Determining Pomegranate Water and Nitrogen Requirements with Drip Irrigation

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ABSTRACT

Despite being an ancient crop there is limited knowledge on the water and nitrogen (N) requirements of pomegranate. We conducted research at the University of California, Kearney Agricultural Research and Extension Center (KARE) to determine the water and N requirements of a developing pomegranate orchard. Pomegranate trees (*Punica granatum L. var. Wonderful*) were planted in 2010. The irrigation treatments were surface drip irrigation (DI) and subsurface drip irrigation (SDI) with three

N sub-treatments (N application rates of 50, 100, and 150 % of current practice) and 5 replications in split-plot design. A weighing lysimeter located in the experimental field was used to automatically irrigate the orchard after 1.0 mm of measured crop water use. The trees received uniform application of fertilizers and water during the first two years of growth to insure uniform stand establishment prior to beginning the experiment. The pH of the irrigation water was maintained at 6.5+/-0.5 by injection of N as urea sulfuric acid (US-10; 10% N). Differential N treatments were started in 2012 and continued through the end of the project. Phosphorus (PO₄-P) was continuously injected during irrigation and potassium (K₂T) was injected weekly. We report the results of the study from 2013 to 2015. From 2013 to 2015 the applied N ranged from 62 to 332 kg/ha and the total yields ranged from 33,144 to 57,769 kg/ha. There were no statistical differences in yield within any year related to total applied N. The yearly applied irrigation water increased as the plant size increased. The total water requirement is approximately 952 mm and the maximum daily water use was 10.5 mm. The DI irrigation application went from 645 mm to 932 mm and the SDI application increased from 584 mm to

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843 mm from 2013 to 2015. A fifth order polynomial was fitted to the crop coefficient using the 2015 data. The use of SDI resulted in lower weed pressure in the SDI plots than in the DI irrigated plots in all three years. High frequency irrigation resulted in nitrate being managed within the soil profile to a depth of 1.5 m by minimizing deep percolation losses to the groundwater. While the yields were higher in the SDI than the DI system they were not statistically different. Although there were some differences in N content in tree leaves and fruit peels, there were no differences in fruit arils among N rates. The N requirement is in the range of 62 to 112 kg/ha (109 – 198 g/tree) for a mature pomegranate orchard and will ultimately depend on the planting density.

1. Introduction

Pomegranate has been cultivated throughout the Mediterranean region continuously from 3000 BCE (Stover and Mercure, 2007). It is widely considered that pomegranate was native to northern India and areas of Iran and from those origins spread throughout the world reaching China by 100 BCE. In the 1500's and 1600's it was introduced in Central and South America and in the early 1700's in Florida and Georgia in the United States. By 1770 it had made its way to the west coast of the United States and was being grown in the Franciscan missions in California. Pomegranate is ideally suited to a Mediterranean climate with a warm summer and a mild winter which describes the climatic conditions found in the San Joaquin Valley of California, the principal production area in the United States. There are approximately 12,145 ha under production in California compared to 108,000 ha in India, 71,000 ha in China, 65,000 ha in Iran, 27,000 ha in Turkey, and 6,000 ha in Spain (Stover and Mercure, 2007).

One of the drivers of the interest in pomegranate in the United States was the recent demand for juices with healthy bioactive compounds, mineral nutrients, and high antioxidant content (Basu and Penugonda, 2008). The medicinal qualities of pomegranate were recognized 1000's of years ago, with extracts of the tannin rich roots being used to rid people of tapeworms. Pomegranate extractions were also used as plasters to reduce eye and skin inflammation and to aid in digestion. There is an extensive literature on uses of pomegranate in medicine that include: treating diabetes, leprosy, to halting diarrhea, and hemorrhage. Various parts of the tree (leaves, bark, and roots) as well as the fruit are used for medicinal purposes. Some of the medicinal uses have been supported by recent studies (Mertens-Talcott, et al. 2006; Al-Muammar, et al. 2012; Galindo, et al. 2014; Li, et al. 2015).

Despite this long history of use throughout the world there is limited literature that has quantified the basic agronomic requirements (fertilizer, water) for production of pomegranate. Research has evaluated the effect of N on the juice quality and the effect on the antioxidant properties but very little on the N requirement for crop production and the effect of N levels on yield. Dhillon (2011) evaluated the N requirement of developing pomegranate and found that increasing the level of N from 0 to 60 g/tree/ year resulted in larger trees and yield for the highest N levels with

the number of fruit and fruit size increasing as well. This was characterized as being a result of the increase in tree size. The maximum N rate was equivalent to 36 kg/ha of N. Other studies on mature trees estimated the N requirement as 500 to 625 g N/tree (Prabhakar, et al. 2006). Current N usage in California is approximately 60 to 112 kg/ha where N is commonly applied as a split application in the winter and then in the spring. Initial studies didn't show any benefit to yield, size and fruit quality from the application of P and K (La Rue, 1977)

Pomegranate is characterized as being drought tolerant but few studies have quantified the actual water requirement. Kattah et al. (2011) found that the yield increased as the applied water increased from 280 to 600 mm of applied water in a 20-year-old pomegranate orchard. Most studies determined the water requirement for surface (furrow, sprinkler) irrigated crops using a variety of water balance methods to determine evapotranspiration and to develop crop coefficients for irrigation scheduling. Meshram et al. (2011) estimated the water requirement for a pomegranate orchard up to five years of age using surface drip irrigation. They found the maximum crop coefficient (k_c) to be 1.18 and daily water use of 5.3 mm/day for a 5-year-old tree.

High level of nitrate (NO_3^-) in the groundwater is a significant problem in California aquifers (Harter, et al. 2002; Harter et al. 2012) and irrigated agriculture has been identified as a significant source of nitrate pollution. Nightingale (1972) sampled groundwater aquifers under areas in grape, orchard, row crop production, and fallow and found a significant correlation between the crop N management and the levels of nitrate in the soil profile and in the groundwater. This was at a time when furrow irrigation was the principal irrigation method and deep percolation losses were significant and would be the transport mechanism for nitrate. Since that time drip irrigation has been widely adopted on many perennial crops and the potential for nitrate transport has been significantly reduced with the implementation of improved irrigation scheduling and irrigation system management. Research has shown that well-managed surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems can eliminate runoff, deep drainage, minimize surface soil and plant evaporation, reduce transpiration of drought tolerant crops, and significantly reduce fertilizer losses, thus protecting groundwater quality (Ayars, et al. 1999).

This project was initiated to determine the water and N requirements of a 6-year-old fully irrigated pomegranate orchard using high frequency surface and subsurface drip irrigation.

2. Materials and Methods

This project was located on the University of California Kearney Agricultural Research and Extension Center (KARE) on a 1.4 ha field that included a large weighing lysimeter (Phene, et al. 1991; Ayars et al. 2003). Pomegranate trees (*Punica granatum* L. var. Wonderful) were planted in 2010 with 4.9 m between row spacing and a within row spacing of 3.6 m (567

trees/ha). The orchard was laid out in a split-plot design with 2 irrigation methods as the main treatments and 3 N levels as the sub-treatments with 5 replicates (Fig. 1). Each plot contained 3 tree rows and a minimum of 7 trees per row. The center row was used as the experimental row with the center 5 trees being sampled for yield and fruit quality data. The trees were allowed to grow free form with multiple trunks (Day and Wilkins, 2011) with little pruning and the height maintained at approximately 3 m.

The main treatments were surface drip irrigation (DI) and subsurface drip irrigation (SDI) with the drip laterals installed at a depth of 50 - 55 cm. There were 2 drip laterals per tree row with a lateral located on each side of the tree row at a distance of 1.1 m from the row. The emitter discharge rate was 2 L/hr spaced at 1 m apart along the lateral. The trees were irrigated after 1 mm of crop water use had been measured in the lysimeter. During peak crop water use this could result in up to 8-12 irrigations per day.

Figure 1. Layout of experimental plots.

The 3 N fertility sub treatments were designed to be 50% (N1), 100% (N2), and 150% (N3) of current California practice (60 - 112 kg/ha) (La Rue, 1977). The N was applied by continuous injection of urea sulfuric acid (US 10;10% N as urea, 18% S) to maintain the pH of the irrigation water at 6.5+/-0.5 to avoid precipitation of phosphates that typically starts occurring with pH greater than 7.2. Ammonium nitrate (AN-20; 10% NH₄-N and 10% NO₃-N) was injected as needed to provide the additional N required for treatments N2 and N3.

Previous research (Bauer, et al. 2002; Liu, et al. 2011; Buckman and Brady, 1966) has shown that phosphorus (P) can become deficient for a variety of crops at soil depths greater than 20 cm. To prevent P deficiency in this study phosphoric acid (H₃PO₄, PO₄-P) was continuously injected at a concentration of P=15-20 mg/L to maintain adequate P level in both the DI and SDI treatments.

Previous research has shown that potassium may become extremely deficient in sandy loam soil (Bauer, et al. 2002; Phene et al. 1989), especially as soil depth increases. In this study potassium (K₂T) was injected once weekly at a concentration of K=50 mg/L to maintain adequate K level in both SDI and DI treatments. The total application of K was increased as the plants grew.

The soil profile was sampled in the spring and fall to a depth of 1.2 m in 15 cm increments in each replication of each treatment and analyzed for nitrate using a 1:1 soil water extract and filtered prior to analysis. The filtrate was analyzed using a colorimetric method (Mulvaney, 1996) with an Astoria 2 Analyzer (Astoria-Pacific Inc., Clackamas, OR, USA). Tree leaf samples were collected biweekly from each treatment, dried at 42° C, ground and analyzed for total N.

After harvest fruits were separated into arils and peels and were processed similar to the leaf samples and analyzed for total N. The total N content in plant tissues was determined using a combustion method with a LECO TurMac CN Macro Determinator (LECO Corporation, St. Joseph, MI, USA).

There was only one tree on the lysimeter and it was irrigated using a SDI system with the same number of emitters (8) per tree as the remainder of the orchard. The lysimeter determined the water use for a fully irrigated (100%) subsurface drip irrigation (SDI) with N treatment (N2) and automatically scheduled the irrigation for the field (Phene, et al., 1989). When the differential N treatments were begun in 2012 the water applied to the DI treatments was increased by 10% over the SDI treatments to account for evaporation from the soil surface and water use by weeds.

Reference evapotranspiration (ET_o) was taken from nearby (0.7 km) California Irrigation Management Information System (CIMIS) weather station and the crop water use (ET_c) was measured by the weighing lysimeter. A crop coefficient (K_c) was calculated daily as the ratio of ET_c/ET_o . For irrigation scheduling the lysimeter water use was adjusted to account for the difference between the surface area of the lysimeter and the area for each field tree based on the spacing (Phene et al., 1989).

Precipitation was measured with a calibrated rain gauge installed next to the lysimeter, drainage from the soil tank was measured using a tipping bucket rain gauge located at the drain outlet of the lysimeter, and runoff was prevented by the design of the lysimeter tank. The water applied by the SDI and DI systems was measured with electronic water meters. We calibrated heat dissipation soil water matric potential (SMP) sensors (CSI-229, Campbell Scientific Inc. Logan, Utah, USA) to provide the SMP status of the soil in the lysimeter (Phene and Howell 1984). These SMP sensors were installed in columns located in the north and south ends of the lysimeter at depths of 0.6, 0.9, 1.2 and 1.5 m from the soil surface. The SMP data were averaged by depth and were used to calculate the hydraulic gradient to determine the direction of water flow in the root zone and to infer the leaching potential under high frequency SDI (Phene et al., 1989; Phene et al. 2015).

Rate of water flow and the direction of flow can be determined using Darcy's law (Smith and Warrick, 2007). We calculated the gradient based on soil matric potential and depth of the sensor within the soil profile using the SMP data

$$\Delta H / \Delta Z = (H_2 - H_1) / (Z_2 - Z_1) \quad (1)$$

with $H = \Psi - Z$ where Ψ is the soil matric potential, H is the head, and Z is the sensor depth.

This results in
$$\Delta H / \Delta Z = (\Psi_2 - \Psi_1) / (Z_2 - Z_1) - 1 \quad (2)$$

with $(\Psi_2 - \Psi_1)$ being the SMP difference between 2 depths and $(Z_2 - Z_1)$ is the corresponding soil depth difference measured downward from the soil surface and (-1) represents the gravitational component of the gradient. However, the downward flow due to gravity was insignificant due to the high frequency of irrigation with the SDI systems applying water at the rate being taken up by evapotranspiration. As a result, the equation 2 reduces to

$$\Delta H / \Delta Z = (\Psi_2 - \Psi_1) / (Z_2 - Z_1). \quad (3)$$

Pomegranate fruits were harvested annually in a single harvest by a local packer and subsamples were taken from the 5 center trees of each of the yield rows and measured for total number, weight, and quality. The quality designations were prime, subprime, green, marketable, and culls. For analysis we combined the various categories into prime and subprime fruit. The prime fruit included fruit with good color, minimal cracking with no open cracks, diameter greater than 8 cm, and were marketable as fresh fruit. The subprime included fruit suitable for juicing, and contained some green and open cracked fruit. The sum of all the categories gave the total production.

Water productivity (WP) was calculated as the average yield for all N treatments per ha divided by the applied water in mm for the SDI and the DI systems. It was also calculated for the individual N treatments in each irrigation system by averaging the DI and SDI by N treatment for the prime, subprime, and total production. The N productivity (NP) was calculated by dividing the prime, subprime, and total yield by the total applied N for each treatment.

A split plot mixed model was fit using the SAS PROC MIXED program (SAS, 2013). Irrigation, N and their interaction are the fixed effects and the replications (reps) and irrigation by reps are random effects. Means were taken over the tree subsamples prior to analysis. The analysis included means and 95% confidence intervals for the irrigation and N main effects and linear and quadratic contrasts for the N main effects. For N concentration data in tree leaf samples (sampled biweekly), the fixed effects are irrigation type, N rate, date, and their interactions and the random effects are block, irrigation type $\times$ block and irrigation type $\times$ N rate $\times$ block; and this latter 3-way interaction defines the experimental units for incorporating a first-order, autoregressive covariance structure among the repeated measures. Focus was on the significant irrigation type $\times$ N rate interaction for which the least square means and their 95% confidence intervals were obtained. For N concentration data in fruit samples, the fixed effects and random effects are the same as the yield data analysis.

3. Results

3.1. Crop Water Use

The crop water balance is given in table 1 from 2010 to December 15, 2015. The water balance data from the first 3 years (2010 – 2012) were included to characterize crop water use during early plant development. The experiment ended in December 2015 when the trees were removed from the field. There was cold weather prior to the tree removal in 2015 that resulted in leaf drop and the cessation of transpiration prior to tree removal.

The total annual reference evapotranspiration (ET_o) was lower in 2010-2011 than in 2012-2015. From 2013 to 2015 there was approximately a 6% variation in the total ET_o . The precipitation values are below the regional averages of 250 mm due to the drought in the last 5 years of the study. Most of the rainfall occurred during the winter which is typical of the Mediterranean climate in the Central Valley of California.

Crop water use was increasing each year as the plants grew larger and the maximum daily use increased to approximately 10 to 10.5 mm per day which is slightly higher than what was reported by Meshram et al. (2011). The maximum crop coefficient (K_c) increased from a 0.85 in 2013 to 1 to 1.2 in 2015 which is lower than what was reported by Meshram et al. (2011). The data for 2015 (Fig. 2) were used in the crop coefficient calculation since they represented a mature tree. The crop coefficient was calculated as a 7-day running average of the ratio of the 2015 crop water use data and reference potential evapotranspiration fitted with a 5th order polynomial

$$K_c = -0.125 - 0.000585x + 0.0001624x^3 - 1.452E^{-6}x^3 + 5.314E^{-9}x^4 - 7.13E^{-12}x^5 \quad (1)$$

where x is the day of the year. There is quite a bit of variability in the crop coefficient. Also, note that the maximum K_c occurs August and September and not during the hottest month (July) of the year. This is a result of the calculation when the plant water use is high late in the year and the potential evapotranspiration has reduced from peak values.

Table 1. approximately here

Fig. 2 approximately here

Equal depths of irrigation water were applied to the DI and SDI systems in 2010 and 2011 to ensure good stand development and reasonably uniform plant size. The irrigation data for the DI and SDI systems show a progressive increase in applied water to meet crop water use which was expected as the trees matured and increased in size over the six-year period. The difference in SDI and DI applied water beginning in 2102 was a result of the deliberate addition of approximately 10% more water to the DI treatment than the SDI treatment to compensate for water loss due to surface evaporation and water use by weeds. The last two years (2014 – 2015) show that the crop water use measured by the lysimeter is in the range of 912 - 952 mm which

reflects the mature crop water requirement. The applied irrigation water was 932 mm for the DI system and 843 mm for the SDI system. The difference in applied water was by design and highlights a significant advantage of SDI over DI systems and a potential opportunity to conserve water without creating negative impacts on plant size or yield. Additional study will be required to determine if additional savings are possible through sustained reduction in SDI treatment.

No drainage was measured from the lysimeter by the tipping bucket rain gauge installed in the lysimeter. The lack of drainage from the lysimeter resulted in part due to the high frequency irrigation with SDI based on the precise determination of the hourly crop water use. The ability to meet crop water demand with small applications of water minimizes the potential for deep percolation with SDI by meeting the crop water use and only requiring storage of small volumes of water compared to surface irrigation methods that may apply in excess of 250 mm in an irrigation. With high frequency irrigation, it is possible to control the soil matric potential (SMP) and thus the resulting hydraulic gradients with the net result being minimal to no deep percolation. The on-going drought during the experiment and lower than average rainfall during this period probably contributed to the lack of drainage particularly during the winter months when there was no crop demand and the majority of the rain occurs.

3.2. Soil Matric Potential (SMP) Measurements and Hydraulic Gradient (HG) in the SDI Irrigated Lysimeter:

With the concern for transport of nitrate to the groundwater it is essential to quantify the movement of water and NO_3^- through and below the crop root zone. Potential deep percolation and N transport through and below the crop root zone was determined using hydraulic gradients (HG) calculated from soil matric potential measurements (SMP) collected in the lysimeter.

Figure 3 shows the average SMP measurement at depths of 0.6 m, 0.9 m, 1.2 m, and 1.5 m in 2013 (a), 2014 (b) and 2015 (c). The data show that the SMP was maintained in a range of -30 to -45 kPa in each year during the operation of the irrigation system which is a well-watered range for this Hanford sandy loam soil. The spike in the data in June of 2013 occurred when the irrigation system was not well controlled and excess water was applied. The spike in February 2014 was a result of a 33 mm rainfall. The subsequent decline in the soil matric potential was a result of the trees leafing out and using soil water. This is followed by the beginning of irrigation and the trees reaching full bloom about day 110. The spikes in the SMP demonstrate the sensitivity of the sensors to changes in water content. The SMP data for 2015 show the same pattern of control within a narrow range of matric potential.

Figure 3. Daily average soil matric potential (SMP) sensor measurements in the KARE weighing lysimeter for 2013 (a), 2014 (b) and 2015 (c).

287

288 Calculated daily averaged hydraulic gradients (HG) for 2013, 2014 and 2015 are shown in Fig. 4
289 a, b, and c (HG > 0 indicates upward flux and HG < 0 indicate downward flux). HG-1 is the
290 gradient from 0.6 to 0.9 m. HG-2 is the gradient from 0.9 to 1.2 m and HG-3 is the gradient from
291 1.2 to 1.5 m. Results in Fig. 4 indicate that HG-1 and HG-3 are positive each year with upward
292 flow while the zone from 0.9 m to 1.2 m has water moving downwards in each year. However,
293 the gradient from 1.2 to 1.5 m is upward thus preventing drainage and nitrate leaching (none
294 measured from the lysimeter). While these data were collected in the lysimeter, it is reasonable
295 to expect a similar flow situation in the field in both the DI and SDI systems since the irrigation
296 in the field was controlled by the lysimeter.

297 Figure 4. Hydraulic gradients of soil water flow

298 3.3. Fertility Management

299 In all year's most of the N was applied by mid-June to meet the large N demand at budbreak and
300 leaf and fruit development (Wang et al., 2015). After the initial injection of N early in the season
301 the remaining application is a result of the continuous injection of the US-10, which was used for
302 pH control and to provide N for the N1 treatment.

303 The total applied N, P and K for the 3 years of the study are summarized in Table 2. The total
304 seasonal phosphorous application depended on the total applied water since it was injected
305 continuously at a constant level of 15 ppm throughout the irrigation season. The total applied P
306 increased over (Bauer et al. 2002) the years in part due to the increased applied water to meet
307 crop water requirement.

308

309 Table 2 about here.

310 The applied fertilizers provided a wide range of total application to evaluate the response of yield
311 to applied fertilizer. The higher value of K in 2015 was the result of control problems with the
312 fertilizer injection pump.

313 3.4. Yields, Water Productivity (WP) and N Productivity (NP):

314 The yield data were statistically analyzed by averaging yields for each N treatment by irrigation
315 system and by averaging irrigation system (SDI, DI) yields within the N treatments (Table 3).

316 Table 3 here.

317 We evaluated the interactions between irrigation systems and N treatments, and between N
318 treatments in all three years. In 2013 there were statistical differences between the fruit weight of

the prime and subprime fruit in the SDI and the DI systems. There was no difference in the total weight between the SDI and DI across the 3 N levels. In 2014 the prime yields were different by N treatments with yield increasing with applied N. The opposite was true with the subprime yield and yield decreased as N increased. The net effect was that the total yield was not different across the N treatments. In 2015 the only effects that were identified were between irrigation system types. The subprime yield differed between DI and SDI but not between N treatments. There were no statistical differences in total yield in any of the years. The yield of prime fruit for 2014-2015 was between 31,563 to 40,731 kg/ha which is in the comparable yield range reported in the literature (Rymon, 2015; Day and Wilkins, 2011). The total yield increased from an average of 34 MT in 2013 to 51 MT in 2015 in part due to the increase in plant size and additional fruit.

There were no consistent statistical trends across the 3 years of the study that demonstrate a yield response to increasing applied N or between irrigation systems. The average yield was consistently higher in the SDI system compared to the DI system but not statistically different. The total applied N at the N1 level ranged from 62 to 112.8 kg/ha (109 – 198 g/tree) which is in the range of current practice in California (LaRue, 1977).

The water productivity (WP) was calculated as the average yield for all N treatments per ha divided by the applied water in mm for the SDI and DI systems. This was done for the prime, subprime, and total production. These data are given in Table 4.

The data show that the WP was consistently higher in the SDI treatments than in the DI treatments. This was a result of the higher average yields in the SDI treatments than in the DI and lower values of applied water in SDI compared to DI each year. The WP values for the total yield were similar across the treatments in the 3 years of the study.

Table 4. here

The yield data were sorted by N level and the SDI and DI yields were averaged at a given N level and the WP was calculated using the average applied water. These data are given in Table 5. In 2013 and 2014 the prime yields increased with increased applied N but the opposite demonstrated in 2015. There was no significant difference in total yield as a function of N level in any given year. The total yield increased from 2013 to 2015. This would be expected as the trees size increased. The WP was statistically different between years and not within years for the 3 N treatments.

Table 5 here.

The N productivity (NP) data are summarized in Table 6. The data show that SDI had a higher NP than the DI treatments in 2013 and 2014 but not in 2015. This can be explained in part due to the placement of the N with the root zone with the SDI system which would improve the uptake

by the plant. In each year the NP decreased with increasing levels of applied N since there was no yield increase associated with the increased levels of applied N. The N1 treatment had the highest value of NP in each year demonstrating that 62 to 112 kg of N per ha will maintain yield which is consistent with other research (Dhillon et al. 2011). In all years, the N1 treatment had yield values equal to the higher N treatments (N2, N3).

Table 6 here

All fruit were lumped together to determine the average yield per tree and fruit weight for each of the N treatments and irrigation systems. These data are given in Table 7. The yield per tree increased from 2013 to 2015 for the N treatments averaged by irrigation system. There was no difference in yield by N treatment within a given year. This is true for the yields by N and irrigation treatment over the year. The average fruit size was the same within treatments in a given year.

Table 7 here.

3.5. Plant N Uptake

Total N content was analyzed in pomegranate leaves sampled biweekly during the course of the field experiment. The 2015 data are provided here to demonstrate N content changes after trees had reached a mature stage (Fig. 5). The tree leaf N concentration started high in new leaves in spring time and reduced slightly over the growing season for all treatments. Statistical analysis showed significant differences caused by N rate, sampling date, and Irrigation type x N rate. Figure 5 clearly shows that the N1 rate resulted in lower responses than N2 and N3 rates for both irrigation types and that the differences were greater for the DI irrigation type than that for the SDI. The data indicate that the N2 application had likely maximized the N uptake by pomegranate trees.

Figure 5

N content in pomegranate fruits, separated into peels and arils, were determined after harvest in 2014 and the averages for all six treatments are plotted in Fig. 6. The concentration ranged from 0.7-0.9% in peels and 1.0-1.4% in arils. For the N in peels, there was significant effect of N rate, but no significant effect of irrigation type and irrigation x N rate interaction. The N1 resulted in significantly lower N concentration than those from N2 and N3 with no differences between the two higher rates. For the N concentration in arils, however, no significance was attained for any of the fixed effects. The data imply that regardless of the differences in tree leaves and fruit peels, N content in arils (the edible part) in N1 rate were not any different from the higher rates.

Figure 6.

Although some differences were determined in pomegranate fruit N, there were no differences observed in fruit yield (Table 3) between any of the three N application levels. As the orchard reached a mature stage in 2015, the N application rate at N1 was 112 kg/ha when no differences in leaf N were found between the N1 and higher N levels especially under SDI. The data support the estimates that the N requirement for a mature pomegranate orchard can be approximated at 62 - 112 kg/ha for SDI, and higher for DI, which could be caused by insufficient N uptake. The N application rate at N2 was above 200 kg/ha in 2014 and 2015 (Table 2) which was considered to be excessive because of the little difference in leaf and fruit N between N2 and N3. It is unknown if the low N level in fruits would affect fruit quality which was not determined in this study. Total N concentration data show no significant differences in arils among the three N rates.

3.6. Soil Nitrate Profiles.

The fate of N and nitrate movement is a significant environmental concern in irrigated agriculture and is determined by both the placement and the total application of N fertilizers. N injection with SDI places nitrate below the soil surface and within the tree root zone which facilitates crop uptake. A DI system applies the water and thus N to the soil surface which requires transport to the root zone and increases the opportunity for loss through volatilization and denitrification.

The distribution of the average nitrate from all three N treatments by irrigation system for each of the sampling dates is given in Fig. 7. The differential N treatments were begun in 2012. The nitrate distribution throughout the soil profile in both the SDI and DI systems were similar as can be seen by comparing the nitrate distribution in Fig. 7a and 7b for March 2013.

Figure 7.

Fig. 7a gives the distribution under the surface drip irrigation system. All the fertilizers were applied through the drip irrigation and were applied to the soil surface. The lowest profile concentrations occurred in March 2013. There was a gradual increase in concentration throughout the profile over time with the highest levels occurring at 1.2 m in January of 2015. Recall that the net hydraulic gradients measured in the lysimeter for this portion of the profile were upwards and potentially minimized the N transport deeper in the profile.

The data in Fig 7b is for the SDI system with all the N treatments averaged at each depth. The SDI system is installed at 50 to 55 cm below the soil surface and most of the N is located above the drip system. The average concentration at 1.2 m is significantly lower at the end of the experiment in this system than in the surface drip system. This is a result of the injection of the nutrients close to the roots. Recall that the hydraulic gradients measured in the lysimeter for this portion of the profile were upwards and potentially minimizes the transport deeper in

the profile. Comparing the two systems there is the potential for significantly less N being lost to deep percolation with the SDI than the DI system.

3.7. Weed population under DI and SDI

One of the advantages of SDI is the potential for lower weed populations than with surface drip as shown in September of 2012 (Fig. 8). We evaluated this proposition in 2013 by sampling and drying the total weed mass in a square meter in each replicate. The residual weed biomass in the pomegranate orchard was measured on August 28, 2013 after herbicide burn-down and results are shown in Table 8. Results indicate that the weed biomass in the SDI treatment was significantly lower than that in the DI treatment. The relationship between weeds and the soil temperature at solar noon were measured on Sept. 3, 2013 and there was a significant relationship. $R = -0.636$, $P=0.0002$. The infrared soil surface temperature was significantly higher in the SDI than in the DI treatments due to lack of weeds.

Table 8 here.

Figure 8. Differences in weed population between DI and SDI irrigated pomegranate.

Measurement of the weed mass was not conducted for other growing seasons but we observed that the weed mass was consistently greater in the DI than in the SDI treatments as would be expected.

4. Discussion

As noted in the introduction there has been very little research to describe the N and water requirements and most of the literature comes from research in India, Israel and Spain. Previously, the water requirements were based on pan evaporation and estimated evapotranspiration using an energy balance equation. The irrigation systems used included surface drip and surface irrigation (furrow, basin) which have very different efficiencies which may affect the estimates. Part of the challenge is the lack of standardization with row and tree spacing. Firake and Kumhbar (2002) used a 4 by 4 m spacing for rows and trees within rows with the resulting density of 625 trees/ha. This compares to 567 trees in this experiment. They estimated that the crop water requirement of an 8-year-old tree cultivar G-137 was 789 mm for surface drip and 1129 mm for surface irrigation. Crop water use was estimated at 0.75 of pan evaporation during *Ambe Bahar* season which is equivalent to 12,624 L/tree. Meshram et al. (2012) estimated the water use for a 5-year-old tree during this same period to be 11,949 L/tree using the Penman-Montieth equation. The crop water use measured with the weighing lysimeter was 843 mm which is equivalent to 14,867 L/tree for a SDI irrigated tree.

Friake and Kumbhar (2002) reduced the applied water by 80% in the drip irrigated plot. The result was significantly smaller fruit compared to this research. The fruit were approximately 50% of the size of the fruit in this study.

Given the competition for water between agricultural and municipal interests, irrigation should be done using the most efficient system available typically pressurize systems e.g. sprinklers, drip irrigation. We demonstrated that high frequency drip irrigation was effective in reducing deep percolation losses and that additional reductions were possible with the use of subsurface drip irrigation. We demonstrated the ability to manage N in the root zone and minimize deep percolation losses and N transport.

Yields varied widely throughout the world with average yields less than 11.2 T/ha in India and > 40 T/ha in Israel, Spain and Turkey. The yields from this study ranged an average of 34.3 T/ha in 2013 to 51.2 T/ha on 2015 and were typical of yield averages in California (Day and Wilkins 2011).

The N:P:K requirements typically set at 625:250:250 g/tree (Prabhakar, et al. 2006) which is a significantly larger requirement for N than was demonstrated in this study with a range of 109 – 198 g/tree as the plant developed. The use of g/tree is probably the best way to characterize the N requirement, since there are no established practices for tree and row spacing (Day and Wilkins 2011) in California or throughout the world and specifying N requirements on an area basis may result in significant over-fertilization. The fruit quality was not affected by increasing the N above the lowest level as demonstrated by the N content in the arils. There were increases in the leaf and woody tissue with increased N application but not in the arils that are the edible portions of the fruit.

5. Conclusions

High frequency surface (DI) and subsurface drip irrigation (SDI) were used to determine the water and N requirements of a developing pomegranate orchard. We determined that the water requirement of a 6-year-old multi-trunk tree was 953 mm using a weighing lysimeter and the peak daily water use was 10.5 mm. The crop coefficient was described using a 5th order polynomial based on the day of the year. The difference in applied water between the DI and SDI (843 mm vs 932 mm) did not result in any negative effects on crop yield and fruit quality in any year. Subsurface drip irrigation can be used to irrigate pomegranate.

The N requirement was determined to be in the range of 62 to 112 kg/ha (109 – 198 g/tree). There was no increased yield and increased N content in fruit arils in response to N applied in excess of 112 kg/ha. There was a consistent non-statistical difference in yield between the SDI and DI systems with the SDI out producing the DI systems. Water productivity was statistically

different across each year but not within N levels within a year. N productivity was higher in the SDI systems because of the higher yields in the SDI system compared to the DI system. The NP was highest with the lowest applied N since there was no yield response to increased N applications.

The use of high frequency subsurface drip irrigation resulted in no deep percolation losses measured at a depth of 1.5 m in a weighing lysimeter during the 5 years of the experiment. Soil matric potential was maintained within a narrow range during the irrigation season using high frequency drip irrigation which contributed to controlling deep percolation losses. Use of subsurface drip irrigation resulted in reduced weed pressure compared to surface drip irrigation.

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References

Al-Muammar, M., and F. Khan. 2012. Obesity: The preventive role of the pomegranate (*Punica Granatum*). *Nutrition*, 28(6), 595-604.

522 Ayars, J. E., R. S. Johnson, C. J. Phene, T. J. Trout, D. A. Clark and R. M. Mead. 2003. Crop
523 water use by late season drip irrigated peaches. *Irrigation Science* 22: 187-194.
524

525 Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail, and R.M.
526 Mead. 1999. Subsurface drip irrigation of row crops: a review of 15 years of research at the
527 Water Management Research Laboratory. *Agricultural Water Management*. 42:1-27.

528 Basu, A. and K. Penugonda. 2008. Pomegranate juice: a heart-healthy fruit juice. *Nutrition*
529 *Reviews*. 67(1): 49-56.
530

531 Bauer, P. J., J. R. Frederick and W. J. Busscher. 2002. Tillage effect on nutrient stratification in
532 narrow- and wide-row cropping systems. *Soil and Tillage Research* 66(2): 175-182.
533

534 Buckman, H.O., and N.C. Brady. 1966. The nature and properties of soils. The Macmillan
535 Company, New York, NY. 567pg.

536 Day, K. R. and E. D. Wilkins. 2011. Commercial pomegranate (*Punica Granatum* L.) production
537 in California, International Society for Horticultural Science (ISHS), Leuven, Belgium. Pg. 275-
538 285

539 Dhillon, W. S., P. P. S. Gill and N. P. Singh. 2011. Effect of nitrogen, phosphorus, and
540 potassium fertilization on growth, yield, and quality of pomegranate “Kandhari” International
541 Society for Horticultural Science (ISHS), Leuven, Belgium. Pg. 327-332.
542

543 Galindo, A., Á. Calín-Sánchez, J. Collado-González, S. Ondoño, F. Hernández, A. Torrecillas
544 and Á. A. Carbonell-Barrachina. 2014. Phytochemical and quality attributes of pomegranate
545 fruits for juice consumption as affected by ripening stage and deficit irrigation. *Journal of the*
546 *Science of Food and Agriculture* 94(11): 2259-2265.
547

548 Harter, T., H. Davis, M. C. Mathews and R. D. Meyer. 2002. Shallow groundwater quality on
549 dairy farms with irrigated forage crops. *Journal of Contaminant Hydrology* 55(3–4): 287-315.
550

551 Harter, T., J. R. Lund, J. Darby, G. E. Fogg, R. Howitt, K. K. Jessoe, G. S. Pettygrove, J. F.
552 Quinn, J. H. Viers, D. B. Boyle, H. E. Canada, N. DeLaMora, K. N. Dzurella, A. Fryjoff-Hung,
553 A. D. Hollander, K. L. Honeycutt, M. W. Jenkins, V. B. Jensen, A. M. King, G. Kourakos, D.
554 Liptzin, E. M. Lopez, M. M. Mayzelle, A. McNally, J. Medellin-Azuara, and T. S. Rosenstock,
555 2012. Addressing Nitrate in California's Drinking Water with A Focus on Tulare Lake Basin and
556 Salinas Valley Groundwater, Report for the State Water Resources Control Board Report to the
557 Legislature, Center for Watershed Sciences, University of California, Davis, 87p.

558 Kattah, M. M., A. E. Shaban, A. H. El-Shrief and A. S. El-Deen Mohamed. 2011. Growth and
559 Productivity of Pomegranate Trees under Different Irrigation Levels I: Vegetative Growth and
560 Fruiting. *Journal of Horticultural Science and Ornamental Plants*_3(2): 194-198.
561

562 La Rue, J.H. 1977. Growing pomegranates in California. DANR Leaflet 2459. 6 pg.

563 Li, Z., P. H. Summanen, T. Komoriya, S. M. Henning, R.-P. Lee, E. Carlson, D. Heber and S. M.
564 Finegold. 2015. Pomegranate ellagitannins stimulate growth of gut bacteria in vitro: Implications
565 for prebiotic and metabolic effects. *Anaerobe* 34: 164-168.
566

567 Liu, K., T. Q. Zhang and C. S. Tan. 2011. Processing tomato phosphorus utilization and post-
568 harvest soil profile phosphorus as affected by phosphorus and potassium additions and drip
569 irrigation. *Canadian Journal of Soil Science* 91(3): 417-425.
570

571 Mertens-Talcott, S. U., P. Jilma-Stohlawetz, J. Rios, L. Hingorani and H. Derendorf .2006.
572 Absorption, Metabolism, and Antioxidant Effects of Pomegranate (*Punica granatum* L.)
573 Polyphenols after Ingestion of a Standardized Extract in Healthy Human Volunteers. *Journal of*
574 *Agricultural and Food Chemistry* 54(23): 8956-8961.
575

576 Meshram, D. T., H. K. Mittal, R. C. Purohit, and S. D. Gorantiwar. 2011. Water Requirement of
577 Pomegranate (*Punica Granatum* L.) for Solapur District of Maharashtra_State, International
578 Society for Horticultural Science (ISHS), Leuven, Belgium. Pg. 311- 322.
579

580 Mulvaney R.S. 1996. Nitrogen—Inorganic forms. In: D.L. Sparks (ed.) *Methods of soil analysis*.
581 Part 3. SSSA Book Series 5. SSSA, Madison, WI, pg. 1123–1184.

582 Nightingale, H. I. 1972. Nitrates in soil and ground water beneath irrigated and fertilized crops.
583 *Soil Science* 114(4): 300 - 311.
584

585 Phene, C. J. and T. A. Howell. 1984. Soil Sensor Control of High-Frequency Irrigation Systems.
586 *Transactions of the ASAE* 27(2): 392-396.
587

588 Phene, C.J., R.L. McCormick, K.R. Davis, J. Pierro, and D.W. Meek. 1989. A Lysimeter
589 feedback irrigation controller system for evapotranspiration measurements and real time
590 irrigation scheduling. *Trans of the ASAE* 32(2):477-484.

591 Phene, C.J., G.J. Hoffman, T.A. Howell, D.A. Clark, R.M. Mead, R.S. Johnson and L.E.
592 Williams. 1991. Automated Lysimeter For Irrigation and Drainage Control. *Proceeding of the*
593 *Int. Symposium on Lysimetry*, Honolulu, Hawaii, ASCE pp 28-36.

594 Phene, C.J., J.E. Ayars, R.C. Phene and R.S Schoneman. 2015. Irrigating and fertigating with
595 high frequency subsurface drip irrigation can prevent drainage and groundwater contamination.
596 *ASABE Conf. Proceedings*, Paper # 152146263.

597 Prabhakar, P., A. K. Singh and S. Kamiesh. 2006. Irrigation and fertigation of pomegranate cv.
598 Ganesh in Chhattisgarh. Indian J. of Horticulture 63(2): 148 - 151

599 Rymon, D. 2015. On the economics and marketing of pomegranates in Israel. Acta Horticulturae
600 1089:189-196.

601 SAS Institute Inc. 2013. SAS OnlineDoc® 9.4. Cary, NC: SAS Institute Inc.

602 Smith, R. E. and A. W. Warrick. 2007. Soil water relationships. Chapter 6. Design and Operation
603 of Farm Irrigation Systems. G. J. Hoffman, R. G. Evans, M. E. Jensen, D. L. Martin and R. L.
604 Elliot. 2950 Niles Rd., St. Joseph Michigan, American Society of Agricultural and Biological
605 Engineers: 120-159.

606
607 Stover, E. and E. W. Mercure. 2007. The Pomegranate: A new look at the fruit of paradise.
608 HortScience 42(5): 1088-2007.

609
610 Wang, D., J. Ayars, R. Tirado-Corbala, D. Makus, C.J. Phene, and R. Phene. 2015. Water and
611 nitrogen management of young and maturing pomegranate trees. Acta Horticulturae 1089:395-
612 401.

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629 Table 1. Yearly water balance data 2010 to December 15, 2015 for surface (DI) and subsurface
 630 (SDI) drip irrigated pomegranate measured with a weighing lysimeter irrigated with SDI.

Year	ET _o (mm)	Precipitation (mm)	DI (mm)	SDI (mm)	ET _c (mm)	Drainage (mm)
2010	1262.8	439.4	25.4	25.4	53.3	n/a
2011	1292.9	264.2	215.9	215.9	248.9*	0
2012	1386.8	228.6	472.4	426.7	482.6	0
2013	1397.0	81.3	645.2	584.2	683.3	0
2014	1468.1	218.4	848.4	779.8	911.9	0
2015**	1379.2	167.6	932.2	843.3	952.5	0

631 * ET_c measured from 5/1 – 12/8/11 only

632 ** As of: Dec. 15, 2015 when project ended.

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634

635 Table 2. Summary of applied N treatments (N1, N2, N3) and phosphorous (P) and potassium
636 (K).

Year	N1 (kg/ha)	N2 (kg/ha)	N3 (kg/ha)	P (kg/ha)	K (kg/ha)
2013	69.8	166.3	244.5	65.5	72.8
2014	62.0	223.3	341.7	91.8	85.2
2015	112.8	263.3	331.4	116.0	181.0

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638

639 Table 3. Summary of average prime and subprime and total yields for 2013, 2014 and 2015 by
640 irrigation system (DI and SDI) and N levels N1, N2, and N3.

Year	Irrigation System	Prime (kg/ha)	Sub Prime (kg/ha)	Total (kg/ha)	N treatment	Prime (kg/ha)	Sub Prime (kg/ha)	Total (kg/ha)
2013	SDI	24566.1a	10697.1a	35263.2	N1	21638.4	11413.9	33052.3
	DI	22850.2b	10360.0b	33210.2	N2	24061.0	10506.7	34567.7
					N3	25552.8	9676.8	35229.6
2014	SDI	37369.9	10224.5	47594.4	N1	31562.7a	13520.6a	45083.4
	DI	33572.0	11772.3	45344.3	N2	34118.6b	10755.4b	44872.8
					N3	40731.0c	8721.4c	49452.5
2015	SDI	40917.0	9440.5a	50357.4	N1	38651.2	13070.4	51721.6
	DI	33747.8	18245.9b	51993.8	N2	37273.6	13227.2	50501.9
					N3	36070.7	15232.0	51302.7

641 Letters (a, b, c) following the numbers indicate significance at P=0.05 level.

642

643 Table 4. Water productivity (WP) for prime, subprime, and total production for subsurface drip
644 irrigation (SDI) and surface drip irrigation (DI).

Year	Irrigation System	Prime (kg/ha)	WP (kg/ha/mm)	SubPrime (kg/ha)	WP (kg/ha/mm)	Total (kg/ha)	WP (kg/ha/mm)
2013	SDI	24566.1	42.1	10697.1	18.3	35263.2	60.4
	DI	22850.2	35.4	10360	16.1	33210.2	51.5
2014	SDI	37369.9	47.9	10224.5	13.1	47594.4	61.0
	DI	33572	39.6	11772.3	13.9	45344.3	53.4
2015	SDI	40917	48.5	9440.5	11.2	50357.4	59.7
	DI	33747.8	36.2	18245.9	19.6	51993.8	55.8

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646

647 Table 5. Water productivity (WP) for N treatments (N1, N2, N3) averaged across irrigation
648 systems.

Year	N treatment	Prime (kg/ha)	WP (kg/ha/mm)	Sub Prime (kg/ha)	WP (kg/ha/mm)	Total (kg/ha)	WP (kg/ha/mm)
2013	N1	21638.4	35.2	11413.9	18.6	33052.3	53.8a
	N2	24061.0	39.1	10506.7	17.1	34567.7	56.2a
	N3	25552.8	41.6	9676.8	15.7	35229.6	57.3a
2014	N1	31562.7	38.8	11413.9	18.6	45083.4	73.3b
	N2	34118.6	41.9	10506.7	17.1	44872.8	73.0b
	N3	40731.0	50.0	9676.8	15.7	49452.5	80.4b
2015	N1	38651.2	43.5	13070.4	21.3	51721.6	84.1c
	N2	37273.6	42.0	13227.2	21.5	50501.9	82.2c
	N3	36070.7	40.6	15232.0	24.8	51302.7	83.5c

649 Letters (a, b, c) following numbers indicate significance at P=0.05 level.

650

651 Table 6. N productivity (NP) calculated as the yield in kg/ha divided by the total N applied in
 652 kg/ha.

Year	Irrigation System	Prime	Sub Prime	Total	N treatment	Prime	Sub Prime	Total
2013	SDI	153.3	66.8	220.1	N1	310.0	163.5	473.5
	DI	153.3	64.7	207.3	N2	144.7	63.2	207.9
					N3	104.5	39.6	144.1
2014	SDI	178.8	48.9	227.7	N1	509.1	218.1	727.2
	DI	160.6	56.3	217.0	N2	152.8	48.2	201.0
					N3	119.2	25.5	144.7
2015	SDI	173.5	40.0	213.5	N1	342.7	115.9	458.5
	DI	143.1	77.4	220.5	N2	141.6	50.2	191.8
					N3	108.8	46.0	154.8

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656 Table 7. Average yield per tree and fruit weight for all the irrigation and N treatments for 2013,
 657 2014, and 2015.

Year	Irrigation System	Yield (kg/tree)	Average Fruit wt. (kg)	N treatment	Yield (kg/tree)	Average Fruit wt. (kg)
2013	SDI	62.9	0.42	N1	69.4	0.46
	DI	60.5	0.40	N2	67.6	0.45
				N3	69.1	0.46
2014	SDI	84.7	0.45	N1	87.2	0.48
	DI	77.9	0.44	N2	86.5	0.51
				N3	94.8	0.47
2015	SDI	90.0	0.40	N1	101.7	0.43
	DI	93.0	0.37	N2	99.3	0.44
				N3	100.9	0.42

658

659

660 Table 8. Residual weed biomass and the relationship between weeds and solar noon
 661 temperatures measured on August 28, 2013 after herbicide burn-down.

	Weed Biomass	IR Surface Temperature
	g/m ² (d.w. basis)	°C
Irrigation method (I)		
Surface Drip	569 a	49.9 b
Subsurface Drip	81 b	57.0 a
Prob. > "F" value:	0.0001	0.0001
N rate; (N)		
46 lb/ac	250 b	53.7 ab
148 lb/ac	416 a	55.2 a
249 lb/ac	310 ab	51.6 b
Prob. > "F" value	0.07	0.12
I X N interaction:	NS	NS