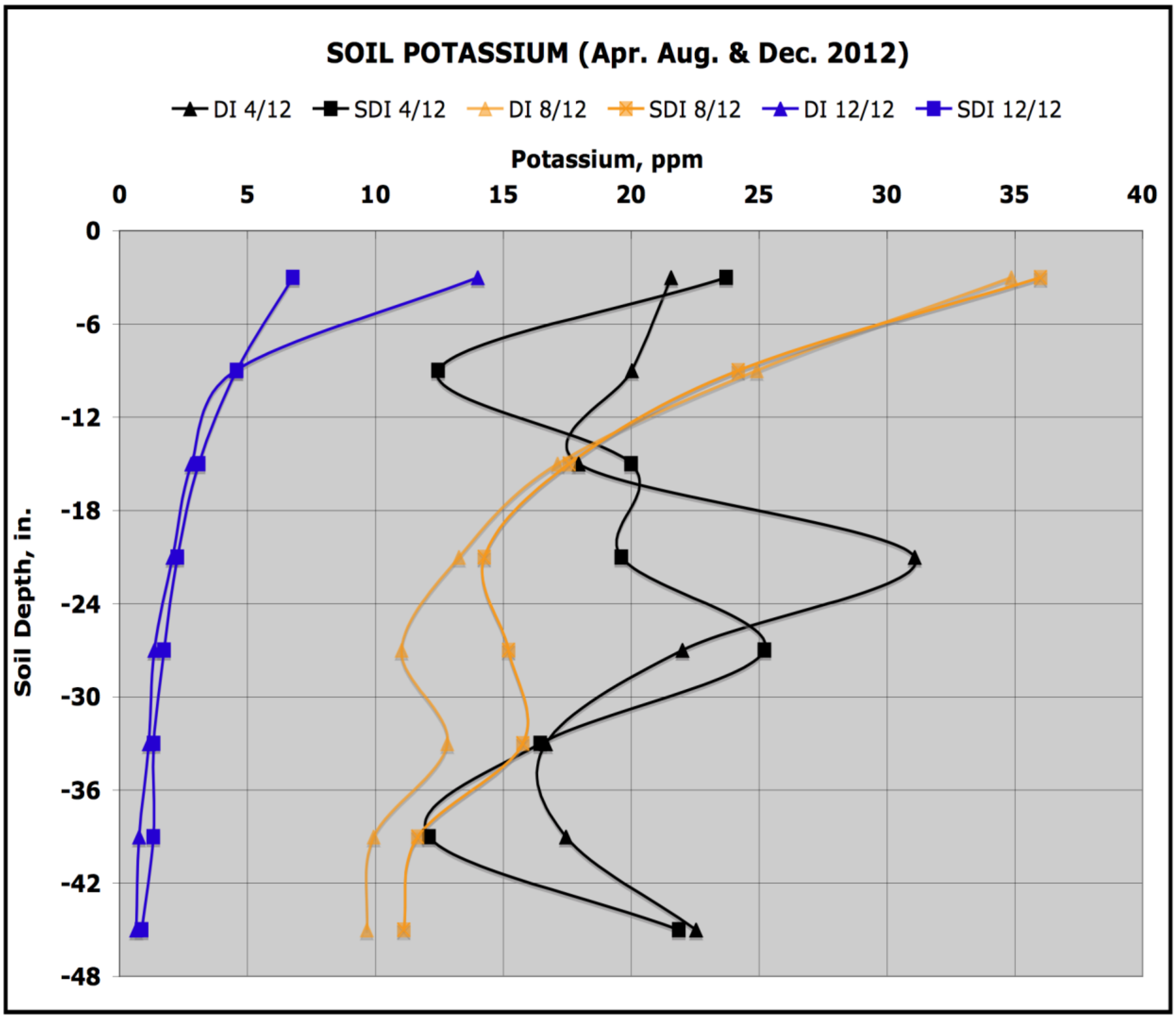


Figure 15. Soil potassium (ppm), in the DI and SDI irrigation treatments, averaged for the three N treatments for April 2012, August 2012 and December 2012.

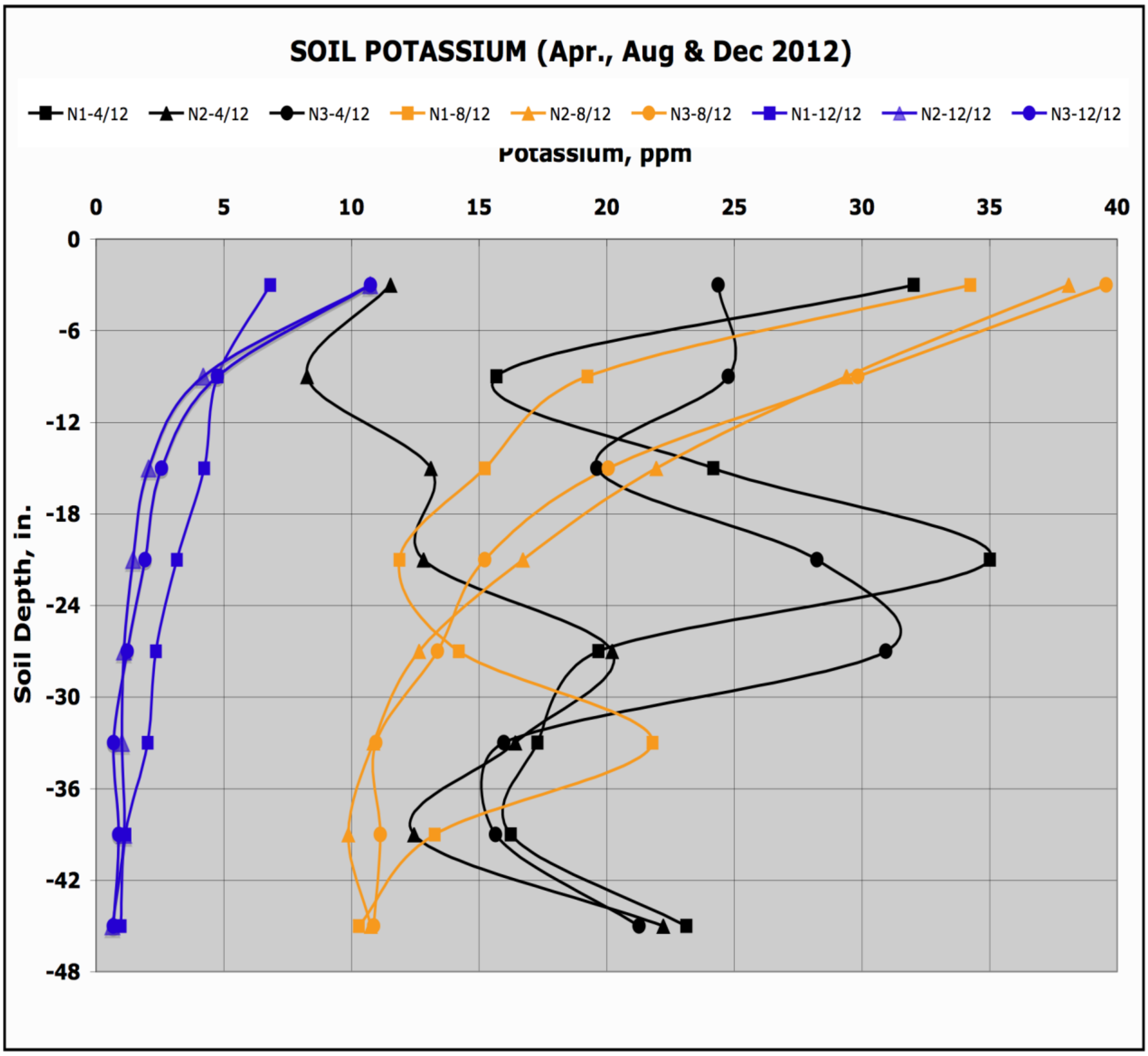


Figure 16. Soil potassium (ppm) in the three nitrogen treatments averaged for the DI and SDI irrigation treatments for April 2012, August 2012 and December 2012.

b. Soil Nitrates

The distributions of soil nitrate on April, August and December 2012 are given in figures 17, 18 and 19.

Figure 17 shows the soil nitrate (ppm) for the DI and SDI irrigation treatments, averaged for the three nitrogen treatments and for April, August and December samplings. The average increase in soil nitrate for DI over SDI ranges from 14% at 9-in depth to 80% at 33-in depth. These increases are the results obtained from 360 measurements for each treatment.

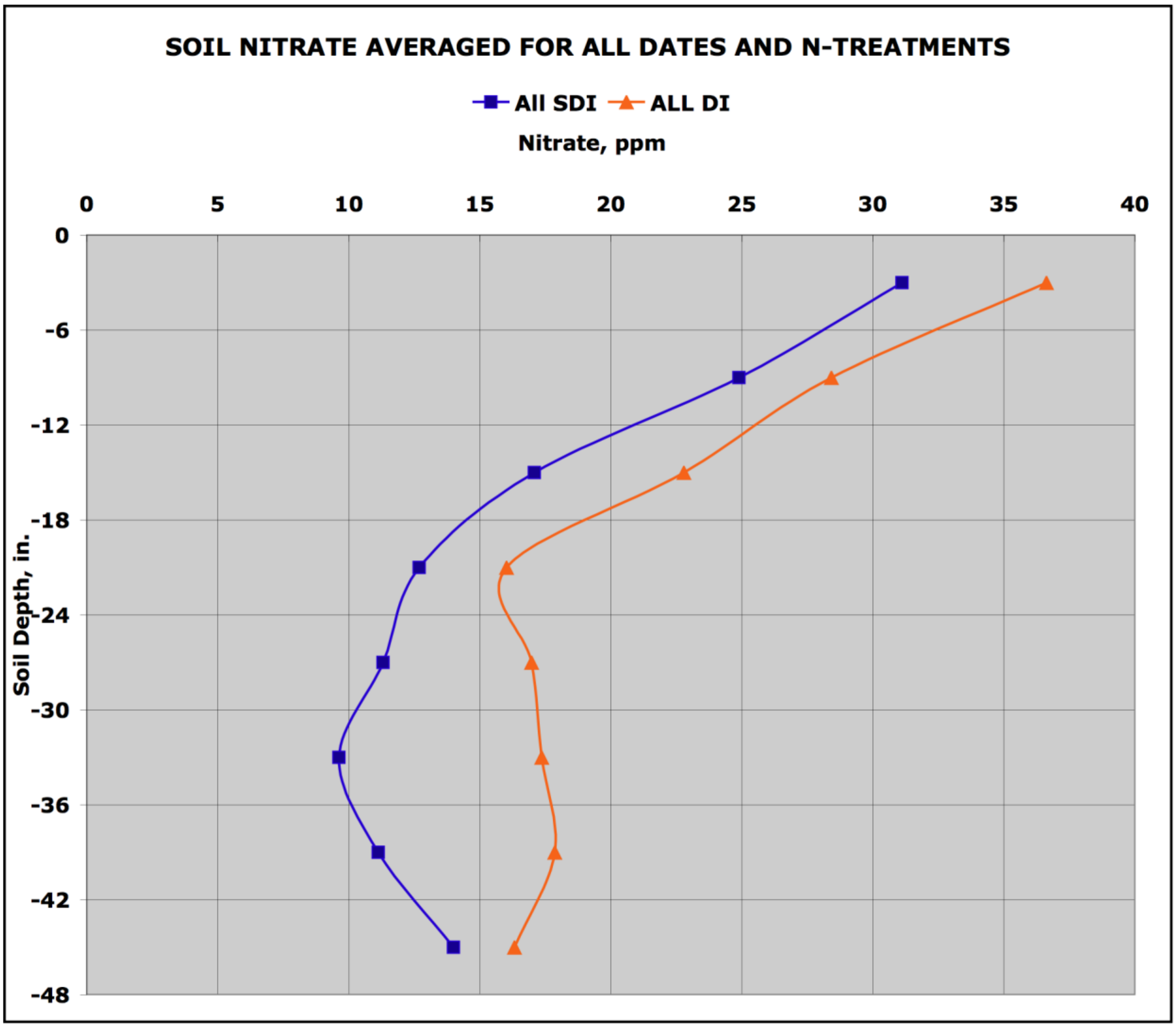


Figure 17. Soil nitrate (ppm) for the DI and SDI irrigation treatments, averaged for the three nitrogen treatments, for April, August and December samplings.

Figure 18 shows the soil nitrate (ppm) averaged for the three nitrogen treatments irrigated by the SDI and DI irrigation systems for April, August and December samplings. Here again, there are similar increases in the average soil nitrate for DI over SDI, although not as well defined because these increases were obtained from 120 measurements for each treatment.

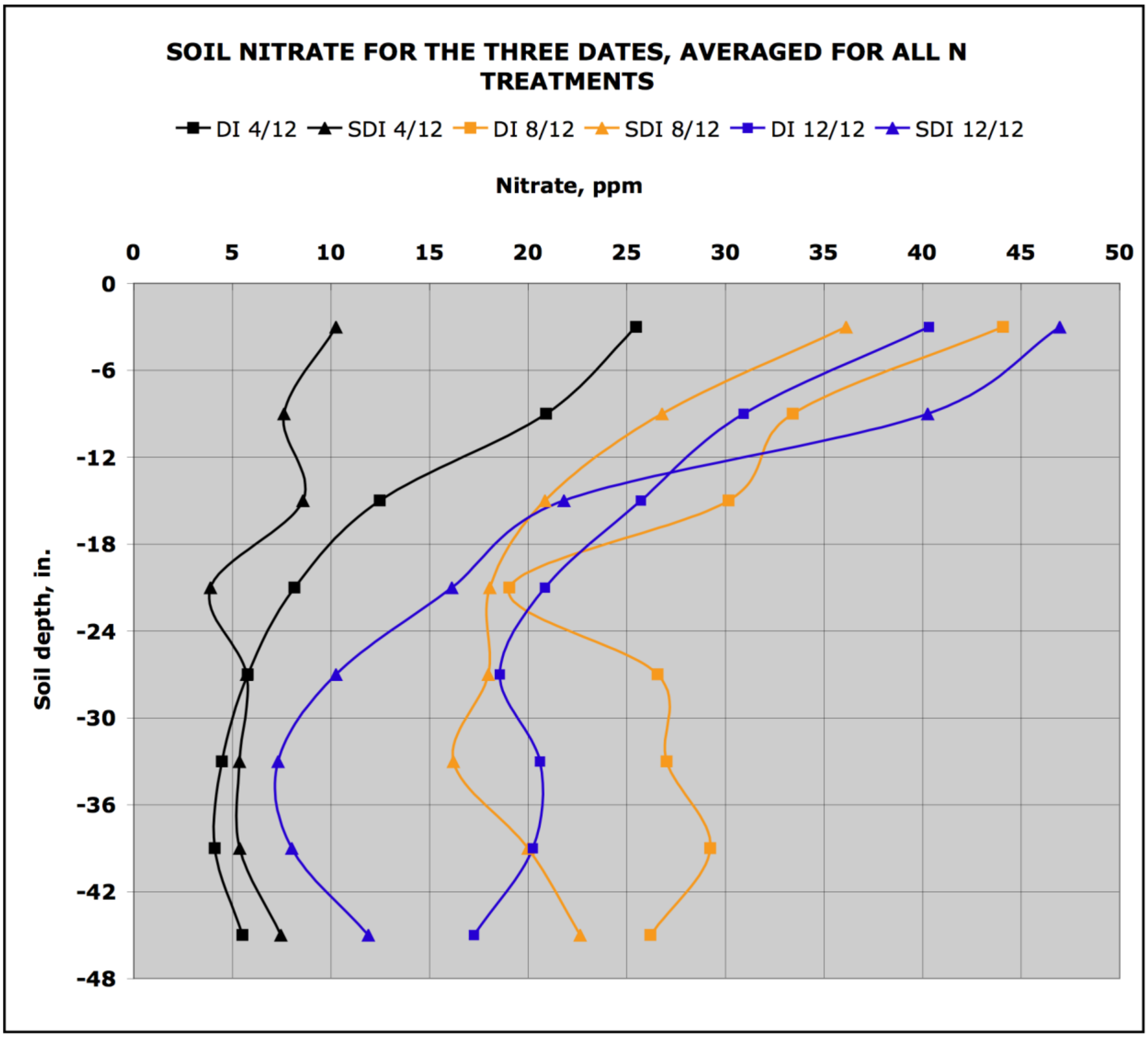


Figure 18. Soil nitrate (ppm) averaged for the three nitrogen treatments irrigated by the SDI and DI irrigation systems for April, August and December samplings.

Figure 19 shows the soil nitrate (ppm) for the three nitrogen treatments, averaged for the DI and SDI irrigation systems for April, August and December 2012. The April measurements are quite low and relatively free of NO_3 differences because the N treatments had not yet been applied. In 2011 all the nitrogen was applied at a low level and uniformly across all plots.

The August measurements were taken at the peak of the N injection and show that the N-1 treatment had the lowest nitrate level from the soil surface down to 33-in depth but was not different from the N-2 and N-3 treatments at deeper deaths. This would seem to indicate that the higher levels of applied N (N-2 and N-3) had not caused some significant increases in NO_3 leaching.

The December measurements were taken at the end of the season, two months after the N injection had stoped, and after the fruit harvest. There is no significant difference between the N-1 and N-2 treatments from the soil surface down to 18-in. depth. The N-3 treatment has significant higher NO_3 levels than the N-1 and N-2 and

N-3 treatments until 21-in depth. Thereafter, the N-2 treatment has the highest levels down to the 45-in depth.

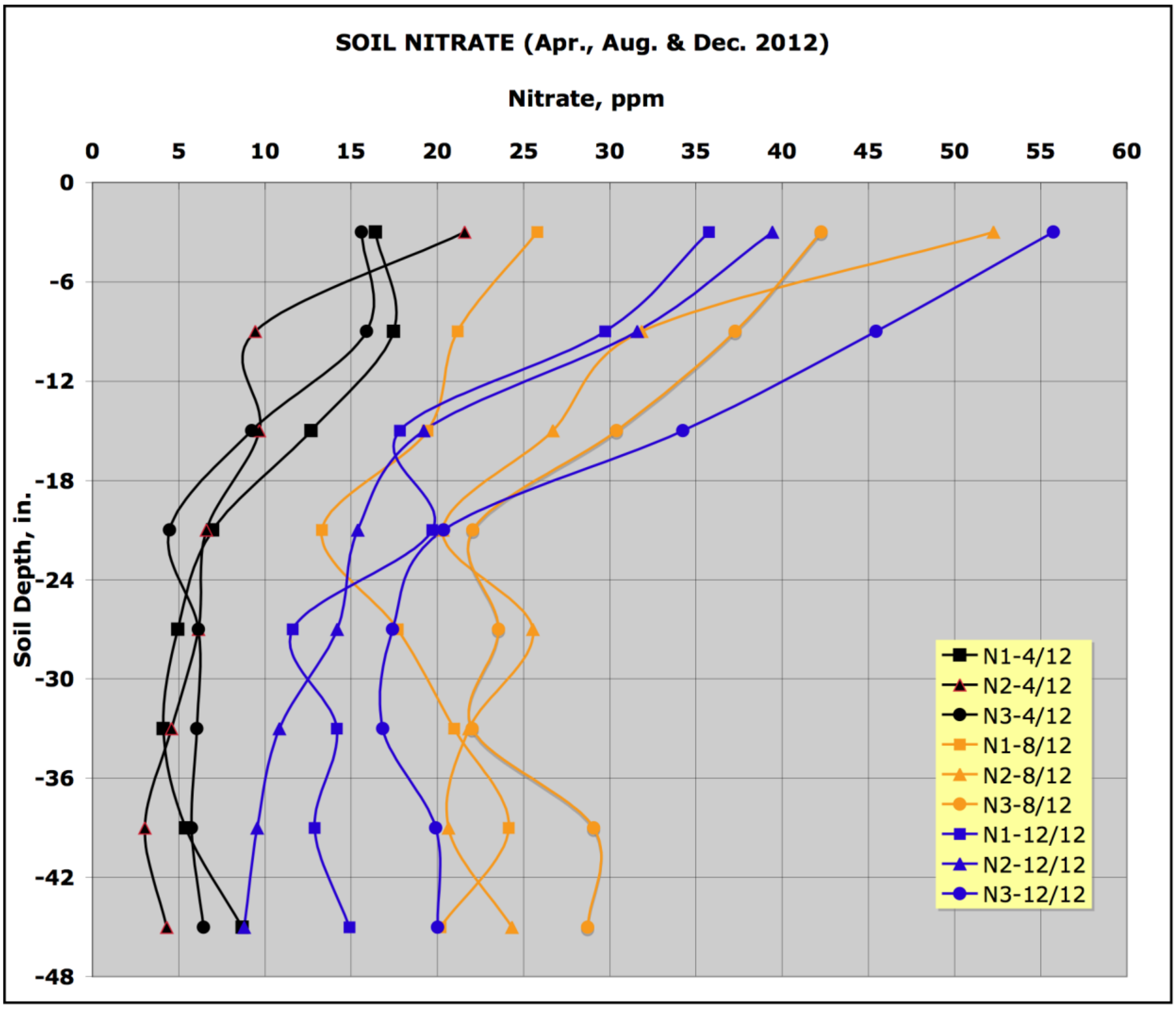


Figure 19. Soil nitrate (ppm) for the three nitrogen treatments, averaged for the DI and SDI irrigation systems, for April, August and December 2012.

5. Pomegranate Yields and Quality

Pomegranates were commercially harvested by a local packer on Oct. 30, 2012 for prime fruit and Nov. 8, 2012 for 'Juice' fruit. Fruit used for research were harvested from five trees in the center-row within each plot and placed in trays; figure 20 shows a sample of prime fruit harvested from one tree on Oct. 30, 2012 (these fruits typically sell in the market for $2.00 to $3.00 each). Data in Table 2 show means of the fruit harvested from five trees in the center- row within each plot converted to lb fruit/ac. Season yield (marketable yield) is only the sum of prime and juice fruit. The SDI prime fruit yield is 16% greater than that of the DI fruit yield, mostly due to the 9.3 % significant increase in fruit weight. The season total marketable fruit yield increase of the SDI is 10.1% greater than that of the DI season marketable fruit yield. Data from the three N-fertigation levels does not show any significant difference although there is 6.9% increase for the season total marketable fruit yield of the N- 3 above that of the N-1 treatment.

Table 2. Means represent the fruit harvested from five trees in the center-row within each plot. Harvests 1 and 2 were completed on Oct. 30 and Nov. 8, 2012, respectively. Season yield is only the sum of fresh market and juice fruit.

	HARVEST #1 10/30/12 Prime Fruit		HARVEST #2 11/08/12 Juice Fruit		HARVEST #2 11/08/12 Non Marketable Yields		SEASON TOTAL 10/30 & 11/08/12 marketable yields
Main Effects **Irrigation Method:**	Yield lb/ac	Fruit wt. lb	Yield lb/ac	Fruit wt. lb	Cracked lb/ac	Undersized lb/ac	lb/ac
Surface Drip, DI	9967	1.18 b	8771	0.80 b	698	299	18,738 b
Subsurface Drip, SDI	11561	1.29 a	9070	0.86 a	598	399	20,631 a
Prob.>'F' value	0.067[y]	0.0002	NS	0.032	NS	NS	0.0548
Nitrogen Level:							
46 lb/ac	10365	1.19	8671	0.79	897	199	19.136
148 lb/ac	10963	1.27	8372	0.82	698	299	19,435
249 lb/ac	10864	1.25	9568	0.83	399	399	20,432
Prob.>'F' value	NS[Z]	NS	NS	NS	NS	NS	NS
Contrast:							
1 vs. 2 and 3	NS	0.006	NS	0.045	NS	0,025	NS
Polynomial fit:	---	**L^{*SD}**	---	**L$^{.09\ SD}$**	---	**L^{*D}**	---

ZNS,*,** = not significant, significant at P=0.01, respectively. L = linear, Q = quadratic.
Y Probability of a greater 'F' value. Mean separation at P < 0.05.
D = Surface Drip only; SD = Subsurface drip only.

Figure 20. Sample of prime fruit harvested from one tree on Oct. 30th 2012.

Results in Table 3 show the Weight and internal attributes of fruits harvested Nov. 8, 2012 for juice. There are no irrigation methods x nitrogen level interactions. In this study, the lower ‘L’, ‘a’, ‘b’, and chroma values are indications of more intense red-colored fruit. Hue angle values were similar to Hue (‘a’/’b’) and were not presented.

Table 3. Weight and internal attributes of fruits harvested Nov. 8, 2012 for juice.

	HARVEST #2 11/08/12 Juice Fruit									
SOURCE Irrigation Method:	Fruit wt. lb	Aril Wt. lb	Soluble Solids, %	Juice pH	Color Abs. 516 nm	Objective Juice Color L	'a'	'b'	Hue	Chroma
Surface Drip, DI	0.606	0.0008 b	16.6 a	3.09	2.328	24.03	34.02	12.04	2.89	36.11
Subsurface Drip, SDI	0.626	0.0009 a	16.2 b	3.10	2.208	24.50	34.96	12.90	2.74	37.28
Prob.>'F' value	0.12[y]	0.04	0.04	NS	NS	0.19	0.13	0.15	0.08	0.16
Nitrogen Level:										
46 lb/ac	0.622	0.0009	16.6	3.15 a	2.113	24.53	34.97	12.87	2.75	37.28
148 lb/ac	0.615	0.0008	16.1	3.07 b	2.196	24.68	34.40	13.23	2.70	37.81
249 lb/ac	0.611	0.0008	16.3	3.06 b	2.495	23.58	33.09	11.30	3.01	34.99
Prob.>'F' value	NS	0.08	NS	0.02	0.18	0.16	0.17	0.14	0.11	0.13
Contrast:										
1 vs. 2 and 3	NS	0.02	0.06	0/001	0.04	NS	NS	NS	NS	NS
Polynomial fit:	---	**L*,Q*[w]**	--	**L****	**L***	**Q[.08X]**	**Q[.09X]**	**Q[.07X]**	**Q[.09X]**	**Q[.09X]**

[Z]NS,*,** = not significant, significant at P=0.05 and P = 0.1 respectively.

[Y] Probability of a greater 'F' value. Mean separation at P $\leq$ 0.05.

[X]Surface drip only.

[W]Subsurface drip Linear and surface drip Quadratic

6. Nitrous Oxide Emission Measurements in Pomegranate Orchard (Gao's Lab)

Greenhouse gas nitrous oxide N_2O emissions from the pomegranate orchard at the UC KARE Center were measured using the static chamber method (Figure. 21).

Upon the chamber placement, N_2O concentration (ppm, µg/m^3) increased inside the chamber. Air samples were collected at time intervals of 0.5 or 1.0 h depending on the linearity in concentration increase. Emission flux (f, µg m^{-3} h^{-1}) was calculated from the linear model:

$$f = \left(\frac{V}{A}\right)\frac{dC}{dt}$$

Where *dC/dt* is the slope of the linear fitting by plotting N_2O concentration (ppm) vs. time (h), *V* is the chamber volume (m^3), and A is the surface area (m^2).

Emission flux measurements in the field began in early May before irrigation (May 2), after irrigation or before N application, and after fertilizer application (May 24). Figure 22 shows N_2O concentration changes inside chamber before fertilizer application. There were no differences in N_2O concentration between the two irrigation treatment plots prior to irrigation. Due to a short time of N fertilizer pumping, surface drip irrigation (DI) plot showed N_2O concentration increase while that from the subsurface drip irrigation (SDI) remained flat. After fertilizer application began (12 min application on May 18 and continuous application since May 24), significant differences in N_2O emissions were observed from the two irrigation systems and N application rates. Figure 23 shows N_2O concentration changes inside flux chamber during measurement on May 31 and Figure 24 shows N_2O emission rates from May 1 through June 12. These data show that N_2O emission significantly increases with the increase of N application rate in the surface drip irrigation.

However, N_2O emissions from the subsurface drip application were considerably lower regardless of N application rate.

Figure 21. Static chambers used for N_2O emission measurement and placed above drip tape in surface drip irrigation (top) and subsurface drip irrigation (bottom) systems.

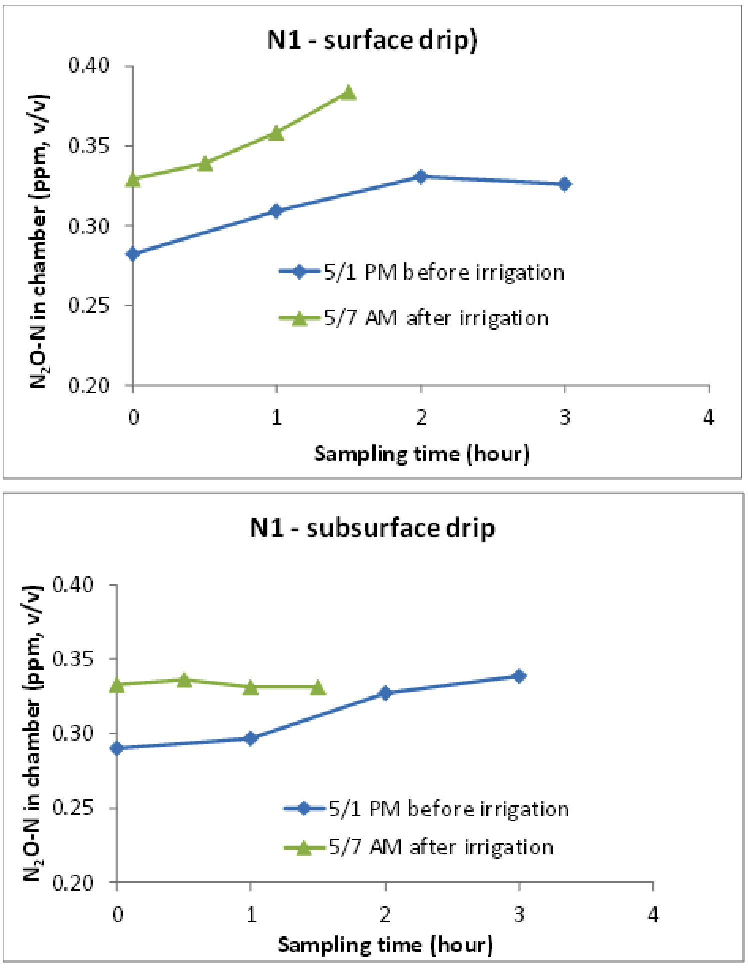


Figure 22. Nitrous oxide (N2O) concentration changes inside flux chamber for emission measurement before fertilizer application. May 1: before irrigation, N2O flux 2.11-2.74 µg N m^{-2} h^{-1}. May 2: irrigation began with 2-3 min N application pumping for testing system. May 7: after irrigation began and no N application yet: N2O flux 4.61 for surface drip irrigation (DI) and 0.04 from subsurface drip irrigation (SDI).

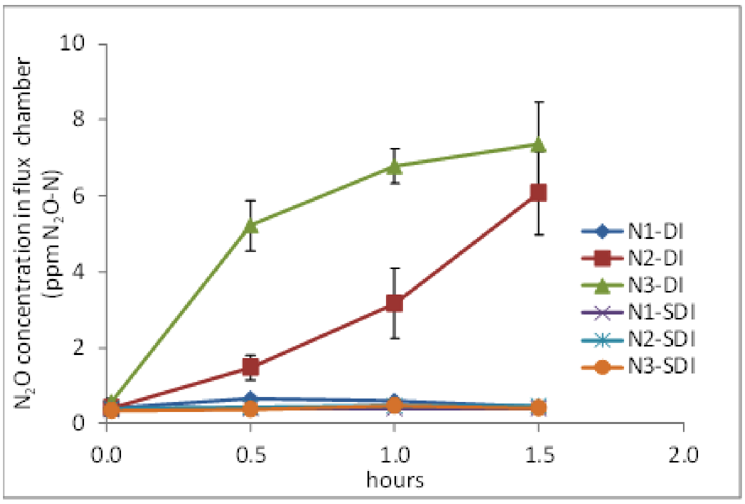


Figure 23. Nitrous oxide (N2O) concentration increase inside flux chamber upon placing on soil from measurement on May 31, 2012 after fertilizer application began. DI, surface drip irrigation; SDI, subsurface drip irrigation; N1, N2, and N3, application rates at 50%, 100%, and 150% of plant N requirement, respectively.

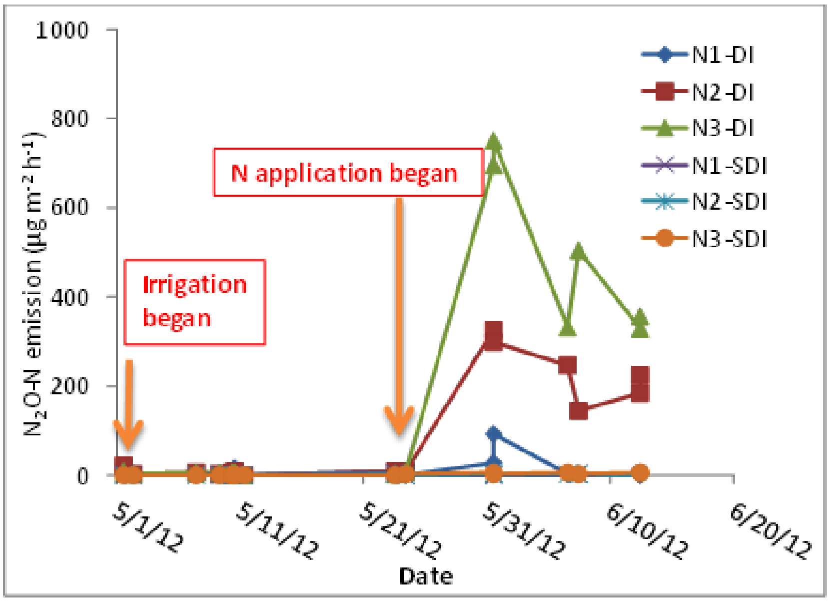


Figure 24. Nitrous oxide (N2O) emission rates affected by N application rate and irrigation system. DI, surface drip irrigation; SDI, subsurface drip irrigation; N1, N2, and N3, application rates at 50%, 100%, and 150% of plant N requirement, respectively.

7a. Pomegranate Canopy Cover with Multispectral Camera Measurement

Tree canopy cover in each treatment plot was measured with a TetraCam ADC multispectral camera (TetraCam Inc., Chatsworth, CA). The camera contains a single precision 3.2 megapixel image sensor optimized for capturing green, red, and near-infrared wavebands of reflected light. A TeleScoping Pole Tripod system (GeoData Systems Management Inc., Berea, OH) was used to suspend the camera directly above the trees and aim vertically downward at nadir view.

The tripod system was attached to a Gator (Figure 25). A cross bar mounted with the camera was attached and locked to the tip of the pole. The pole was extended and raised to a vertical position. Sufficient counterweight was applied on the bottom of the pole to keep it stay vertically. The camera was suspended 5.6 m above the ground surface. An image was taken above the middle pomegranate tree of the center row in each treatment plot.

A digital image of the canopy of pomegranate tree is shown in Figure 26. The green vegetation was indicated in red color. Beside tree, soil, grass, and other background (drip tubing etc.) can be seen in the image. The image was pre-processed in LView Pro Image Processor software (Cool Moon Corp., FL) to paint out the pixels of soil, grass, shadow and other background. The pre-processed image was then analyzed using PixelWrench software which is provided by Tetracam Inc. Tree canopy was separated from background and the percentage of the pixels that represent tree canopy area was calculated. The fraction of canopy cover occupied by the pomegranate tree over a representative area (i.e., row spacing x tree spacing) was calculated by multiplying the percentage of canopy cover from the image by the ratio of the camera Field of View (FOV) to the representative ground area per tree.

Figure 25. Measurement of canopy cover for pomegranate using TetraCam multispectral camera.

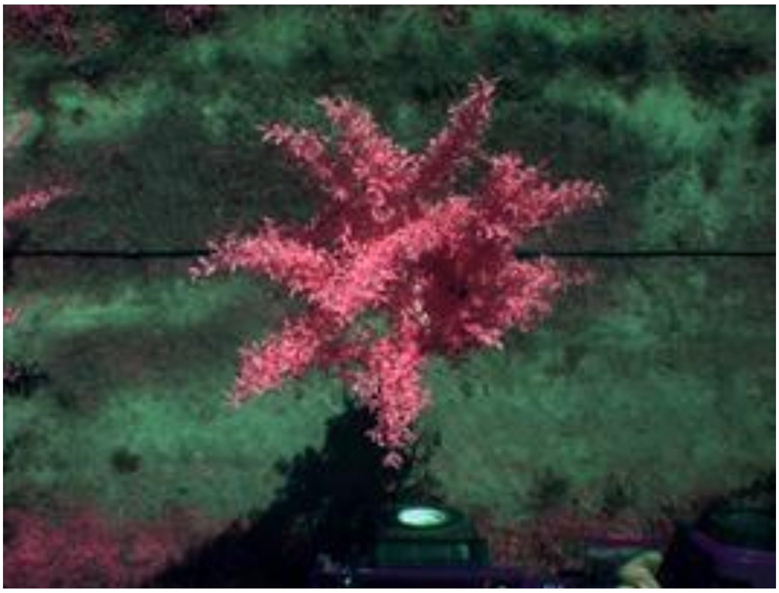


Figure 26. Pomegranate tree canopy taken with TetraCam camera.

Results presented in Table 4 indicate a 36% increase in the SDI treatment canopy cover over that of the DI treatment.

Table 4. Percent light interception calculated from TetraCam measurements.

	Light Interception											
	REP 1/DI	REP 1/SDI	REP 2/DI	REP 2/SDI	REP 3/DI	REP 3/SDI	REP 4/DI	REP 4/SDI	REP 5/DI	REP 5/SDI	MEAN DI	MEAN SDI
	16.0%	31.6%	19.0%	21.0%	25.2%		28.6%	29.6%	20.8%	15.5%	**0.22**	**0.24**
	31.5%	38.2%	27.1%	38.7%	26.3%	28.7%	31.9%	30.9%	13.5%	19.1%	**0.26**	**0.32**
	7.0%	30.5%	36.1%	45.0%	17.3%	23.3%	13.9%	20.3%	15.3%	40.0%	**0.18**	**0.34**
REP. Means	0.18	0.33	0.27	0.35	0.23	0.26	0.25	0.27	0.17	0.25	**0.22**	**0.30**

7b. Pomegranate Canopy Light interception with Light Bar

Figure 27 shows the plant canopy light interception (CLI) obtained in August 18, September 8. 2011 and in 2012, on June 15, July 3 and July 16. CLI was related to ETc from the lysimeter to help generate canopy-related crop coefficients (Kc).

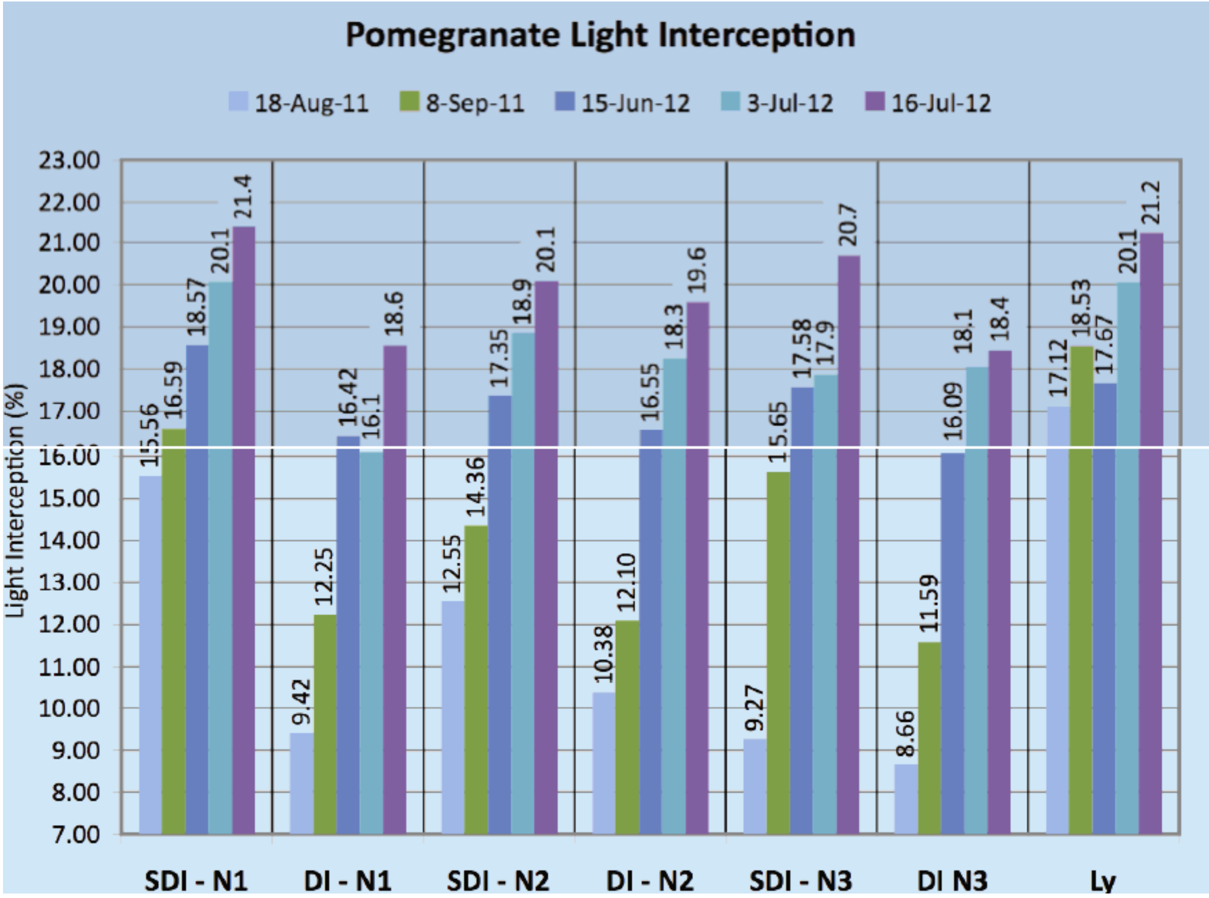


Figure 27. Plant canopy light interception (CLI) was measured obtained with the light bar in August 18, September 8. 2011 and June 15, 2012, July 3, 2012 and july16 2012.

7c. Leaf color measured with the SPAD meter and canopy correlation.

Leaf color measurements were measured on July 27, Aug 17, and Sept 20, 2012 using the SPAD 502 Chlorophyll Meter (Konica Minolta Inc., NJ). The meter was clamped over leafy tissue, and measured an indexed chlorophyll content reading (-9.9 to 199.9) in less than 2 seconds. Darker leaf has higher reading. Many researchers have shown a strong correlation between SPAD measurements and leaf N content. Ten SPAD readings were gathered from the middle tree within each treatment plot. Statistical analysis results are shown in Table 5.

Table 5. SPAD measurements corresponding to different nitrogen treatments †

Treatment	July 27, 2012	Aug 17, 2012	Sept 20, 2012
N1 (50%)	57.40^{b}	63.71^{b}	64.90^{a}
N2 (100%)	62.18^{a}	66.12^{b}	65.79^{a}
N3 (150%)	62.75^{a}	69.29^{a}	67.02^{a}

†Means followed by a different letter within column are significantly different at *p* = 0.05 according to the Tukey' studentized range (HSD) test.

Figure 28 shows the comparison of SPAD readings between treatment plots and lysimeter plot. Lysimeter tree has higher readings than others in each measurement day.

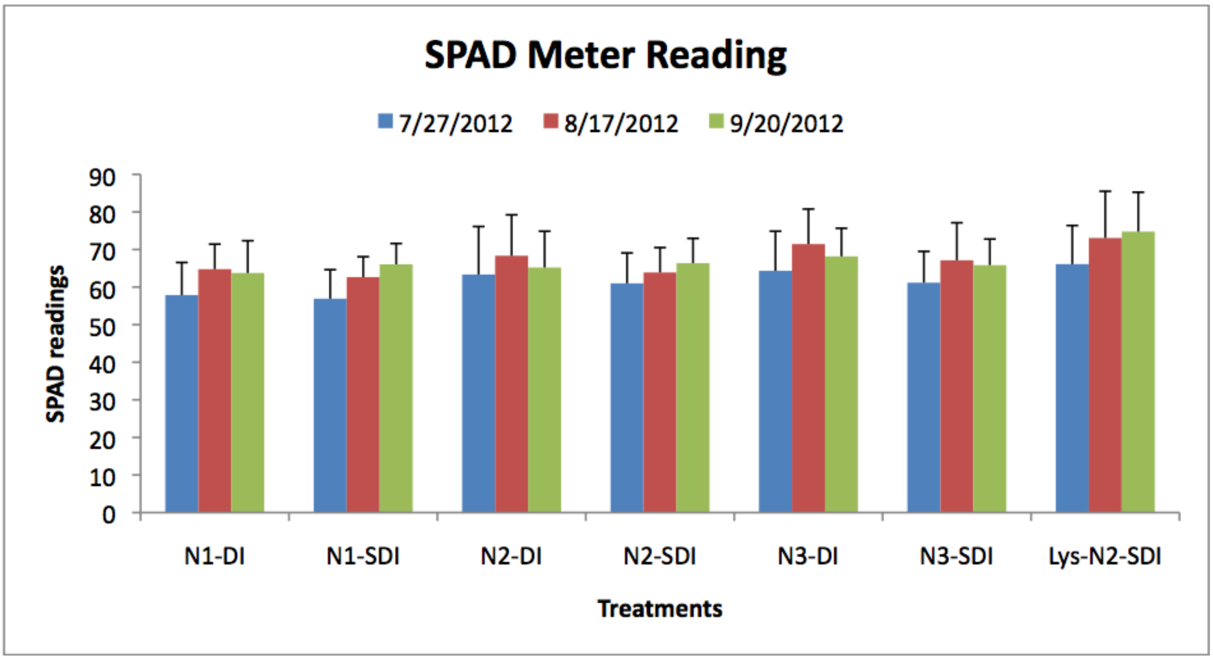


Figure 28. Means of SPAD meter readings in each block of each treatment on July 27, Aug 17, and Sept 20, 2012.

Crop canopy cover measurement

The canopy cover was also measured with a TetraCam multispectral camera on June 13, July 17, August 16, and September 27, 2012. Figure 29 shows the comparison of canopy cover among treatments.

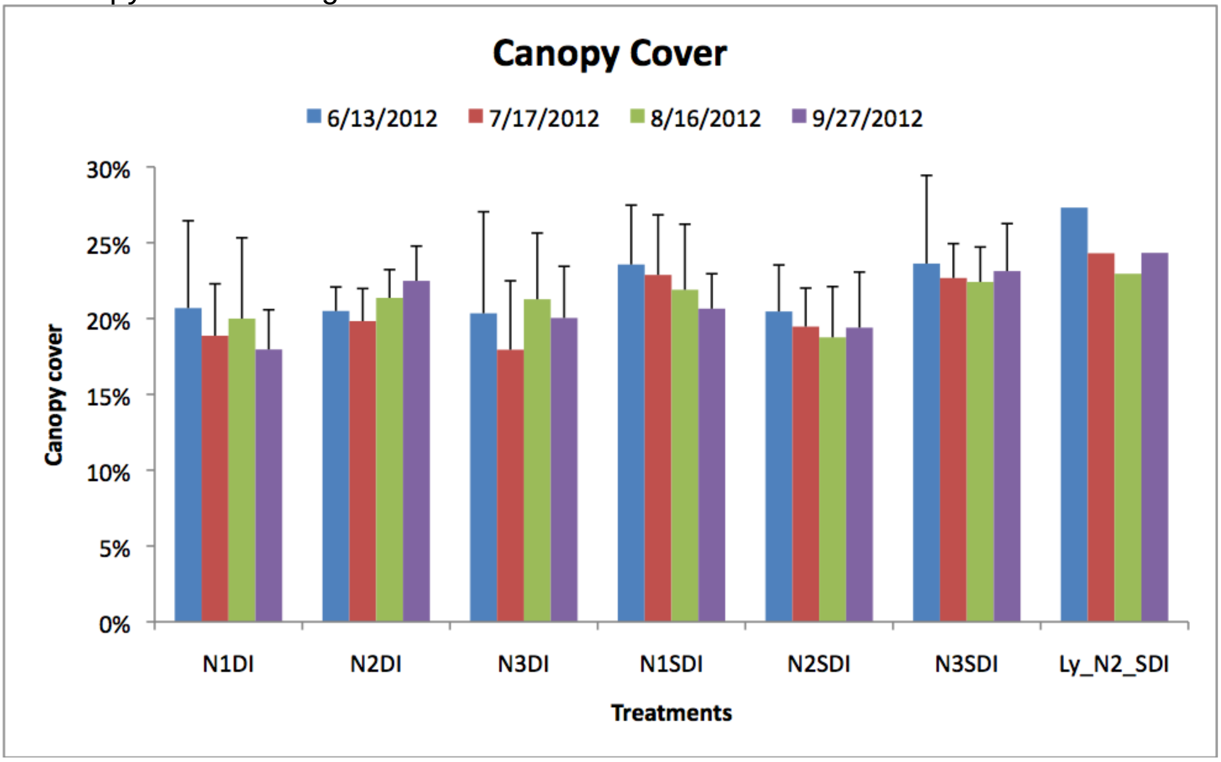


Figure 29. Comparison of canopy cover among treatment plots obtained on June 13, July 17, Aug. 16, and Sept. 27, 2012.

The results from the four days show that 10%, 14%, 1% and 4% increase in the SDI treatment canopy cover over that of the DI treatment. The lysimeter tree has 21%, 12%, 9% and 16% more canopy cover than those in the SDI treatment (Figure 30).

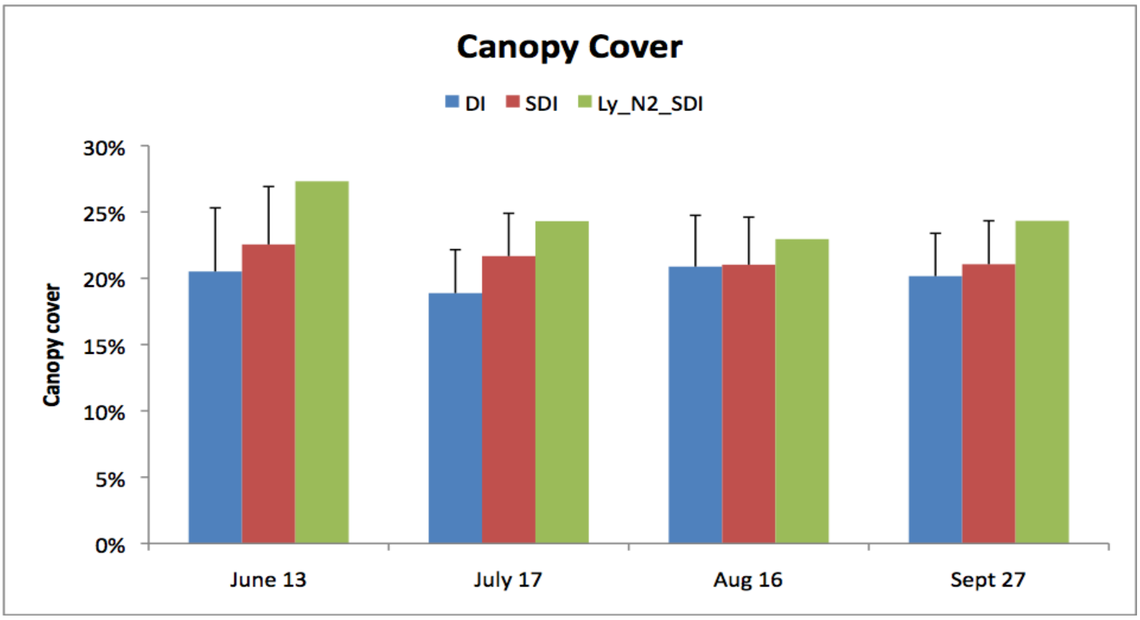
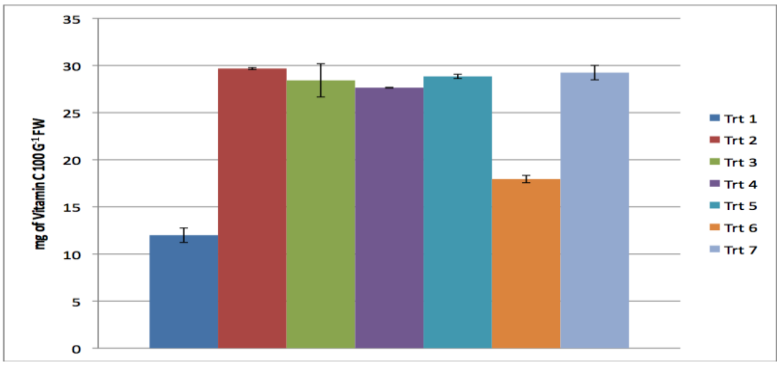


Figure 30. Comparison of canopy cover between DI, SDI and Lysimeter plots obtained on June 13, July 17, Aug. 16, and Sept. 27, 2012.

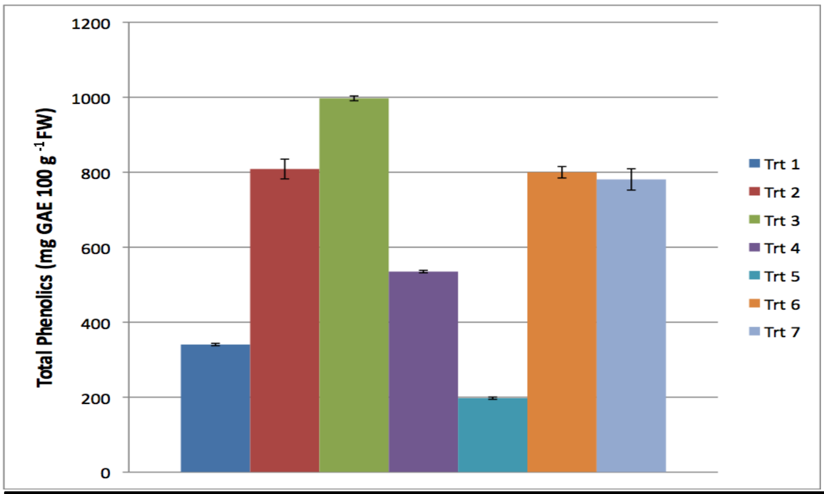
8. Effects of poor quality water on nutritional content in pomegranates

The potential effects on different nutritional parameters in 2-year old pomegranate trees were evaluated with typical water qualities present in the Westside of the California Central Valley. Irrigation waters consisted of salinity ranging from 1 to 6 dS/m, and having boron and selenium (Se) concentrations of 4 mg/L and 0.25 mg/L, respectively. Trees were irrigated individually with respective water treatment under micro-plot field conditions in Parlier, CA based in part by weather data collected from CIMIS. Results showed that vitamin C levels (Figure 31) and most total phenolic levels (Figure 32) increased in the fruit with irrigation water containing selenium, boron, or salinity. Macronutrient concentrations, e.g., Ca, Mg, K, P, S, and Se also increased in the fruit when poor quality waters were used (Tables 6 and 7). These increases in nutrient content were not observed in the seeds, except for Se. In the leaf samples collected from each treatment, the most significant increase was observed for Se concentrations. These preliminary results indicate that waters of poor quality may actually improve the nutritional content of young pomegranate fruit. This observation may be useful for growers of pomegranates on the Westside of central California.



Treatments	
1	Control
2	< 1 dS/m + 0.250 ppm Selenate
3	< 1 dS/m + 0.250 ppm Selenate + 4
4	3 dS/m + 0.250 ppm Selenate
5	3 dS/m + 0.250 ppm Selenate + 4 ppm
6	6 dS/m + 0.250 ppm Selenate
7	6 dS/m + 0.250 ppm Selenate + 4 ppm

Figure 31. Effects of water quality on Vitamin C level of pomegranate.



Treatments	
1	Control
2	< 1 dS/m + 0.250 ppm Selenate
3	< 1 dS/m + 0.250 ppm Selenate + 4 ppm B
4	3 dS/m + 0.250 ppm Selenate
5	3 dS/m + 0.250 ppm Selenate + 4 ppm B
6	6 dS/m + 0.250 ppm Selenate
7	6 dS/m + 0.250 ppm Selenate + 4 ppm B

Figure 32. Effect of water quality on total phenolics levels of pomegranate

Table 6. Effect of 7 water qualities on flesh and seed contents of Ca, Mg, K and P.

Fruit			Ca	Mg	K	P
			ppm	ppm	ppm	ppm
1	**Control**	**flesh**	**149**	413	15114.4	1445.3
2	6 dS/m + 0.25 ppm Se	flesh	388	628	18043.6	3191.9
3	0.25 ppm Se	flesh	268	592	17287.7	2467.1
4	0.25 ppm Se + 4 ppm B	flesh	243	486	15282.3	2228.3
5	3 dS/m + 0.25 ppm Se	flesh	329	573	14672.4	2408.2
6	3 dS/m + 0.25 ppm Se a+ 4 ppm B	flesh	476	878	18173.0	4588.1
7	6 dS/m + 0.25 ppm Se a+ 4 ppm B	flesh	296	655.7575	16232.1	3282.3
8	**Control**	**seeds**	**844**	1161	7103.4	4289.7
9	6 dS/m + 0.25 ppm Se	seeds	966	945	7559.6	3670.2
10	0.25 ppm Se	seeds	677	1197	6103.4	4204.2
11	0.25 ppm Se + 4 ppm B	seeds	695	909	6703.1	3330.2
12	3 dS/m + 0.25 ppm Se	seeds	969	1146	5722.3	4204.1
13	3 dS/m + 0.25 ppm Se a+ 4 ppm B	seeds	1553	1016	8875.3	4402.5
14	6 dS/m + 0.25 ppm Se a+ 4 ppm B	seeds	925	1093.593	6330.6	3003.8

Table 7. Effect of 7 water qualities on flesh and seed contents of S, Na, Cu, Fe, Mn, Zn and Se

Fruit			S	Na	Cu	Fe	Mn	Zn	Se
			ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	**Control**	**flesh**	463.3	44.3	4.0	6	2	8.4	0
2	6 dS/m + 0.25 ppm Se	flesh	963.2	79.2	2.1	3	4	7.5	0
3	0.25 ppm Se	flesh	611.7	43.2	3.6	10	5	8.2	1
4	0.25 ppm Se + 4 ppm B	flesh	750.3	35.9	1.6	4	3	6.0	1
5	3 dS/m + 0.25 ppm Se	flesh	722.3	44.5	2.5	3	3	8.4	0
6	3 dS/m + 0.25 ppm Se a+ 4 ppm B	flesh	1147.3	78.4	4.6	6	7	15.1	1
7	6 dS/m + 0.25 ppm Se a+ 4 ppm B	flesh	1024.7	51.6	3.9	6	4	11.0	0.175395
8	**Control**	**seeds**	1405.5	41.5	14.1	26	12	20.8	0
9	6 dS/m + 0.25 ppm Se	seeds	1168.9	23.9	6.7	14	8	12.6	0
10	0.25 ppm Se	seeds	1340.5	15.3	9.9	14	9	14.6	1
11	0.25 ppm Se + 4 ppm B	seeds	1124.8	15.9	6.7	10	8	12.3	1
12	3 dS/m + 0.25 ppm Se	seeds	1309.1	23.5	9.2	19	11	16.0	0
13	3 dS/m + 0.25 ppm Se a+ 4 ppm B	seeds	1284.7	32.5	8.7	19	11	16.6	1
14	6 dS/m + 0.25 ppm Se a+ 4 ppm B	seeds	1176.1	40.2	11.1	10	9	18.6	0.189645

9. Soil Matric Potential Sensors

Eight heat dissipation soil water matric potential sensors (SMPS, Campbell Scientific Instruments CSI 229) were calibrated in a pressure plate maintained at 25^{O} C at pressure ranging from 10 to 150 kPa. Figure 33 shows an example of a SMPS (CSI SSN #15630) calibration performed in a pressure plate system. This SMPS is installed in the weighing lysimeter at location L-2 (left column, 36-in. depth, 18 in. from the lysimeter side). It is electrically connected to differential channel #10 of the CSI CR3000 datalogger, via a CE8 current excitation module. Two columns of 4 SMP sensors each are installed in the lysimeter at depths of 24, 36, 48 and 60 in. from the soil surface. !n 2013-15, these SMPS will be used to measure the SMP status in the lysimeter, to calculate the hydraulic gradient and to infer the nitrate leaching potential under high frequency SDI (Phene et al, 1989).

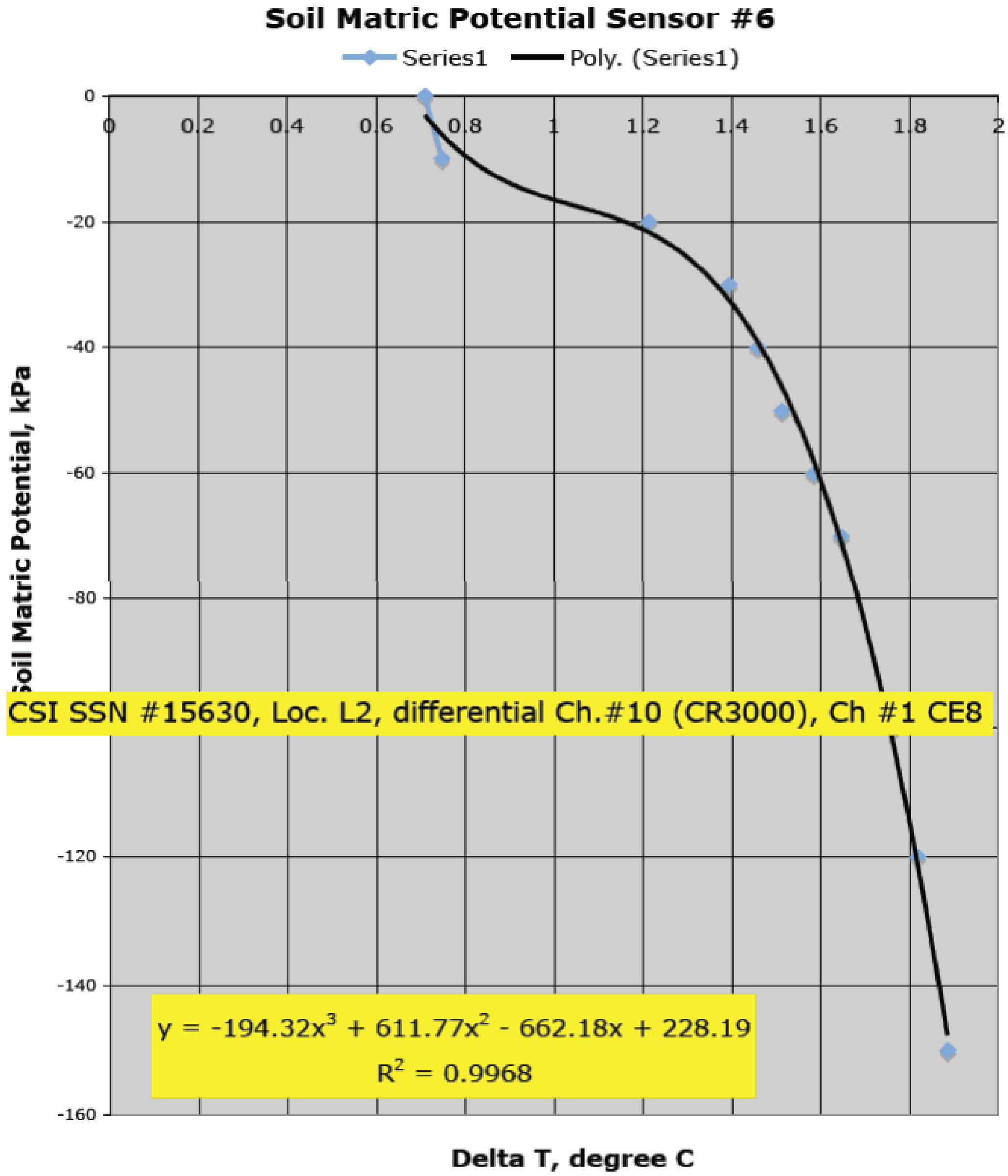


Figure 33. Example of a soil matric potential sensor (CSI SSN #15630) calibration performed in a pressure plate system, maintained at a constant temperature of 25^{O} C. This sensor is installed at location L2 in the weighing lysimeter and electrically connected to differential channel #10 of the CSI CR3000 datalogger.

Discussion/Conclusions:
In response to water shortages, rising water and energy costs and environmental pressure to manage nitrate leaching, California growers are changing their irrigation practices from flood and furrow irrigation to sprinkler and drip irrigation. However, many growers are still using conventional fertilizer methods such as: soil incorporating and banding methods that apply most fertilizers early in the season when crops need it the least. These fertilizer application methods are not efficient and/or well suited for DI and SDI irrigation methods. These practices do not satisfy plant needs, result in N losses to the ground water and the atmosphere and are not N-use efficient**. Although this project used pomegranate as the experimental crop, the practices used here can be applied to perennial crops grown in California using drip irrigation.**

Importance of Irrigation Scheduling on nitrogen use efficiency (NUE)
Water and nitrogen are the two most important components needed by plants to efficiently
achieve plant growth. Unfortunately, if not applied adequately in time and space, significant amounts of water and nitrate can be lost below the root zone and not be available for plant growth. In addition, the transformations and losses of nitrogen as gaseous emission of nitrous oxide (N_2O) under over-irrigation are also significant and detrimental to environmental quality. Therefore, **it is critical to understand the dynamic process involved in the Soil- Plant-Atmosphere Continuum (SPAC) and use this knowledge to manage the water- nitrogen application in order to maintain them in the root zone and minimize losses.**

Factors Affecting Irrigation Scheduling
Factors that affect irrigation scheduling are listed in Table 1. Most of these factors are interdependent and variable, both spatially and temporally. Many crops are good integrator; however, accurate scheduling of irrigation, and especially drip irrigation and more specifically subsurface drip irrigation, can minimize the adverse effects of some of these factors and maximize crop productivity without causing detrimental effects to the environment. **The basic closed loop feedback methods that are commercially available and accessible on the internet or via cell phone and radio include: (1) soil water content and potential, (2) plant water status, (3) reference evapotranspiration on the internet (CIMIS) and with own equipment, and (4) combination of 1, 2 and 3. These methods are being demonstrated in this project.**

Water Use and Applied Water
The 2012 yearly cumulative grass reference ET_O (CIMIS ET_O), cumulative precipitation (P) and the cumulative orchard evapotranspiration (ETc) were respectively: ET_O = 54.37 in (1381 mm), P = 8.70 in (221 mm) and ET_C = 18.19 (462 mm). The irrigation systems were operated in a full automatic high frequency mode. The mean yearly cumulative applied irrigation water for the SDI and DI treatments were respectively 18.0 in. (456 mm) and 17.4 in. (441 mm). A small amount of stored soil water from precipitation (effective P<3.0 in.) may have been used by the trees early in the season at the early leaf out stage. The 7-day averaged crop coefficient (K_C) and the 4th order polynomial regression of the 7-day averaged Kc were calculated. The K_C is defined as the ratio of the orchard ET_C to the CIMIS ET_O from January 1st, 2012 to Dec 31st 2012. The 7-day averaged K_C reached a maximum of 0.6 on October 7th 2012 (the season was relatively cool except for October that was extremely hot).
This Kc could be used by growers using automated or manual drip irrigation managed with CIMIS.

Fertigation Management
a.Nitrogen -The three nitrogen fertility sub-treatments are 50, 100 and 150% of adequate N

(?). They were determined from biweekly tissue analyses. All N was automatically applied by continuous injection of N-pHURIC (46 lb N/ac) for all treatments and additionally as AN- 20 respectively: (102 lb N/ac) for N-2 and N-3 (203 lb N/ac) treatments The various growth stages of the pomegranate are shown at the top of each injection graph to demonstrate when the trees need N. **Since the 2012 results demonstrated that there is no significant difference in responses between the N-2 and N-3, treatments for 2013-2015 will be reduced to N-2 = 100 lb N/ac and N-3 = 150 lb N/ac.**

b.Phosphorus — Phosphoric acid (H_3PO_4) was continuously injected at a rate of P=15 ppm to maintain adequate P level in the SDI treatment. Previous research has shown that phosphorus becomes deficient as soil depths are greater than 10 in (0.25 m). The pH of the irrigation water was automatically maintained at 6.5+/-0.5 with the N-pHURIC to avoid precipitation of phosphates that typically start occurring at pH in excess of 7.2. The total of applied P was 47 lb P/ac for all treatments from 5/31/2012 to 9/6/2012.

c.Potassium — Potassium thiosulfate (K_2T) was continuously injected at a rate of K=23-35 ppm to maintain adequate K level in both SDI and DI treatments. Previous research has shown that potassium may become deficient in sandy loam soil, especially as soil depths increase. The total applied K was 67 lb K/ac for all treatments from 6/14/2012 to 9/6/2012.

Leaf Tissue Nitrogen and Carbon
Most of the N-uptake by plants is in the NO_3-N form because of its solubility and mobility with water from the soil to the plant. Bi-weekly tissue samples were taken around the mid- section of the trees. The total N analysis was used to characterize the long term N response to the three N treatments. The % total nitrogen in leaf tissue in the DI and SDI irrigation treatments, averaged for the three N treatments from May 1 and May 15 prior to any significant N-fertigation dropped rapidly. The large drop in tissue total N levels from 5/1 to 5/15 happened as trees were leafing out and started to flower rapidly**. This may indicate that even under very large N storage capacity, earlier N application may be recommended.** Thereafter the tissue N started to recover slowly and slightly faster for the DI than for the SDI treatment. The total % N in leaf tissue for the three N treatments averaged for the DI and SDI irrigation treatments dropped similarly but, on June 30th, the tissue in the N-1 treatment was 0.2% below that of the N-2 and N-3 treatment but N levels seemed to have recovered by Aug. 30th. **This may indicate that the N-1 level is slightly N-deficient and since there was no** % total N difference between the N-2 and N-3, the N-2 treatment may be adequate. Reducing the N-2 and N-3 treatments for 2013-2015 to N-2 = 100 lb N/ac and N-3 = 150 **lb N/ac may help narrow down the real drip irrigated pomegranate N requirements.**

There was no % tissue carbon difference between DI and SDI or the N-1, N-2 and N-3 treatments.

Soil Nutrients
In 2012, soil samples were collected in April, August and December 2012, from eight soil depths at 0-6, 6-12, 12-18, 18-24, 24-30, 30-36, 36-42, 42-48 in. from the soil surface (sampling at deeper depths was prevented by the presence of

extremely compacted hardpan).

a. Potassium

In general, the soil K levels are slightly higher at a depth of 0-6 inches under both irrigation systems except for the April samples. For the December 2012 samples, the soil K is very low throughout the whole soil profile except in the DI treatment where it is nearly twice that of the SDI treatment at the 0-6 in depth. The low residual soil K at the end of the season might be due to uptake by the pomegranate even though 64 lb K/ac was injected during the season. The potassium levels decreased uniformly with depth under the three N injection levels in August and December but were randomly distributed for the April sample, before any potassium was injected.

b. Nitrates

Results obtained from 360 measurements for each irrigation treatment (DI and SDI) and averaged for the three nitrogen treatments (N-1, N-2 and N-3) and for April, August and December samplings show an average increase in soil nitrate for DI over SDI ranges from 14% at 9-in depth to 80% at 33-in depth. **These data indicate that nitrate leaching can be minimized by injecting nitrogen fertilizer using high frequency SDI systems and applying N as needed by the crop.** When taken at the peak of the N injection these data show that the N-1 treatment had the lowest nitrate level from the soil surface down to 33-in depth but was not different from the N-2 and N-3 treatments at deeper deaths. **This would seem to indicate that the higher levels of applied N (N-2 and N-3) had not caused some significant increases in NO_3 leaching.**

Pomegranate Yields and Quality

Pomegranates were commercially harvested by a local packer on Oct. 30, 2012 for prime fruit and Nov. 8, 2012 for 'Juice' fruit. The SDI prime fruit yield of 5.8 ton/ac is 16% greater than that of the DI fruit yield, mostly due to the 9.3 % significant increase in fruit weight. The season total marketable fruit yield increase of the SDI is 10.1% greater than that of the DI season marketable fruit yield. Data from the three N-fertigation levels do not show any significant difference although there is 6.9% increase for the season total marketable fruit yield of the N-3 above that of the N-1 treatment. **These 3rd leaf yields are outstanding based on the industry typical yields**.

Water and Nitrogen Use Efficiency (WUE and NUE)

Table 8 summarizes the pomegranate water use efficiency (WUE) and nitrogen use efficiency. The pomegranates were irrigated and fertilized by surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems in 2012, as described above. The SDI WUE-prime increase of 23% over the similar DI WUE-prime yield and the NUE's increases of 16% (Prob.>'F' value = 0.067[y]) are further indications of the ability of SDI systems to increase WUE and NUE for prime fruits.

Table 8. Pomegranate water use efficiency (WUE) and nitrogen use efficiency irrigated and fertilized via surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems in 2012.

Treatments	WUE-Prime lb/ac/in	WUE-Juice lb/ac/in	WUE-Total lb/ac/in	NUE-N1 lb P/lb n/ac	NUE-N2 lb P/lb n/ac	NUE-N3 lb P/lb n/ac
DI	554	487	0.56	217	67	40
SDI	680	534	0.59	251	78	46
% SDI Inc. over DI	**23[y]**	**9**	**6**	**16[y]**	**16**	**16**

WUE = Water use efficiency, Fruit yield/irrigation water applied.
NUE = Nitrogen use efficiency, Fruit yield/pound of nitrogen applied per acre
[Y] Probability of a greater 'F' value. Mean separation at P ≤ 0.05.

Nitrous Oxide Emission in Pomegranate Orchard

Greenhouse gas nitrous oxide (N_2O) emissions from the pomegranate orchard were measured using the static chamber method. As N_2O concentration (ppm, µg/m^3) increased inside the chamber, Air samples were collected at time intervals of 0.5 or 1.0 h depending on the linearity in concentration increase. Flux chamber measurements show that N_2O emission significantly increases with the increase of N application rate in the surface drip irrigation.

However, N_2O emissions from the subsurface drip application were considerably lower or negligible regardless of N application rate. **These results demonstrate another potential advantage of the high frequency SDI/fertigation for minimizing air pollution from agricultural activities**.

Pomegranate Canopy Evaluations

a. Multispectral Camera Measurements: Tree canopy cover in each treatment plot was measured with a TetraCam ADC multispectral camera. The camera contains a single precision 3.2 megapixel image sensor optimized for capturing green, red, and near-infrared wavebands of reflected light. Results indicate a 36% increase in the SDI treatment canopy cover over that of the DI treatment.

b. Pomegranate Canopy Light interception with Light Bar: Pomegranate canopy light interception measurements (CLI) were obtained in 2011 (Aug. 18 and Sept, 8) and in 2012 (Jun. 15, Jul. 3 and Jul. 16). CLI was related to ET_c from the lysimeter to help generate canopy-related crop coefficients (K_c).

c. Leaf color measured with the SPAD meter and canopy correlation: Leaf color measurements were measured in 2012 using the SPAD 502 Chlorophyll Meter. The meter was clamped over leafy tissue, and measured an indexed chlorophyll content reading (-9.9 to 199.9) in less than 2 seconds. Darker leaf has higher reading and many researchers have shown a strong correlation between SPAD measurements and leaf N content with darker color indicating higher levels of plant N.

In 2012, the canopy cover was also measured with a TetraCam multispectral camera. Comparison of canopy cover among treatment plots from the four days show that 10%, 14%, 1% and 4% increase in the SDI treatment canopy cover over that of the DI treatment.

These different methods for indirectly assessing tree growth and N-status demonstrate the potential advantage of high frequency SDI/fertigation for achieving high WUE and NUE since less irrigation water was used and a greater yield was generated with SDI than with DI.

Effects of poor quality water on nutritional content in pomegranates

The potential effects on different nutritional parameters in 2-year old pomegranate trees were evaluated with typical water qualities present in the Westside of the California Central Valley. Irrigation waters consisted of salinity ranging from 1 to 6 dS/m, and having boron and selenium (Se) concentrations of 4 mg/L and 0.25 mg/L, respectively. Results showed that vitamin C levels and most total phenolic levels increased in the fruit with irrigation water containing selenium, boron, or salinity. Macronutrient concentrations, e.g., Ca, Mg, K, P, S, and Se also increased in the fruit when poor quality waters were used. These preliminary results indicate that waters of poor quality may actually improve the nutritional content of young pomegranate fruit. **These observations may be useful for growers of pomegranates on the Westside of central California.**

Soil Matric Potential Sensors

Eight heat dissipation soil water matric potential sensors (SMPS, Campbell Scientific

Instruments CSI 229) were calibrated in a pressure plate maintained at 25^{o} C at pressure ranging from 10 to 150 kPa. In 2013-15, these SMPS will be used to measure the SMP status in the lysimeter, to calculate the hydraulic gradient and to infer the nitrate leaching potential under high frequency SDI.

Project Evaluation:

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Outreach Activities:

Results were presented at UC Cooperative Extension Small Farm Advisors Program on pomegranate held at UC Kearney Agricultural Research Center on Aug. 21, 2012. The data were well received. A field day will be planned for 2013 to describe system operation and results.

The following presentations were made:

1. Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation. C.
J. Phene et al., UCCE, KARE, Parlier, CA Pomegranate Field Day, Aug. 21, 2012.

2. Measurement of N2O Emissions from Drip Irrigated Soils in a Pomegranate Orchard. S. Gao, A. Hendratna, and C. J. Phene. ASA/SSSA/CSSA national meeting, Nov. 2012.

3 Dissolved Organic Carbon, Total Carbon and Nitrogen in SJVASC Pomegranate Cultivation under Drip Irrigation Systems. R. Tirado-Corbalá, J. E, Ayars, C. J. Phene and D. Wang. ASA/SSSA/CSSA national meeting, Nov. 2012.

4. Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation.
J.E. Ayars et al. FREP Annual Meeting, Modesto, CA, Dec. 2012

ACCOMPLISHMENTS

Orchard, lysimeter and control system were fully operating and monitored to achieve objectives. Soil sampling, water used and applied, measured evapotranspiration, basic plant growth Pomegranate fruit yield and quality were measured and analysed and reported herewith.

LITERATURE CITED

T. Harter, J. R Lund et al. UC Davis Report for the SWRCB SBX21 Report to the Legislature. 2012.

C. J. Phene et al., Lysimeter feeback irrigation controller system for evapotranspiration measurements and real time irrigation scheduling. 1989. Trans ASAE, vol. 32-2, pp. 477-484.

C. J. Phene et al., Automated lysimeter for irrigation and drainage control. 1991. In ASCE Proceedings Lysimeters for Evapotranspiration and Environmental Measurements, *Ed*. R G. Allen et al. pp. 28-36.

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Paramount Farming – trees
Toro Irrigation – drip tubing
Lakos – filter set
Dorot – Electronic Control Valves
Verdegaal Brothers - fertilizer
SDI+-Consulting time and miscellaneous
equipment AGQ – Deep percolation N analysis

ATTACHMENT # 1. List of tables

ATTACHMENT # 2. List of figures

Figure 19. Soil nitrate (ppm) for the three nitrogen treatments irrigated by the DI irrigation system.

Figure 20. Sample of prime fruits harvested from one tree on Oct. 30th 2012.

Figure 21. Static chambers used for N_2O emission measurement and placed above drip tape in surface drip irrigation (top) and subsurface drip irrigation (bottom) systems.

Figure 22. Nitrous oxide (N_2O) concentration changes inside flux chamber for emission measurement before fertilizer application. May 1: before irrigation, N_2O flux 2.11-2.74 µg N m^{-2} h^{-1}. May 2: irrigation began with 2-3 min N application pumping for testing system. May 7: after irrigation began and no N application yet: N_2O flux 4.61 for surface drip irrigation (DI) and 0.04 from subsurface drip irrigation (SDI).

Figure 23. Nitrous oxide (N_2O) concentration increase inside flux chamber upon placing on soil from measurement on May 31, 2012 after fertilizer application began. DI, surface drip irrigation; SDI, subsurface drip irrigation; N1, N2, and N3, application rates at 50%, 100%, and 150% of plant N requirement, respectively.

Figure 24. Nitrous oxide (N_2O) emission rates affected by N application rate and irrigation system. DI, surface drip irrigation; SDI, subsurface drip irrigation; N1, N2, and N3, application rates at 50%, 100%, and 150% of plant N requirement, respectively.

Figure 25. Measurement of canopy cover for pomegranate using TetraCam multispectral camera.

Figure 26. Pomegranate tree canopy taken with TetraCam camera.

Figure 27. Plant canopy light interception obtained with the light bar in August 18, September 8. 2011 and June 15, 2012.

Figure 28. Means of SPAD meter readings in each block of each treatment on July 27, Aug 17, and Sept 20, 2012.

Figure 29. Comparison of canopy cover among treatment plots obtained on June 13, July 17, Aug. 16, and Sept. 27, 2012.

Figure 30. Comparison of canopy cover between DI, SDI and Lysimeter plots obtained on June 13, July 17, Aug. 16, and Sept. 27, 2012.

Figure 31. Effects of water quality on Vitamin C level of pomegranate.

Figure 32. Effect of water quality on total phenolics levels of pomegranate

Figure 33. Example of a soil matric potential sensor (CSI SSN #15630) calibration performed in a pressure plate system, maintained at a constant temperature of 25^{o} C. This sensor is installed at location L2 in the weighing lysimeter and electrically connected to differential channel #10 of the CSI CR3000 datalogger.