Irrigation and irrigation management strategies of pistachio orchards

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SUMMARY – Irrigation is a required management practice in pistachio nut production for higher quality and quantity. A proper irrigation management technique that maintains an optimum soil moisture and environment in the root zone increases yield of the pistachio nut tree. Since pistachio tree on the *Pistacia vera* rootstock does not tolerate excess water in the root zone, over-irrigation must be avoided. In the determination of water requirement of pistachio tree, pan evaporation is commonly used due to its simplicity. However, development and use of a stochastic evapotranspiration model involves solar radiation, vapour pressure deficit and leaf area index and can be a more accurate solution in the irrigation of the pistachio orchard. General principles of irrigation and irrigation management of pistachio nut trees were given in this study.

Key words: Irrigation, irrigation management, pistachio orchard, evapotranspiration.

RESUME – *"Irrigation et stratégies de gestion de l'irrigation des vergers de pistachiers". L'irrigation est une pratique de gestion nécessaire pour la production de pistaches, afin d'obtenir une meilleure qualité et quantité. Une technique de gestion de l'irrigation appropriée qui maintienne une humidité optimale du sol et de l'environnement dans la zone des racines augmente le rendement des pistachiers. Etant donné que les pistachiers sur porte-greffe* Pistacia vera *ne tolèrent pas un excès d'eau dans la zone des racines, il faut éviter l'irrigation excessive. Dans la détermination des besoins en eau du pistachier, l'évaporation à partir d'une casserole est couramment utilisée en raison de sa simplicité. Cependant, la mise au point et l'utilisation d'un modèle stochastique d'évapotranspiration fait intervenir le rayonnement solaire, le déficit de pression de vapeur et l'indice de surface foliaire et peut être une solution plus précise pour l'irrigation des vergers de pistachiers. Les principes généraux de l'irrigation et la gestion de l'irrigation des pistachiers ont été présentés dans cette étude.*

Mots-clés : *Irrigation, gestion de l'irrigation, vergers de pistachiers, evapotranspiration.*

Introduction

James (1993) stated that between 60 and 95% of living plant biomass is water. Although plants need water primarily for transpiration, it also require water for other processes including photosynthesis, transport of minerals, structural support and growth.

Pistachio nut tree is one of the crops which have drought tolerance. But, it dose not mean that pistachio trees require less water for optimal performance. The drought tolerance of the pistachio refers to its ability to survive under severe water stress conditions. Indeed, studies conducted in this area showed that proper irrigation especially during summer months increased productivity of the pistachio nut tree (Goldhamer, 1995).

A proper irrigation or irrigation scheduling must be based on quantitative knowledge of tree water requirement and relationships among soil, weather and plant characteristics. While planning an irrigation scheduling, we should consider growth stages and age of the tree. For example, irrigation requirement during full bloom is normally minimal. As spring advances, faster shoot and fruit growth rates lead to full canopy development and thus increasing irrigation requirement. The stage of fruit bud development is very sensitive to water deficit. Furthermore, deficit irrigation techniques should never been applied for young pistachio orchard (Tekinel and Yazar, 1988).

Although pistachio trees tolerate drought, commercial nut production requires adequate soil moisture, particularly late winter, spring and early summer. Pistachio trees do not tolerate ponding water originated from over-irrigation or high water table (Woodroof, 1982). In this study, basic principles of irrigation and previous application of irrigation with respect to pistachio nut tree were investigated.

Evapotranspiration and water requirements

Evapotranspiration (ET) is a basis in the determination of the water requirement of the pistachio tree like any other plant. Therefore, ET process should be understood well for a correct estimation of water requirement. ET loss from orchards is the combined total amount of water lost via transpiration and evaporation from the soil and tree surfaces. Evaporation occurs from all open surfaces whenever there is sufficient energy for latent heat of vapourization. Transpiration involves movement of water from soil into tree roots, transport of the water through stems into leaves, and evaporation of the water from leaves into the atmosphere. Because it is difficult to determine each loss rate precisely and because larger plants (trees) lose water mostly by transpiration, they are generally grouped together as ET (Nokes, 1995; Keach, 1998). Figure 1 shows a schematic representation of the ET process.

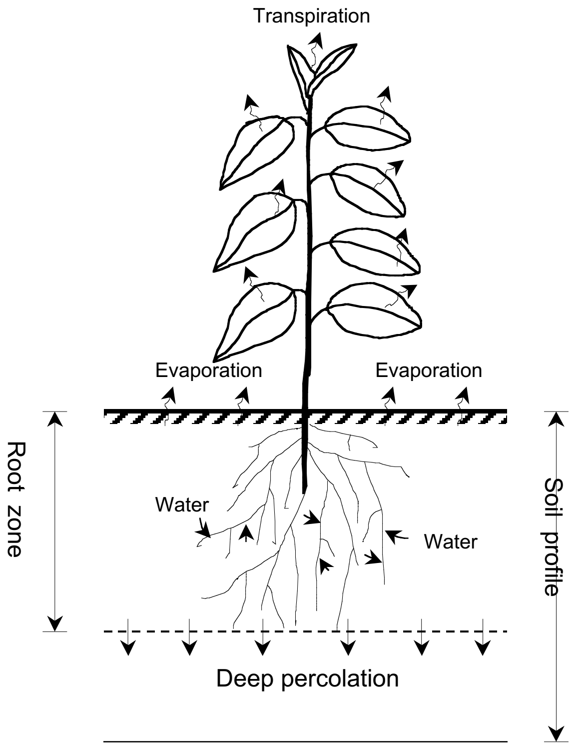

Fig. 1. Schematic representation of the evapotranspiration process.

Two essential components for ET to occur are latent heat of vapourization and a vapour pressure gradient. Transpiration is generally favourable to trees since it aids in absorption and transport of mineral nutrients; it also cools the leaves during radiant periods due to latent heat of vapourization. Too much transpiration can result in stress and most trees have mechanisms for diminishing transpiration when necessary, including reduction in leaf area by rolling of leaves or by changing leaf orientation to reduce intercepted solar radiation (Kramer, 1987).

Transpiration, however, is affected more by the meteorological conditions than by plant characteristics. Transpiration losses from the pistachio orchards are directly related to solar radiation intercepted by tree foliage and thus, canopy size and shape (Kirnak, 1998).

ET is a very complex process because there is always a dynamic interaction among the plant, the soil and the atmosphere, which in turn affect this process. The plant requires water for growth, the soil stores the water, and the atmosphere provides the energy required by the plant to withdraw water from the soil (James, 1993; Schwab *et al.*, 1993).

ET losses from orchards are influenced primarily by micrometeorological, plant, and soil factors. The portion of the water inside the soil that the tree can use is termed available water (AW). The available water content is the difference between the permanent wilting point (PWP), lower limit of moisture and field capacity (FC), upper limit of moisture. In general, the matric potential of soil water at the PWP is 15 bars, and that of FC is 1/10-1/3 bars. In order to prevent plant water stress, the soil moisture content should never drop under PWP or increase above FC. Although pistachio trees do not visibly wilt, the PWP is also a significant term for them (Hillel, 1982; Brady, 1990; Goldhamer, 1995).

Spiegel-Roy *et al.* (1977) conducted a study to determine response of pistachio to low moisture conditions. According to the study results, moisture level was dropped to PWP and yield reduction was not observed under severe water stress for mature pistachio orchard.

Although pistachio trees tolerate a wide range of soil types, a deep, fertile, and well-drained soil is recommended for the best growth (Goldhamer, 1995). Water holding capacity or AW is affected by soil type. Coarse sandy soils hold less water than fine clay soils. Accordingly, required irrigation frequencies for coarse soils are greater than for fine soils. There is generally more water available for plants in fine soils, but they hold water very tightly (Jury *et al.*, 1991).

Since the ET process is very complex, researchers simplified it by defining potential and actual ET. Actual ET occurs under ambient environmental conditions and can be limited by low soil moisture availability. Potential ET, on the other hand, is the amount of ET that would occur if soil moisture is not a limiting factor (Jensen *et al.*, 1990; Schwab *et al.*, 1993).

Leaf water potential ( ) is not used as a tree water status indicator since leaf water potential is influenced by many variables other than soil water supply such as evaporative demand, stomatal conductance, hydraulic resistance to water flow. Leaf water potential is generally used to indicate the direction of water flow in the tree. However, leaf water potential has proven its usefulness as a reliable indicator of tree water stress in the pistachio nut (Tekinel and Yazar, 1988).

In order to measure actual ET from trees, many methods have been developed. These methods can be divided into two main categories. First, simple, inexpensive methods include soil water depletion and water balance methods. They are labour intensive and spatial and temporal variability of soil characteristics can create sampling errors. Second, a more precise, but also more expensive method is the lysimeter technique (Kirnak, 1998).

Irrigation requirement in water budget technique is determined subtracting ET from total of effective rainfall and irrigation system losses. The most common method of predicting water loss from the trees has been pan evaporation approach. However, there are many concerns about the accuracy and relevance of the pan evaporation since the environmental conditions around a pan can not represent the environment around a tree canopy. On the other hand, since pan evaporation approaches provides a simplicity for the determination of water requirement of the trees, class A-Pan is widely used for this purpose (Kirnak, 1998).

Besides direct measurement of ET, there are many different approaches to estimating ET indirectly from empirical or physically-based models using easily obtained meteorological data (Wright and Jensen, 1978). The empirical approach uses statistics to identify correlations between input parameters and transpiration rate of the tree. The weakness of this approach is that empirical formulae developed for a specific region during a specific time period may not always be used accurately for other time periods and regions. Using energy balance, physically-based models typically provides a more comprehensive estimate of transpiration from orchards. The disadvantages of the physically-based models are that they have extensive data requirements that are often unavailable (Linacre, 1977).

When there is sufficient water in the soil and stomata are fully open, atmospheric conditions control the transpiration rate of the tree. The most important environmental factors affecting the transpiration rate in the orchard are ambient temperature, humidity, solar radiation intercepted by canopy foliage, and wind speed (Oke, 1987).

One of the important characteristics of plant canopy structure is Leaf Area Index (LAI). It is a critical value to achieve an accurate estimation of the ET. LAI is defined as the ratio between total leaf area and horizontally projected plant canopy area. There was a high correlation between LAI vs ET and LAI vs crop coefficient. Crop coefficient is a dimensionless ratio used to relate potential ET to actual ET for a specific plant at a specific time (Kirnak, 1998). Developing a stochastic ET model based on solar radiation and/or vapour pressure deficit can be very practical solution in the calculation of pistachio nut tree ET.

Most approaches computing pistachio tree ET involve the following equation:

$$ET = K_c \quad ET_0 \qquad [1]$$

where: K_c = crop coefficient, ET_0 = reference or potential ET. Many researchers used E_0 (pan evaporation) instead of ET_0 to determine ET for simplicity.

Since ET from nut trees is mainly controlled by transpiration, use of ET_0 or E_0 can not be appropriate. In the measurement of ET from orchards, climatological conditions (vapour pressure deficit, solar radiation, etc.) and canopy characteristics (especially stomatal conductance and LAI) should be considered for correct estimation of ET. According to Doorenbos and Pruitt (1977), K_c values of pistachio in the midseason can go up 1.10-1.20. In the determination of the crop coefficient for pistachio, the age, height and canopy architecture should be evaluated carefully because of dominant effects of windspeed and boundary layer conductance in orchard.

Monastra *et al.* (1995) studied the effects of different volumes of irrigation influence on vegetative growth, ripening, production, and dehiscence of the fruit. Irrigation volume was determined using equation 1. They concluded that the pistachio was positively influenced from irrigation in regards to its vegetative growth and commercially bearing. Besides, irrigation accelerated trunk development, LAI, and the number of inflorescence on the shoots. They concluded that watering effects appear early in the ripening and increase the number of inflorescences per tree but the number of fruit per inflorescence is negatively influenced by high volume irrigation.

As the soil dries down from the field capacity, the rate of absorption of the water is reduced due to increased resistance to water movement in the soil and within the tree as well as loss of soil-root contact. Poor soil aeration decreases water absorption by inhibiting root growth, inducing decay of roots, and suppressing development of mycorrhizae. Low soil temperature reduces absorption of water by decreasing the permeability of roots, increasing viscosity of water, and inhibiting root growth. High concentration of salts and fertilizers in the soil solution may also reduce absorption of water by osmotic effects (Kozlowski, 1987). Even if there is an available moisture in the soil profile, nut trees can not use it unless the environment conditions around the root such as aeration, temperature, concentration of salts and fertilizers are suitable.

Sepaskhah and Maftoun (1981) conducted a study to determine the potential use of saline water for pistachio nut production under greenhouse conditions. At the 4.5 mmhos/cm salinity level, an average of 38% reduction in the growth was observed with a 7-day irrigation interval. Under wet irrigation regimes the reduction in shoot growth occurred at the electrical conductivity of soil saturation extract of 12.5 mmhos/cm.

Sepaskhah and Maftoun (1982) studied the effects of irrigation intervals and salinity levels of irrigation water on the chemical composition of pistachio under the greenhouse conditions and concluded that irrigation interval and salinity level influenced the uptake and distribution of various nutrients in pistachio nut trees. Increasing in the salinity level of irrigation water increased the accumulation of Cl and Na ions. This ion accumulation was less when irrigation interval (3 days) was less. Increasing salinity level of water had no define effects on N, P, K, Ca and Mg contents.

Irrigation scheduling

A rapidly growing population is placing increasing demands on the earth's limited resources. Of those resources, water is fundamentally important because it is essential for all life. A significant portion of the water consumed in the world is used for irrigation. Conservation of water resources is especially vital in arid and semi-arid regions.

Irrigation scheduling methods used in nut trees are generally based on either monitoring soil and/or plant water status or predicting water depletion in the root zone. In general, the success of agriculture is totally dependent on irrigation, even in humid areas. Water is a limited resource that has to be managed intelligently. Irrigation scheduling is a decision-making process to determine the timing and quantity of water applications based on soil, plant and weather information (Kirnak, 1998).

Improper scheduling of irrigation results in either under-irrigation or over-irrigation. Under-irrigation reduces growth and yield, whereas over-irrigation can cause root rot, salinization, leaching of nutrients and pesticides, and ground water degradation. In order to eliminate negative effect of salinity, extra water besides irrigation requirement should be applied to leach the salts away from the root zone. Monitoring the salinity levels in the soil profile should be done periodically if irrigation water quality is poor.

Kirnak (1998) pointed out that efficient irrigation is the art of providing water to plants exactly when they need it and in the correct quantities. Efficient irrigation often requires a relatively high investment, but can offer a significant increase in net income for farmers. Efficient irrigation scheduling and optimum crop production requires the determination of soil moisture conditions in the root zone frequently and correctly.

Tensiometers are the most commonly used sensors for measuring soil water status and they are relatively cheap and practical sensors compared to gypsum blocks, neutron probe, TDR (time domain reflectometry) or other types of soil matric potential sensors. It is better to measure the soil-tension at two different depths. It should be noted that tensiometers show soil-water matric potential not total soil-water potential. Tensiometers cannot measure the full range of soil tension values. Ceramic porous cup tensiometers can measure values of soil water matric potential up to 80-85 kPa whereas dry soils can reach values up to 1500 kPa. Use of the tensiometers for irrigation scheduling would be more useful in coarse textured soils than in fine textured soils since the coarse textured soils holds the water at a tension less than 80 kPa. The soil tension represents how tightly water is held by soil particles. High-tension values mean that water is held very tightly, and low-tension values mean that water is held very loosely by soil (Harrison and Tyson, 1993; Tamari *et al.*, 1993).

The major limitation of the use of soil sensors is the spatial variation in soil water status and uncertainty of the root distribution in the nut trees. Once a representative location identifies, tensiometer provides an effective irrigation scheduling. It should be noted that tensiometer answers the question when we should irrigate the nut tree. The question about how much water must be applied to orchard is answered by either measuring ET (lysimeter) or predicting ET.

If the water is limited, regulated deficit irrigation scheduling approach can be used to save water while having a minimal impact of sustained tree productivity. Goldhamer (1993) conducted a research to evaluate influence of deficit irrigation on mature pistachio nut tree and concluded that mature trees were tolerant of water stress between the time the shell has expanded and the initiation of rapid kernel growth. A 50% of water reduction can be done during this period. On the other hand, tree water stress should be avoided during the time close the harvesting because it would reduce shell splitting and ease of nut removal at the harvest. Growers should be avoided stressing an immature tree and the trees at leaf development stage. Pistachio growers can save as much as 25% water and a substantial amount of money by using deficit irrigation technique.

Metheney *et al.* (1996) investigated the potential use of drainage water for irrigation of mature pistachio orchards and concluded that drainage water with ECw of 8 dS/m can be used for one season's irrigation without decreasing tree growth and yield. However, data trends showed that use of drainage water for two sequential years could affect growth and yield.

Michailides and Morgan (1991) stated that an intelligent irrigation management technique could help control the disease in the pistachio orchard effectively. MacDonald *et al.* (1992) investigated effect of the different irrigation system and frequency of water application on root distribution and likelihood of infection in young pistachio orchard. Results showed that root length density and microsclerotial populations under the microsprinkler irrigation were higher according to the drip irrigation system. Hence, probability of root infection was higher under the microsprinkler irrigation. The differences in the numbers of microsclerotia might be related to differences in surface wetting and extent of weed growth.

Irrigation methods for pistachio orchard

A good water management involves distinct decisions respecting the various elements of irrigating to achieve maximum returns from the use of water on a crop. Irrigation water management calls for maximising application efficiency, and the ability to apply the water uniformly. Application uniformity and loss of water are two main elements of irrigation efficiency. System design and maintenance affect the uniformity predominantly. Poor uniformity of distribution or excessive water loss will result in poor irrigation efficiency. Application of more water than ET rate of the nut tree results in water loss. Over-irrigation can reduce yields, leach out necessary nutrients and fertilizers, and require investment into tailwater recovery or drainage systems. The excess water not lost via deep percolation will run off the field so that non point source pollution (NPS) occurs as an environmental problem.

There are two practical irrigation methods for pistachio orchard irrigation. They are first, a traditional method called surface irrigation and second, pressurized irrigation systems. Besides these two methods, an automated irrigation scheduling technique based on a feedback control for both microirrigation and surface irrigation methods can be used to promote irrigation management strategies of the pistachio orchard.

Pressurized irrigation systems

Pressurized irrigation systems for pistachio orchard includes portable or permanent sprinkler, microsprinkler and drip irrigation systems. Precise delivery of water, nutrients and chemicals to a plant's root zone is the trademark of microirrigation. Unlike conventional surface irrigation, microirrigation ensures that each tree receives the same amount of water and nutrients in both hilly and flat terrain. As a result, most growers achieve high distribution uniformity over various terrain and run lengths, which can maximize production and profits, and reduce labour costs. Growers also conserve a significant amount of water. Water delivery from pressurized irrigation systems is more easily controlled than from systems using surface irrigation system.

Microirrigation allows you to produce very high yields of quality product with very little water. Since nut quality such as shell split, shell staining and kernel decay is critical factors in marketing tree fruit, many growers in the world use microirrigation technique to obtain a high quality nut. Microsprinklers can be installed under trees to promote growth, over trees to promote cooling, and in or above trees to offer frost protection. Also, microirrigation system is well-suited to fertigation which increases the effectiveness of the irrigation management markedly (Oostenbrink, 1998).

Surface irrigation systems

Most of the pistachio orchards have been irrigated by one of the surface methods (furrow, basin or border) since first investment cost of surface irrigation method is low compared to pressurized systems. Basin irrigation is commonly applied around the world. Basins varying in size from a single tree to over 0.4 ha are filled water by either a pressurized pipe placed under the soil or over the soil or a surface irrigation method. On the other hand, border irrigation requires a high instantaneous flow rate. Water is delivered to furrows through siphons over the ditch or through plastic or aluminium gated pipe. With furrow irrigation, only a fraction of the soil surface (20-40%) are wetted (Hoffman *et al.*, 1983). Especially, in the design of the surface irrigation system, soil hydraulic characteristics (infiltration and hydraulic conductivity) become very important planning criteria. The soil infiltration rate controls the amount of water infiltrated into soil. If the soil infiltration rate is so low that surface irrigation method can not be applied, soil management practices besides irrigation should be promoted to increase infiltration rate.

Conclusion

As goal of the irrigation management is to obtain high productivity without compromising the environment, a good irrigation management strategies for pistachio orchard consists of determining when to irrigate, the amount to apply at each irrigation and during each stage of the tree growth. Since the trees loose water mostly trough transpiration process and microclimatological and plant features are dominant factors in the determination of the water consumption of the pistachio orchard, a stochastic ET model involves solar radiation, vapour pressure deficit and LAI should be used for accurate estimation of the irrigation requirement. In the water management of the pistachio orchard, excess irrigation and high water table should be prevented since they reduce yield and cause some diseases.

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