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# Effects of Different Water and Nitrogen Levels on the Yield and Periodicity of Pistachio (*Pistacia vera* L.)

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**Abstract:** The effects of 2 irrigation intervals ($I_{f1}$: 7 days and $I_{f2}$: 14 days), 4 nitrogen doses ($N_g$, $N_0$, $N_1$, $N_2$ and $N_3$) and 2 crop coefficients ($K_{pc1}$: 0.60 and $K_{pc2}$: 0.90) on pistachio nut fertigation were studied to establish suitable irrigation and fertigation scheduling. The nitrogen levels were 0, 10, 15 and 20 mg $L^{-1}$. In the traditional treatment, $N_g$, each tree received 500/600/400 g of NPK fertilizer at the beginning of February. Other fertilizer doses were applied in the irrigation water through a drip system. Irrigation water amount was calculated based on Class A-Pan evaporation. Wetted percentage in each irrigation was 30%. Irrigation treatments were watered 15($I_1$) and 8($I_2$) times in both years based on the irrigation intervals. Irrigation depths ranged from 324 to 907 mm for the wetted area in 2001 and from 311 to 837 mm in 2002. Evapotranspiration for the corresponding areas ranged from 586 mm to 1133 mm and 721 mm to 1212 mm for the 2001 and 2002 growing season, respectively. The maximum nitrogen amount (18.1 g $m^{-2}$ in 2001 and 15.9 g $m^{-2}$ in 2002) was applied to the treatment with high nitrogen and high water ($I_{f1}N_3K_{pc2}$). In 2001, all pistachio trees received 4.9 and 3.2 g $m^{-2}$ phosphorous and potassium while in 2002 these values decreased to 4.2 and 2.8 g $m^{-2}$. The maximum yields were harvested from $I_{f2}N_3$ with an average of 11.7 kg per tree in 2001 and from $I_{f1}N_0$ with an average of 11.6 kg per tree in 2002.

**Key Words:** Fertigation, Drip Irrigation, Pistachio, Evapotranspiration, Yield

## Farklı Su ve Azot Düzeylerinin Antepfıstığında Verim ve Periyodiziteye Etkileri

**Özet:** Çalışmada farklı sulama aralıkları ($I_{f1}$: 7 gün ve $I_{f2}$: 14 gün), azot dozları ($N_g$, $N_0$, $N_1$, $N_2$ ve $N_3$) ile bitki-pan katsayıları ($K_{pc1}$:0.60 ve $K_{pc2}$:0.90) en iyi sulama ve gübreleme programını belirlemek ve sulama ile gübreleminin antepfıstığı verimine etkilerini araştırmak amacıyla ele alınmıştır. Azot konuları, sulama suyu derişimine göre 0, 10, 15 ve 20 mg $l^{-1}$ olarak düzenlenmiştir. $N_g$ konusunda geleneksel olarak Şubat başında her bir ağaca 500/600/400 NPK (saf madde, g) verilmiştir. Diğer gübre dozları fertigasyon tekniği ile sulama suyu ile birlikte uygulanmıştır. Sulama suyu, açık su yüzeyi buharlaşmasına göre hesaplanmıştır. Sulamalarda arazinin % 30'u ıslatılmıştır. Sulama konuları heriki sulama mevsiminde de, sulama aralıklarına bağlı olarak, toplam 15 ($I_1$) ve 8 ($I_2$) kez sulanmışlardır. Konulara, ıslak alan hesabına göre 324-907 mm (2001 yılında) ve 311-837 mm (2002 yılında) sulama suları uygulanmıştır. Mevsimlik su tüketimi ise, yine ıslak alanlarda yıllara göre sırasıyla, 586-1133 mm ve 721-1212 mm arasında değişmiştir. Sulanan konular arasında en yüksek azot, çok su ve çok azot uygulanan, $I_{f1}N_3K_{pc2}$, konusuna 18.1 g $m^{-2}$ (2001 yılında) ve 15.9 g $m^{-2}$ (2002 yılında) olarak uygulanmıştır. Denemedeki tüm fıstık ağaçlarına 2001 yılında 4.9 g $m^{-2}$ fosfor ve 3.2 g $m^{-2}$ potasyum 2002 yılın da ise 4.2 g $m^{-2}$ fosfor ve 2.8 g $m^{-2}$ potasyum verilmiştir. Çalışmada en yüksek verim 2001 yılında $I_{f2}N_3$ konusundan 11.7 kg/ağaç, 2002 yılında ise $I_{f1}N_0$ konusundan 11.6 kg/ağaç olarak elde edilmiştir.

**Anahtar Sözcükler:** Fertigasyon, Damla Sulama, Antepfıstığı, Bitki Su Tüketimi, Verim

## Introduction

Pistachio (*Pistacia vera* L.) is a native of Anatolia, Syria, Iran, Afghanistan, Baluchistan and some parts of northern India (Kaşka, 1998), as well as of Lebanon, Palestine, Iraq, southern Europe and the desert countries of Asia and Africa (Hendricks and Ferguson, 1995;

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Vargas, 1998). Pistachio is one of the most important crops in the Southeastern Anatolia region of Turkey with respect to production and exports. Although it can be grown in many parts of Anatolia, it is most widely distributed in the southeastern provinces of Gaziantep, Şanlıurfa, Adıyaman, Kahramanmaraş, and Siirt. The first 3 cities of the southeastern region produce 87.88% of the total pistachio yield in Turkey (Ak et al., 1999). However, there are many problems faced by growers, which mainly are: (i) Low yield, and (ii) Irregularity of the yield.

The low yields can be attributed to factors such as periodicity, inadequate pollination, fertilization and prolonged periods of water stress due to low rainfall and lack of irrigation, and primitive traditional cultural practices such as planting, maintenance, fertilization, and harvesting (Kanber et al., 1986). Although pistachio production in Turkey goes back a long time, today's production has not increased to the anticipated levels since pistachios are grown in dry and unproductive lands and thus yield per tree is very low. For instance, the average yield is only 1.4 kg per tree in Turkey, whereas the USA, where modern production and management techniques such as irrigation and fertigation practices are used, has 16-18 kg per tree even though they only started to grow pistachios after the 1960s (Tekin et al., 1990; Ak et al., 1999).

The irregularity of the yield is the biggest problem in Turkey for pistachio production. There are 33 million pistachio trees, but according to an agricultural survey, total pistachio production in Turkey varies from 15,000 t in off-yielding years to 40,000 t in on-yielding years. This irregularity is caused by periodicity (Kanber et al., 1993). Using modern production and management techniques such as irrigation and fertigation can decrease the effect of periodicity. The effects of irrigation, fertigation and nutrient deficiencies as well as the soil on pistachio are not known sufficiently in Turkey (Ayfer, 1990; Kanber et al., 1990). There are a few studies performed in Turkey and other countries on the irrigation and fertilization of pistachio. Those studies show that irrigation is one of the most important preventive measures that need to be considered to reduce yield decline due to periodicity. On the other hand, various researchers have indicated that both a lack of irrigation and inadequate accumulation of nitrogen in plant tissues cause periodicity.

Sykes (1975) indicates that extreme temperatures, both low and high, and low annual rainfalls are the 2 major constraints that limit the extension of pistachio plantations in Turkey. It is reported that the leaf abscission of pistachio occurs as a result of prolonged periods of water stress during dry years when annual rainfall is below 400 mm. The leaf abscission occurring in a given year hinders the bud development in the subsequent year and thereby decreases the fruit yield. Bilgen (1979) indicated that irrigation is among the most important preventive measures that need to be considered to reduce yield decline due to periodicity. On the other hand, a majority of the pistachio growers in Turkey are under the misconception that irrigation may be harmful to pistachio. Sepaskhah and Maftoun (1981) demonstrated that pistachio has wide genotypic variability for water stress and salt tolerance. However, in order to have high yields available soil water content should only be allowed to drop to a minimum of 50% under irrigation practices. Irrigation influences the length of new branches, leaf area and nut size and weight. Goldhamer et al. (1985) showed that marketable yield following 1 year of severe water stress was only half that of unstressed trees. Therefore irrigation should be considered among the most important cultural practices to sustain high yields in pistachio orchards (Bilgen, 1982).

Pistachio trees are very drought tolerant and their roots may go as deep as 2.5 m in search of moist soil layers. In the extreme dry years when available soil water content is below the wilting point root activity may completely cease for a 4 to 5 week period in all soil layers. This implies that irrigation can significantly improve pistachio fruit yield (Spiegel-Roy et al., 1977). Firuzeh and Ludders (1978) have reported that pistachio is quite salt tolerant but very sensitive to frost and water stress when young (up to 5 to 7 years). It is questionable, however, whether irrigation practices can benefit very old (30 to 40 years) pistachio trees, which are well adapted to long periods of drought. Trees with extended rooting systems may effectively extract soil water from deeper moist soil layers.

Pistachio can be grown in dry condition in Turkey whereas, it is grown under irrigation in California (USA) and Iran (Ak et al., 1999). Pistachio trees have a reputation of being drought tolerant, and for being able to survive and even produce modest crops with very little

water. However, drought tolerance does not mean that pistachio trees require little water for optimal performance (Goldhamer, 1995).

Fertigation is the common term for injecting fertilizers through the irrigation system. Micro-irrigation systems are well suited to fertigation because of the frequency of operation and because water application can be easily controlled by the manager (Schwankl, 1995).

The main purposes of this study are (1) to investigate the water relations of pistachio (2) to examine the most appropriate irrigation/fertigation practices of pistachio orchards and (3) to introduce new irrigation technology consisting of a trickle irrigation system and fertigation techniques.

## Materials and Methods

### Site Description

The study was carried out at the experimental garden of the Pistachio Regional Research Institute near the city of Gaziantep in 2001 and 2002. The pistachio orchard is about 3.0 ha in size and 26 km from Gaziantep. The orchard is at 37°28´ east and 36°57´ north longitude and latitude respectively and 705 m altitude.

### Variety

Trees of the pistachio (*Pistachio vera* L.) Uzun variety planted with 10 x 10 m spacing were used for this experiment. Since this variety matures 15-20 days earlier than the others it is recommended for high elevations. The experimental orchard is 27 years old and was in an off-yielding year in 2001 and in an on-yielding year in 2002.

### Soils

The soil in the experimental orchard is in the Gaziantep-Birecik sub-basin. The soils in this basin are of the *Karacaveran* soil series, which is Calcaric Vertisol. The profiles represent widely distributed soils developed on calcretes. The irrigation characteristics of the experimental soil are determined by disturbed and undisturbed soil samples taken from representative places in the orchard using the systematic sampling methods given by Peters and Calvin (1965). All analysis was performed by methods given by Richards (1954) and Tüzüner (1990) and the results are given in Table 1.

### Irrigation System

Irrigation water is supplied from 2 wells almost 220 m deep within the orchard. The water has Electrical Conductivity within the range 0.25-0.75 dS $m^{-1}$ and an SodiumAdsorption Ratio within the range 0-10 ($C_2S_1$ class). The irrigation water is applied by drip irrigation system.

### Description of the Treatments

Different irrigation and fertilization programs were used. Different irrigation intervals ($I_{f1}$ = 7; $I_{f2}$ = 14 days) pan coefficients ($K_{pc1}$ = 0.60; $K_{pc2}$ = 0.90) and nitrogen concentrations (Ng; $N_0$= 0 mg $l^{-1}$; $N_1$ = 10 mg $l^{-1}$; $N_2$ = 15 mg $l^{-1}$; $N_3$ = 20 mg $l^{-1}$) were considered in the experiment (Figure 1).

The treatment, Ng, shows the traditional fertilization program in which 500 g N, 600 g $P_2O_5$, and 400 g $K_2O$ per tree were applied at the projection of the tree crown in February. $N_0$ irrigation was irrigated Ng treatment. The phosphorus and potassium fertilizers were injected at the same concentrations of 15 and 10 mg $l^{-1}$,

Table 1. Some physical and chemical characteristics of the experimental soil.

| Soil Depth cm | Soil Type | FC g/g | PWP g/g | Bulk density g $cm^{-3}$ | pH | Salt Content % | Lime % | Clay % | Sand % | Silt % |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-30 | C | 37.71 | 21.13 | 1.33 | 7.34 | 0.116 | 17.23 | 73.32 | 4.13 | 22.54 |
| 30-60 | C | 37.69 | 21.08 | 1.15 | 7.43 | 0.109 | 17.24 | 71.58 | 2.81 | 26.27 |
| 60-90 | C | 38.05 | 21.22 | 1.33 | 7.56 | 0.098 | 18.31 | 76.21 | 3.19 | 20.59 |
| 90-120 | C | 37.30 | 21.26 | 1.29 | 7.58 | 0.095 | 19.92 | 77.32 | 2.93 | 19.76 |
| 120-150 | C | 34.78 | 21.02 | 1.39 | 7.68 | 0.195 | 23.75 | 75.93 | 4.03 | 20.27 |

FC: Field Capacity
PWP: Permanent Wilting Point

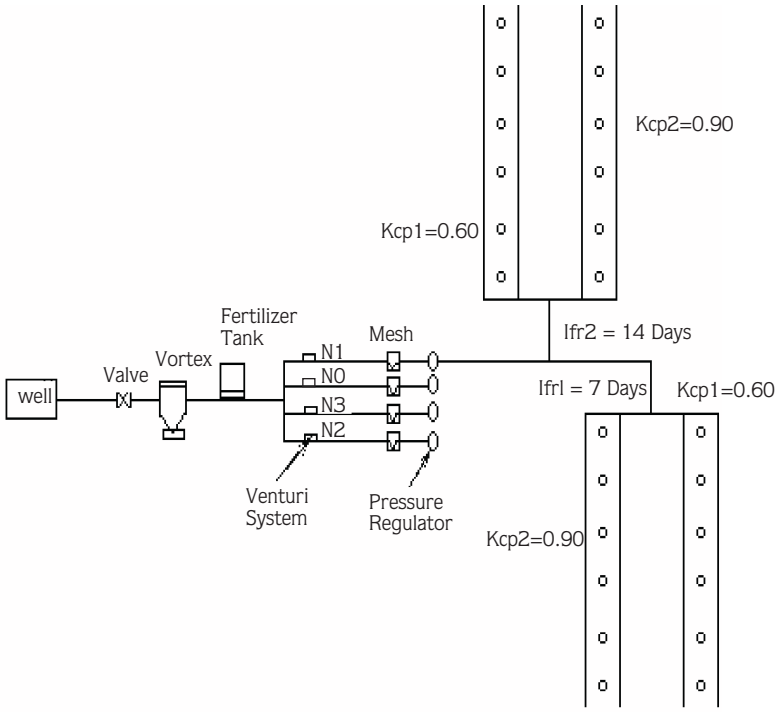


Figure 1. The fertigation system used in the pistachio experiment.

respectively, to all treatments at 2-week intervals except for the traditional treatment. For the treatment of $N_0$ only the phosphorus and potassium were injected into the irrigation water.

The experiment was in a split-split block design with 2 replications. The nitrogen contents, irrigation intervals and crop-pan coefficients were placed in the main plots, sub-plots, and sub-sub (mini) plots, respectively. Every mini plot had 8 to 10 trees and was 813 $m^2$ in area.

### Amount of Irrigation Water

The amount of irrigation water to be applied to the plots was calculated according to the free water surface evaporation measured from Class A-Pan during irrigation intervals with the following equation:

$$I = K_{pc} \times E_o \times C \quad (1)$$

where $K_{pc}$ is the coefficient related to crop and pan type, $E_o$ is the cumulative evaporation and C is the wetting percentage (30% is used). The wetted area was measured after irrigation events to control wetting percentage. An evaporation pan is placed on the bare soil at the central point of the 4 trees in the experimental orchard.

Nitrogen concentrations were prepared and applied using fertigation control units. Water with nitrogen was given directly to the trickle lateral lines that are placed on both sides of the trees.

### Actual Evapotranspiration

Actual evapotranspiration (crop ET) of the treatments was calculated using a water balance approach on a plot basis using Equation 2 (James, 1988):

$$ET_a = IR + P + C_p - D_p \pm R_f \pm \Delta S \quad (2)$$

where $ET_a$ is the actual evapotranspiration calculated for the wetted area, IR is the irrigation water applied to the plots, P is the rainfall, $C_p$ is the capillary rise, $D_p$ is the deep percolation, $R_f$ is the runoff going into or out of the plots and $\Delta S$ is the change of moisture content in the root depth. Irrigation water, rainfall and moisture content are measured and other components are assumed to be zero.

### Measurement of Soil Moisture Content

The moisture content of soil profile in the treatments was measured before and 1 day after irrigations. The moisture levels were also determined before the start of the growing period, which is the leaf freshening time, and at the end of the growing period, which is the leaf-

shedding time. Measurements were obtained by gravimetric methods using a 30 cm soil layer in the 120 cm soil profile.

### Harvest

Pistachio trees were harvested on September 7 and 11 in the experimental years of 2001 and 2002, respectively. Harvesting was after the irrigation season, which finished in September. All pistachio nuts were removed from the trees by hand to determine the gross yield of trees in each plot. Fruits, which reach the physiological maturity stage by having a reddish hull, were harvested by shaking the trees. All remaining nuts were picked by hand and separated from clusters.

## Results and Discussion

### Irrigation and Evapotranspiration

Irrigation dates and water amounts applied in the different treatments and other irrigation parameters are given in Tables 2 and 3. The irrigation period in 2001 begun on May 29 and ended at the harvest, which was on September 10, whereas it was between May 4 and September 10 in 2002. The irrigation treatments with 7-14 day intervals were irrigated 15 and 8 times, respectively, during both irrigation seasons. The total irrigation water varied depending on the irrigation interval and $K_{pc}$ values. The greatest water amounts were applied to treatments with 7-day intervals and 0.90 $K_{pc}$ with 907 and 837 mm, respectively for 2001 and 2002. All treatments received the highest amount of water in July. The minimum amounts were 324 mm (2001) and 311 mm (2002) for 14-day intervals with the coefficient of 0.60.

Seasonal evapotranspiration results of some selected treatments, which have received high and low water amounts including the traditional treatment, are given in Table 4. Compared to the traditional treatment, total water taken from the soil profile was higher in the irrigation treatments. The highest water taken from soil

Table 2. Amount of irrigation water given to treatments in 2001.

| | | Applied Irrigation Water Amount (mm) | | | |
|---|---|---|---|---|---|
| | | $I_{f1}$ = 7 days | | $I_{f2}$ = 14 days | |
| Irrigation Date | Evaporation (CAP) (mm) | $K_{cp1}$ = 0.6 Wetted Area, 244 $m^2$ | $K_{cp2}$ = 0.9 Wetted Area, 244 $m^2$ | $K_{cp1}$ = 0.6 Wetted Area, 244 $m^2$ | $K_{cp2}$ = 0.9 Wetted Area, 244 $m^2$ |
| 29.05.2001 | 64 | 39 | 39 | 39 | 39 |
| 05.06.2001 | 65 | 39 | 59 | | |
| 12.06.2001 | 62 | 37 | 56 | 37 | 56 |
| 19.06.2001 | 65 | 39 | 59 | | |
| 26.06.2001 | 75 | 45 | 67 | 45 | 67 |
| 03.07.2001 | 73 | 44 | 66 | | |
| 10.07.2001 | 75 | 45 | 67 | 45 | 67 |
| 17.07.2001 | 80 | 48 | 72 | | |
| 24.07.2001 | 84 | 50 | 75 | 50 | 75 |
| 31.07.2001 | 77 | 46 | 69 | | |
| 07.08.2001 | 64 | 38 | 57 | 38 | 57 |
| 14.08.2001 | 66 | 40 | 59 | | |
| 21.08.2001 | 57 | 34 | 52 | 34 | 52 |
| 28.08.2001 | 63 | 38 | 56 | | |
| 04.09.2001 | 60 | 36 | 54 | 36 | 54 |
| Total | 1030 | 618 | 907 | 324 | 467 |

CAP: Class A Pan Evaporation
$I_f$: Irrigation Interval
$K_{cp}$: Crop Pan Coefficient

Table 3. Amount of irrigation water given to treatments in 2002.

| | | Applied Irrigation Water Amount (mm) | | | |
|---|---|---|---|---|---|
| | | $I_{f1}$ = 7 days | | $I_{f2}$ = 14 days | |
| Irrigation Date | Evaporation (CAP) (mm) | $K_{cp1}$ = 0.6 Wetted Area, 244 $m^2$ | $K_{cp2}$ = 0.9 Wetted Area, 244 $m^2$ | $K_{cp1}$ = 0.6 Wetted Area, 244 $m^2$ | $K_{cp2}$ = 0.9 Wetted Area, 244 $m^2$ |
| 04.06.2002 | 58.2 | 58.2 | 58.2 | 58.2 | 58.2 |
| 11.06.2002 | 53.9 | 32.3 | 48.5 | | |
| 18.06.2002 | 60.9 | 36.5 | 54.8 | 36.5 | 54.8 |
| 25.06.2002 | 69.6 | 41.7 | 62.6 | | |
| 02.07.2002 | 69.6 | 41.7 | 62.6 | 41.7 | 62.6 |
| 09.07.2002 | 73.0 | 43.8 | 65.7 | | |
| 16.07.2002 | 57.4 | 34.4 | 51.6 | 34.4 | 51.6 |
| 23.07.2002 | 65.2 | 39.1 | 58.7 | | |
| 30.07.2002 | 73.0 | 43.8 | 65.7 | 43.8 | 65.7 |
| 06.08.2002 | 69.6 | 41.7 | 62.6 | | |
| 13.08.2002 | 60.9 | 36.5 | 54.8 | 36.5 | 54.8 |
| 20.08.2002 | 60.9 | 36.5 | 54.8 | | |
| 27.08.2002 | 52.2 | 31.3 | 47.0 | 31.3 | 47.0 |
| 03.09.2002 | 52.2 | 31.3 | 47.0 | | |
| 10.09.2002 | 47.0 | 28.2 | 42.3 | 28.2 | 42.3 |
| Total | 924 | 577 | 837 | 311 | 437 |

CAP: Class A Pan Evaporation
$I_f$: Irrigation Interval
$K_{cp}$: Crop Pan Coefficient

Table 4. Seasonal evapotranspiration for some treatments.

| Treatments | Soil Water ΔS mm | | Rainfall P mm | | Irrigation Water IR mm | | $ET_c$ (Wetted Area) | | $ET_c$ mm (Plot Area)*** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2001* | 2002** | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| $I_{f1}N_3K_{pc1}$ | 151 | 107 | 85 | 236 | 618 | 577 | 854 | 920 | 421 | 516 |
| $I_{f1}N_3K_{pc2}$ | 141 | 139 | 85 | 236 | 907 | 837 | 1133 | 1212 | 498 | 626 |
| $I_{f2}N_3K_{pc1}$ | 177 | 174 | 85 | 236 | 324 | 311 | 586 | 721 | 359 | 503 |
| $I_{f2}N_3K_{pc2}$ | 149 | 134 | 85 | 236 | 467 | 437 | 701 | 807 | 374 | 501 |
| Traditional | 154 | 139 | 85 | 236 | 0.0 | 0.0 | - | - | 239 | 375 |

* April 20-November 07/2001; ** March 18-November 26/2002; *** $ET_c$ in irrigated treatments was calculated by summation of rainfall, soil water and 30% of total irrigation water. $ET_c$: Crop Evapotranspiration

storage occurred in the less frequently irrigated treatments with about 20%. These results are in agreement with those of Kanber et al. (1993), reporting that water taken from soil storage increased with increasing irrigation frequency.

The greatest evapotranspiration value was in the treatments that were frequently irrigated and received more water, such as $I_{f1}K_{pc2}$. In 2001, evapotranspiration varied from 1133 to 586 mm for the wetted area except in the traditional treatments. Similarly, in 2002 the

maximum evapotranspiration was calculated in the treatment of $I_{f1}N_3K_{pc1}$ as 1212 mm for the wetted area. The minimum evapotranspiration value was in the $I_{f2}N_3K_{pc1}$ treatment with 721 mm.

There were significant differences in evapotranspiration among the irrigation treatments. In 2001 the reduction rate of ET for irrigation treatments varied between 25% for $I_{f1}N_3K_{pc1}$ and 48% for $I_{f2}N_3K_{pc1}$ as compared to $I_{f1}N_3K_{pc2}$. Similar results were found in 2002. There were 41 and 24% reductions in evapotranspiration in the $I_{f1}N_3K_{pc2}$ treatment compared to $I_{f2}N_3K_{pc1}$ and $I_{f1}N_3K_{pc1}$, respectively.

Evapotranspiration of pistachio nut was determined to be 803 mm by Kanber et al. (1993), 600 mm by Bilgel et al. (1999) and 1018 mm by Goldhamer et al. (1985). The differences between the evapotranspiration results could be attributed to the differences in the climate and soil characteristics of the experimental locations and in the irrigation methods used.

### Fertilizers

Results for fertilizer as a pure material applied to the treatments during the experimental years are shown in Tables 5 and 6.

The fertilizers varied depending on the irrigation interval and $K_{pc}$ coefficients. Fertilizer (N, P and K) amounts received by the treatments are higher than those in the traditional one. The maximum nitrogen amount was applied to treatment $I_{f1}N_3K_{pc2}$ with 18.1 g $m^{-2}$ (in 2001) and 15.9 g $m^{-2}$ (in 2002). The same amounts of phosphorus and potassium fertilizers were applied to all irrigated treatments except for the traditional one. These chemicals were given via irrigation at 2-week intervals when $I_{f1}$ and $I_{f2}$ treatments were irrigated together.

During the experimental years, the amount of P and K varied depending on the irrigation water applied to the treatments. In 2001, all pistachio trees received 4.9 g $m^{-2}$ of phosphorous and 3.2 g $m^{-2}$ of potassium while in 2002 these values decreased to 4.2 and 2.8 g $m^{-2}$.

Table 5. The amounts of fertilizers as pure elements (N, P and K) given to the treatments in 2001.

| Treatments | IR mm | N g $m^{-2}$ | N for Wetted Area g 244 $m^{-2}$ | P g $m^{-2}$ | P for Wetted Area g 244 $m^{-2}$ | K g $m^{-2}$ | K for Wetted Area g 244 $m^{-2}$ |
|---|---|---|---|---|---|---|---|
| $I_{f1}N_0K_{pc1}$ | 618 | 0.0 | 0.0 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_0K_{pc2}$ | 907 | 0.0 | 0.0 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_1K_{pc1}$ | 618 | 6.2 | 1512.8 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_1K_{pc2}$ | 907 | 9.1 | 2220.4 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_2K_{pc1}$ | 618 | 9.3 | 2269.2 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_2K_{pc2}$ | 907 | 13.6 | 3318.4 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_3K_{pc1}$ | 618 | 12.3 | 3001.2 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f1}N_3K_{pc2}$ | 907 | 18.1 | 4416.4 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_0K_{pc1}$ | 324 | 0.0 | 0.0 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_0K_{pc2}$ | 467 | 0.0 | 0.0 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_1K_{pc1}$ | 324 | 3.2 | 780.8 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_1K_{pc2}$ | 467 | 4.7 | 1146.8 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_2K_{pc1}$ | 324 | 4.9 | 1195.6 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_2K_{pc2}$ | 467 | 7.0 | 1708.0 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_3K_{pc1}$ | 324 | 6.5 | 1586.0 | 4.9 | 1195.6 | 3.2 | 780.8 |
| $I_{f2}N_3K_{pc2}$ | 467 | 9.3 | 2269.2 | 4.9 | 1195.6 | 3.2 | 780.8 |
| Traditional | 0.0 | - | 500.0* | - | 600.0* | - | 400.0* |

* per tree
IR: Applied Irrigation Water Amount
N: Nitrogen
P: Phosphorus
K: Potassium

Table 6. The amounts of fertilizers as pure elements (N, P and K) given to the treatments in 2002.

| Treatments | IR mm | N g $m^{-2}$ | N for Wetted Area g 244 $m^{-2}$ | P g $m^{-2}$ | P for Wetted Area g 244 $m^{-2}$ | K g $m^{-2}$ | K for Wetted Area g 244 $m^{-2}$ |
|---|---|---|---|---|---|---|---|
| $I_{f1}N_0K_{pc1}$ | 577 | 0.0 | 0.0 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_0K_{pc2}$ | 837 | 0.0 | 0.0 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_1K_{pc1}$ | 577 | 5.5 | 1342.0 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_1K_{pc2}$ | 837 | 7.9 | 1927.6 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_2K_{pc1}$ | 577 | 8.2 | 2000.8 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_2K_{pc2}$ | 837 | 11.9 | 2903.6 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_3K_{pc1}$ | 577 | 11.0 | 2684.0 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f1}N_3K_{pc2}$ | 837 | 15.9 | 3879.6 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_0K_{pc1}$ | 311 | 0.0 | 0.0 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_0K_{pc2}$ | 437 | 0.0 | 0.0 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_1K_{pc1}$ | 311 | 2.8 | 683.2 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_1K_{pc2}$ | 437 | 3.9 | 951.6 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_2K_{pc1}$ | 311 | 4.2 | 1024.8 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_2K_{pc2}$ | 437 | 5.9 | 1439.6 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_3K_{pc1}$ | 311 | 5.6 | 1366.4 | 4.2 | 1024.8 | 2.8 | 683.2 |
| $I_{f2}N_3K_{pc2}$ | 437 | 7.9 | 1927.6 | 4.2 | 1024.8 | 2.8 | 683.2 |
| Traditional | 0.0 | - | 500.0* | - | 600.0* | - | 400.0* |

* per tree
IR: Applied Irrigation Water Amount
N: Nitrogen
P: Phosphorus
K: Potassium

The fertilizers were applied at fixed doses to the traditional treatment according to the project. Nitrogen, phosphorous and potassium were given at 500, 600 and 400 g per tree at the beginning of February. The amounts of fertilizers given to the traditional treatment were higher than those of the irrigated treatments, except for treatment with the accepted maximum nitrogen.

Aydeniz (1990) reported that 20-40 g $m^{-2}$ nitrogen and phosphorus applications at least doubled the yield and decreased the periodicity. Tekin (1992) found that 5.5 g $m^{-2}$ nitrogen application under rainfed conditions resulted in a 50% yield increase. Furthermore, Tekin and Güzel (1993) pointed out that urea fertilization decreased the black-bud shedding but did not completely stop it. Kanber et al. (2003) reported that high nitrogen doses applied by fertigation resulted in no deep percolation but there was about 39% nitrogen loss. The nitrogen loss in this study could be attributed to reasons similar to those given by Kanber et al. (2003).

### Yield

The average oven-dry yields for the experimental treatments for both years are shown in Tables 7 and 8. Differences in yields from irrigation and nitrogen interaction are statistically significant at 0.05 levels. From the LSD test all treatments show 3 statistical yield groups (a, b, and c as seen in Table 7). The maximum yields were taken from $I_{f2}N_3$ with an average 11.7 kg per tree in 2001. Then traditional and $I_{f2}N_3$ treatments were compared using the t test. For this purpose 10 trees were used. There were differences between the two treatments at 0.05 significance, indicating that irrigation increased the pistachio yield by about 67% compared to the traditional practice.

For 2002, pistachio oven-dry yield per tree is shown in Table 8. According to the statistical analysis, there are no significant differences between the treatments. The small differences between the treatments may be a coincidence. The highest yield was obtained from $I_{f1}N_0$

Table 7. Pistachio yield (oven dry) from treatments in 2001.

| Treatments | Replications | | Average kg per tree | Statistical Groups* |
|---|---|---|---|---|
| | $R_1$ | $R_2$ | | |
| $I_{f1}N_3K_{pc1}$ | 4.3 | 9.2 | 6.8 | b |
| $I_{f1}N_3K_{pc2}$ | 4.1 | 7.1 | 5.6 | b |
| $I_{f1}N_2K_{pc1}$ | 10.30 | 12.70 | 11.5 | a |
| $I_{f1}N_2K_{pc2}$ | 8.66 | 13.04 | 10.9 | a |
| $I_{f1}N_1K_{pc1}$ | 10.80 | 9.08 | 9.9 | ab |
| $I_{f1}N_1K_{pc2}$ | 10.40 | 9.73 | 10.1 | ab |
| $I_{f1}N_0K_{pc1}$ | 4.85 | 14.62 | 9.7 | ab |
| $I_{f1}N_0K_{pc2}$ | 8.20 | 9.73 | 9.0 | ab |
| $I_{f2}N_3K_{pc1}$ | 8.80 | 12.30 | 10.6 | a |
| $I_{f2}N_3K_{pc2}$ | 11.00 | 14.70 | 12.9 | a |
| $I_{f2}N_2K_{pc1}$ | 9.97 | 8.01 | 9.0 | ab |
| $I_{f2}N_2K_{pc2}$ | 4.97 | 6.64 | 5.8 | b |
| $I_{f2}N_1K_{pc1}$ | 6.96 | 14.46 | 10.7 | a |
| $I_{f2}N_1K_{pc2}$ | 14.7 | 7.35 | 11.0 | a |
| $I_{f2}N_0K_{pc1}$ | 8.10 | 10.90 | 9.5 | ab |
| $I_{f2}N_0K_{pc2}$ | 7.30 | 9.70 | 8.5 | ab |
| $Sx_1$ | 1.21 | | | |
| $Sx_2$ | 1.51 | | | |
| $I_{f2}N_3$ | | | 11.7 | a |
| Traditional** | | | 7.0 | b |
| $t_{0.05} \geq 2.26$ | | | t = 3.3 | |

* Treatments marked with the same letter are in the same group at the $P \leq 0.05$ level.
** Mach analysis

Table 8. Pistachio yield (oven dry) from treatments in 2002.

| Treatments | Replications | | Average kg per tree | % Yield |
|---|---|---|---|---|
| | $R_1$ | $R_2$ | | |
| $I_{f1}N_3K_{pc1}$ | 11.29 | 1.86 | 6.58 | 49 |
| $I_{f1}N_3K_{pc2}$ | 14.38 | 2.73 | 8.56 | 64 |
| $I_{f1}N_2K_{pc1}$ | 5.86 | 2.65 | 4.26 | 32 |
| $I_{f1}N_2K_{pc2}$ | 2.68 | 3.75 | 3.22 | 24 |
| $I_{f1}N_1K_{pc1}$ | 4.80 | 3.62 | 4.21 | 31 |
| $I_{f1}N_1K_{pc2}$ | 2.62 | 4.52 | 3.57 | 27 |
| $I_{f1}N_0K_{pc1}$ | 21.13 | 5.63 | 13.38 | 100 |
| $I_{f1}N_0K_{pc2}$ | 14.74 | 5.06 | 9.90 | 74 |
| $I_{f2}N_3K_{pc1}$ | 2.04 | 3.27 | 2.66 | 20 |
| $I_{f2}N_3K_{pc2}$ | 4.41 | 2.59 | 3.50 | 26 |
| $I_{f2}N_2K_{pc1}$ | 8.85 | 4.03 | 6.44 | 48 |
| $I_{f2}N_2K_{pc2}$ | 11.41 | 2.44 | 6.93 | 52 |
| $I_{f2}N_1K_{pc1}$ | 9.68 | 2.02 | 5.85 | 44 |
| $I_{f2}N_1K_{pc2}$ | 4.61 | 1.23 | 2.92 | 22 |
| $I_{f2}N_0K_{pc1}$ | 4.03 | 1.37 | 2.70 | 20 |
| $I_{f2}N_0K_{pc2}$ | 4.64 | 2.15 | 3.40 | 25 |
| $Sx_1$ | 4.14 | For irrigation intervals at the same nitrogen content | | |
| $Sx_2$ | 1.51 | For irrigation intervals at the same and different nitrogen content | | |
| Traditional | | | 2.53 | 19 |

with an average of 11.6 kg per tree. Irrigation increased the pistachio yield by about 81% compared to the traditional one, which received all fertilizers without irrigation.

In general, pistachio yields in irrigated and fertilized treatments were considerably greater than those in the traditional (fertilized, non-irrigated) treatment. The results of the study indicated that nitrogen generally increased the yield although water seemed to have a greater effect on yield than did nitrogen. Similar conclusions were reported by Goldhamer et al. (1985) and Kanber et al. (1990).

## Conclusions

From the results obtained in the experimental years the following conclusions can be drawn. Pistachio trees seem to respond to irrigation and nitrogen application. Although 2001 was an off-yielding year trees produced yield. This result is attributed to irrigation and fertigation effects in reducing the influence of periodicity. In 2002 (on-yielding year) there were no statistically significant differences among the irrigated treatments. The maximum nitrogen amount was applied to treatment $I_{f1}N_3K_{pc2}$ with 4.4 and 3.9 kg for wetted area among irrigated treatments in the experimental years, respectively. During the experimental years, the amount of P and K varied depending on the irrigation water applied to the treatments. In 2001, all pistachio trees received 4.9 and 3.2 g $m^{-2}$ phosphorous and potassium while in 2002 these values decreased to 4.2 and 2.8 g $m^{-2}$. The maximum yields were taken from $I_{f2}N_3$ with an average 11.7 kg per tree in 2001 and from $I_{f1}N_0$ with an average 11.6 kg per tree in 2002.

Our statistical analysis indicated that pistachio yield increased with appropriate irrigation and fertigation scheduling in the off-yielding year. However, in the on-yielding year, no effects of irrigation and nitrogen on the yield were evident.

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