Production and Marketing Report

Water Management in Irrigated Pecan Orchards in the Southwestern United States

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Additional index words. irrigation, drainage, stress physiology

Summary. Irrigated production of pecans in the southwestern United States started with notoriously inefficient flood irrigation along river basins. Today, most surface-irrigated orchards are laser-leveled, and many orchards in upland areas are under sprinkler or drip irrigation. Technical and scientific knowledge for improving water management also has evolved from studying drought effects on tree performance to an improved understanding of water relations, salt effects, evapotranspiration processes, and the distribution of water and salts in irrigated fields. Yet, many growers still experience difficulties with water management and may benefit from maintaining the soil water suction above saturation but below 30 to 40 cb until shuck opening. The soil salinity should be kept below 2.5 dS·m^{-1}, and irrigation water should be applied to essentially the entire root zone for optimum tree growth. Due to extreme soil variability existing in most irrigated fields of the southwestern region, these guidelines alone are not adequate. Soil profiles, root distributions, water quality, and irrigation methods may have to be examined to improve water management.

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This research was conducted at the Texas A&M Univ. at El Paso. Use of trade names does not imply endorsement of the products named nor criticism of similar ones not named. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact,

Irrigated production of pecans in the southwestern United States started with 'notoriously inefficient flood irrigation along river basins. As pecan plantings expanded to pump-irrigated upland areas, growers' interest in water management increased, mainly to contain irrigation costs. Desire to reduce irrigation labor and improve water-use efficiency and nut production then led to the introduction of laser leveling in surface-irrigated areas and sprinkler and drip irrigation in pump-irrigated areas. Technical and scientific bases for improving water management also have evolved from classic studies of drought effects on pecan trees to an improved understanding of water relations, salt effects, evapotranspiration, and the distribution of water and salts in irrigated fields. The purpose of this paper is to outline the advancements made in water management for pecans in irrigated areas of the southwestern region and provide some guidelines for improving water management.

Consumptive use

The evapotranspirational loss of water from an orchard (commonly referred to as consumptive use) is the basis for estimating irrigation water needs and scheduling irrigation, Significant progress was made in this topic through field studies in El Paso Valley, Texas (Miyamoto, 1982, 1983, 1985), and lysimeter studies in Stephenville, Texas (Worthington et al., 1986), These studies show that the summer peak consumptive use of mature and crowded orchards under surface irrigation is about equal to pan evaporation rates. This means that growers in far western Texas and southern New Mexico must anticipate a water need of 1.2 cm/day, or 13,000 gallons/day per acre at maturity. The annual consumptive use in crowded orchards can reach up to 130 cm, but fluctuates yearly as the atmospheric evaporative demand fluctuates (Miyamoto, 1983).

The consumptive use of trees before maturity depends on tree size, spacing, and leaf devel-

Table 1. ***Monthly pan evaporation and monthly evapotranspiration of pecan orchards with different trunk diameters (d) and tree densities (N) in the El Paso Valley, Texas (Miyamoto, 1983, 1984).***

	April	May	June	July	August	September	October	Seasonal use
				cm/day				(cm)
Pan evaporation	1.00	1.10	1.17	1.12	0.91	0.74	0.28	192
Evapotranspiration [z]								
Index[y]								
1500	0.14	0.20	0.31	0.35	0.33	0.26	0.19	51
2000	0.17	0.25	0.41	0.50	0.48	0.38	0.14	71
3000	0,22	0.34	0.60	0.77	0.74	0.62	0.23	107
4000	0.23	0.38	0.75	0.89	0.86	0.74	0.27	125

[z]*These values are for surface-irrigated orchards, and can vary with irrigation regimes to be used.*

[y]*These indices are the product of trunk diameter (d) in cm and the number of trees/ha (N). If d and N are expressed in inches and no./acre, multiply 6.23 to convert to the product to metric units.*

opment, and it maybe estimated by an empirical equation (Miyamoto, 1983, 1984). Table 1 shows examples of typical daily consumptive use in surface-irrigated pecan orchards of trees with trunk diameter d (cm) and a tree population density N (no./ha) under the climatic condition of El Paso (Miyamoto, 1983). Actual consumption may vary depending on weather conditions of a particular year, soil moisture regimes or irrigation frequencies used, and the extent of wetted area or weeds (Miyamoto, 1984). In warm climates, the consumptive use in April, May, September, and October would be somewhat higher than the listed values. Unless a major early freeze occurs, pecan leaves transpire water well into September and October, but at decreasing rates (Miyamoto, 1983).

Water-quality considerations

Most irrigation water in the pecan-producing areas of the southwestern region contains 500 to 1500 ppm of dissolved salts, This means that 5 to 15 tons of salts/ha are carried into the orchard annually, and these salts must be leached, If salts accumulate in excess of about 2.5 $dS \cdot m^{-1}$ in the saturation extract, tree growth, nut development, and nut filling will be deterred (Miyamoto et al., 1985, 1986a, 1986b). When salinity reaches 6 to 8 $dS \cdot m^{-1}$ in the saturation extract, tree mortality can also occur (Miyamoto and Gobran, 1983), Soils for irrigated production must be permeable, The requirements to leach excess salts demand water-management strategies different from those for supplemental irrigation areas.

The suitability of water for pecan irrigation must be examined considering the potential for salt leaching. In well-drained sandy soils, water containing 1500 ppm of dissolved salts is used successfully, while in clay soils with low permeability, water containing 1000 ppm can cause extensive salt damage (Miyamoto, 1991), Irrigation water having a sodium adsorption ratio (SAR) >5 or those containing boron in excess of 1 ppm are difficult to manage unless the soil is highly permeable (Miyamoto, 1991; Picchioni et al., 1991), 'Wichita' is especially sensitive to boron (Picchioni et al., 1991), When irrigation water supplies from river irrigation projects are curtailed, growers may have to supplement through pumping shallow saline groundwater. Saline water containing 2000 to 3000 ppm of dissolved salts may be used temporarily in sandy soils with high permeability, but should not be used in clay soils, ing irrigation. As indicated earlier, pecan trees are sensitive to salt stress and show leaf-tip burn, usually starting in late summer and progressing into September and October. This pattern of leaf-tip-burn development is usually a symptom of progressive salt accumulation in leaf tissue and is compounded by a sharp increase in salt concentration of the soil solution induced by soil water depletion, especially in sandy soils. It is possible that irrigation water should be applied earlier than that practiced under nonsaline conditions and that the termination dates should be set later under saline conditions. Research into salt effects on transpiration and photosynthesis rates will provide a rational basis to answer this question. In addition, there are some indications that sodium transport to leaves is limited, and sodium may directly harm roots (Miyamoto et al., 1986a).

Irrigation timing, depths, and coverage

Pecan tree-trunk growth is ordinarily not adversely affected if irrigation begins before the soil water suction in the main root zone reaches 1 to 2 bars (e.g., Miyamoto, 1985), However, shoot growth, nut development, nut filling, and shuck opening can be adversely affected at much lower water-stress levels (Finch and van Horn, 1936; Woodruff, 1930; Zertuche, 1982), Nut drop and nut germination (vivipary) can be aggravated by water stress (Sparks, 1989; Zertuche, 1982), and the rate of photosynthesis is also reduced by water stress (Mielke, 1981). In general, early stress (April-May) tends to reduce shoot growth, stress in mid-summer (July–August) can reduce nut size and photosynthesis, and late-season stress (September-October) reduces nut-filling and shuck opening, However, the exact soil water-suction levels that induce these problems have not been quantified adequately and are likely to be affected by weather and nut loads. Productive orchards are usually managed by initiating irrigation at 30 to 40 cb in the main root zone and by maintaining this level of moisture well into shuck opening, which usually occurs sometime in October, When this strategy is used, soil nitrogen levels must be kept low in the fall. Otherwise, late irrigation can make trees susceptible to freeze damage, except in salt-affected areas.

Salts in irrigation water and soil solutions present additional problems for determining irrigation timing and appropriate dates for terminating irrigation.

The traditional method of determining irrigation depths per application based on soil water-holding capacity, root-zone depth, and soil water depletion is a valid first approximation. However, the depth of irrigation per application should be adjusted based on water intake rates, evaporation from the soil surface, capillary upward water flow, and salt leaching. In clay soils with low permeability, for example, irrigation depths per application should be adjusted to avoid prolonged pending, especially during nut development, In stratified soils, irrigation depths may have to be increased to obtain sufficient penetration, especially when clay soils are underlaid by sand. Under sprinkler irrigation, growers have a greater latitude in application depth. Water applications of <5 cm per irrigation can result in excessive evaporation losses and salt accumulation in orchards of sparse canopy (Gardner and Gardner, 1969), When surface-irrigated orchards are converted to sprinklers, application depths and frequencies must be sufficient to wet the preexisting root zone, which is usually highly variable. Incidents of tree deterioration due to insufficient water penetration are common after the conversion to sprinklers.

When saline water is used for irrigation, the quantity of irrigation water must be increased to maintain a favorable salt balance, The extra quantities needed were previously computed by the leaching formula originally proposed by Eaton and subsequently modified by several workers (e.g., Rhoades, 1974). There is now increasing awareness that such equations are merely conceptual models and that actual salt leaching is controlled largely by the depth of water applied per irrigation, soil water penetrability, and spatial variation in soil permeability, A sure way to leach salts is to apply large quantities of water in the spring when trees are dormant and the soils are most permeable, using, if needed, several consecutive irrigations after appropriate soil structural improvement measures (Miyamoto, 1991; Miyamoto and Storey, 1995).

The proportion of the ground area that must be irrigated has been a matter of conjuncture.

Table 2. ***Typical irrigation intervals for net irrigation rates of 5 and 10 cm for orchards with tree population density offal and tree trunk diameter of d under a typical climatic condition of western Texas.***

	Irrigation interval (days)				
	April	May	June/July	Aug.	Sept.
Net irrigation of 5.0 cm (2 inches)					
Index[z]					
1500	35	25	16	15	19
2000	29	20	11	10	13
3000	23	15	7	7	8
4000	22	13	6	7	8
Net irrigation of 10 cm (4 inches)					
Index[z]					
1500[z]	(50)[y]	50	32	30	38
2000	(50)[y]	40	22	20	26
3000	46	30	14	14	16
4000	44	26	13	12	14

[z]*These indices are the product of trunk diameter (d) in cm and the number of trees/ha (N). If d and N are expressed in inches and no./acre, multiply 623 to convert to the product to metric units.*
[y]*These intervals are adjusted for the requirement to apply the second nitrogen fertilization.*

Traditionally, pecan trees in the supplemental irrigation area of the southeastern United States have received irrigation water only in a portion of the ground near the trees, usually<25% of the orchard floor area (e.g., Goff, 1993; Pivette, 1979). In irrigated pecan-producing areas of the southwestern region where the annual rainfall rarely exceeds 20 to 30 cm, root growth and activities take place exclusively in the area where irrigation water is applied consistently. For optimum tree growth, irrigation water should be applied to the area where pecan roots are projected to be present, The root system of pecan trees extends beyond the tree drip line, usually about twice the canopy diameter

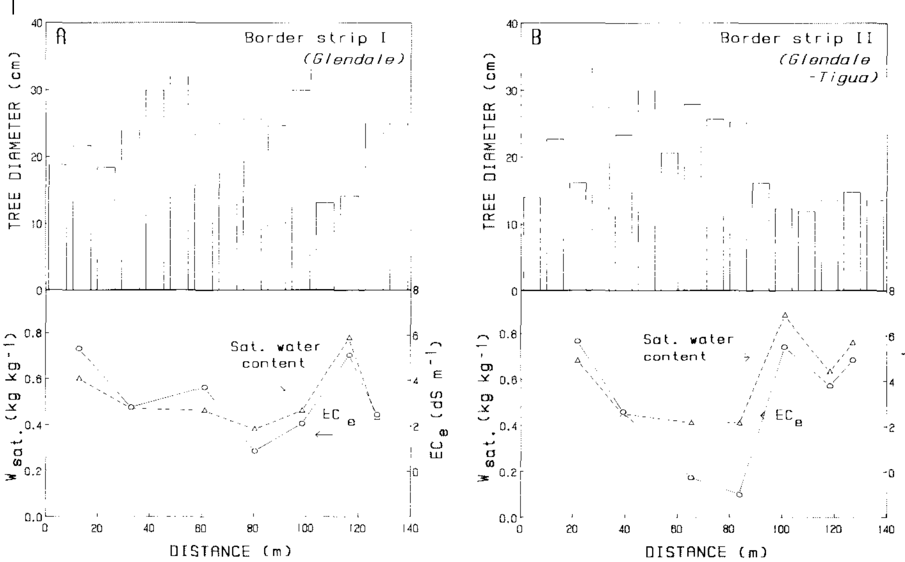

Fig. 1. *Spatial variation in tree trunk diameter, soil salinity (EC_e), and saturation water content (W) in irrigated basins consisting of Glendale silty clay loam and silty clay (A) and Glendale silty clay loam and Tigua clay(B).*

(Woodruff and Woodruff, 1934). This means that orchard floors may be covered with roots in <10 years after tree planting at prevailing tree spacings of 9 to 12 m. Recent studies in mature orchards in western Texas and southeastern New Mexico show that tree growth rates decrease usually in proportion to the extent of the ground area that is not irrigated (Henggeler, 1990; Henggeler and Roark, 1992). In these orchards, the depth of feeder roots typically range from 45 to 100 cm.

Irrigation scheduling methods

Irrigation scheduling methods are classified broadly into two types, one based on soil water accounting and the other based on actual monitoring of soil water or plant water status, Unfortunately, neither method is used extensively for managing pecan irrigation, For typical pecan growers in the southwestern region, soil moisture sensors, especially tensiometers, seem to improve scheduling, In spite of occasional malfunction and misuse, tensiometers provide direct read-outs of the soil water suction, which is less variable than the soil water content in spatially variable soils, Tensiometers also identify under-or over-irrigation by selecting appropriate placement depths, Improved quantification of soil water status and tree performance relationships should make this method more effective.

Monitoring soil moisture is subject to the inherent problem that the measurement represents point data and may or may not represent the soil moisture condition of the entire irrigation block. Increasing the number of monitoring sites helps, but also increases monitoring and maintenance requirements and interferences to orchard-care activities. This problem can be resolved partially by conjunctive use with an irrigation calendar developed from water accounting. Examples of irrigation intervals computed from Table 1 for assumed net Irrigation depths (Table 2) can be used for developing an approximate irrigation calendar, The calendar should then be adjusted using the actual tensiometer records. This combination of methods has been used successfully by growers, with the knowledge that the calendar is subject to adjustments for rain or unusually hot weather, and, at times, to under-irrigation.

Computer software is available for scheduling irrigation in advance for large orchards (Miyamoto, 1984). This program computes daily water evapotranspiration for trees of different sizes and spacings using actual pan evaporation or actual weather data. Irrigation dates and depths are determined from previous irrigation records, estimated water loss, and rainfall using water accounting. The use of tensiometers is recommended for several years mainly to check and adjust certain parameters in the program until satisfactory agreements are attained. This method is suited for sprinkler or surface-irrigated orchards where irrigation quantities and efficiencies can be assessed with some degree of certainty. The program can also predict crop developments using cumulative heat units computed from daily temperatures,

Any of the irrigation scheduling methods mentioned above are simply tools and must be used considering crop developments and scheduled orchard-care activities, such as fertilization and zinc foliar application. The first irrigation, usually begins before budbreak in surface-irrigated orchards (e.g., 10-15 Mar.), and sometimes later in sprinkler-irrigated orchards, but no later than the first week of April when root and shoot growth rates begin to accelerate. The second irrigation in surface-irrigated orchards usually commences at the end of April when the soil is still relatively wet, using alight application to minimize fertilizer leaching and allow adequate shoot growth and timely fertilization and foliar zinc applications. Irrigation becomes intensive with arrival of summer heat. This is the period when trees carry out photosynthesis at a maximum rate (Mielke, 1981).

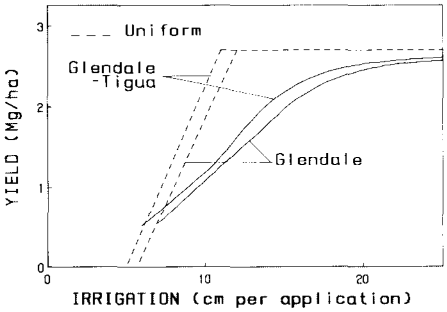

Fig. 2. *Nut yields as related to irrigation depths per application when irrigation basins are assumed to consist of uniform soils (dashed lines) and those consisting of multiple soil types (solid lines), by a computer model of Miyamoto (1990).*

Irrigation depths may be reduced as nuts enter the filling stage to avoid prolonged water pending. Irrigation termination must be gauged against excessive soil water depletion before shuck opening along with timely termination of nitrogen fertilization to avoid late-season shoot growth and potential freeze damage, These judgement calls place a considerable responsibility on orchard managers.

Irrigation systems and efficiencies

The prevailing system of irrigation for pecans in the southwestern region is the surface method, which generally is considered to yield low water-distribution efficiencies and demands excessive labor, Laser leveling has improved water-distribution efficiency of surface irrigation to a level comparable to many pressurized irrigation systems, except in highly permeable or spatially variable soils. The large flow rates common to river basin irrigation projects also allow the use of large leveled basins and short irrigation times, saving considerable labor. However, large basins, covering as much as 10 to 15 ha, have created uneven water penetration and salt leaching within the basins, which consist of multiple soil types (Fig.1) (Miyamoto and Cruz, 1987). Basin 1, for example, consists of Glendale silty clay loam and Glendale silty clay, and salts have accumulated in the silty clay portions of the basin, causing deterred tree growth (Fig. 1A), Basin II (Fig. 1B) consists of Glendale silty clay loam and Tigua clay. Salt accumulation and deterred tree growth are evident in the Tigua clay portion. Obviously, ponded irrigation water had penetrated preferentially into the areas of high permeability, leaving the low-permeability section poorly irrigated and poorly leached. Placing a check border along the soil boundary or localized modification of soil permeability would equalize salt leaching and tree growth. Otherwise, extra quantities of irrigation water must be provided to irrigate the low-permeability section adequately (Fig. 2). Spatial variability in soil permeability lowers water efficiency in leveled basins, even though water application uniformity may be high. Should the basin consist of multiple soil types, growers must not arbitrarily reduce irrigation depths, just because the basin was laser-leveled.

When water supply rates are limited, such as in the case of most pump-irrigated areas, the basin size has to be small, and leveled border irrigation is a method commonly used. This method requires somewhat greater irrigation labor input, but does not require extensive slope modification or large-capacity conveyance systems, thus reducing capital costs. Old concrete irrigation ditches can be converted to low-pressure conduits equipped with control valves for improved control of water application with minimal labor. When compared with pressurized systems, the flow rates required for leveled-border irrigation are still higher, yet this method provides flexibility of diverting excess water for surface irrigation of other crops

When water supply rates are insufficient to perform surface irrigation effectively or the land slope is excessive or when soils are too shallow, sandy, or variable, the use of or conversion to a pressurized irrigation system is a logical option. The timing of the conversion varies, but it usually takes place when trees begin to require irrigation of nearly the entire floor or when the trees begin to bear sizable yields, which pay for the new system. Some growers make the conversion after the first phase of tree thinning to reduce the cost of sprinkler-pipe installation and sprinkler-head requirements, Sprinklers provide wetting patterns compatible with the rooting patterns that have developed under surface irrigation, The system should be installed by considering the ease of equipment movement, flow rates required for mature orchards, and future tree-thinning plans, Soil improvement projects, especially subsoiling and deep chiseling, must be completed before sprinkler-pipe installation. Sprinkler heads should be of low angle with minimal spray to tree leaves to avoid foliar salt burn Solid and portable sets are available, and fertilizer application through the system is an added feature (Stockton, 1987b). The water application uniformity of well-designed sprinklers easily can reach 80% or more(e.g., Little et al., 1993), but the main benefits of sprinkler irrigation are reduced labor, compatibility with limited water supply rates, and improved water-application control, which usually translates to improved tree performance in areas where surface methods were not effective.

Drip or micro jet irrigation also has been used in some areas where pump capacities are limited, These methods provide high water-use efficiencies in young orchards (Helmers, 1984; Worthington el al., 1987), but usually are not suitable for use in conversion from surface methods in mature orchards. The wetting pattern of drip irrigation is usually not compatible with the horizontal rooting patterns developed under surface-irrigation methods. Growers using drip or micro jets in western Texas also have experienced other difficulties, including emitter clogging, malfunction of spray heads, increased weed growth, or inadequate wetting of the root mass (e.g., Stockton, 1987a). The effects of salts accumulated at the edge of the wetting pattern on tree growth is also a concern, since rainfall in the southwestern region is usually insufficient to leach salts. However, the use of buried, closely spaced parallel laterals can overcome many of these difficulties (Henggeler and Word, 1995). About four to eight drip-line tubes (equipped with line emitters spaced at 30 to 75 cm) buried between tree rows can provide good wetting patterns with minimal evaporation. When the soil is deep and sandy, some orchards have been maintained successfully using six to ten emitters placed on a loop around a tree, but this system seems to require more water than the closely spaced drip tubes (Henggeler and Word, 1995), The most appropriate design of drip irrigation systems for pecans depends on tree size, soil type, rooting pattern, rainfall, costs, and convenience. Current indications are that emitter densities must be higher than those commonly used in the east.

Excess water and drainage measures

There has been increasing awareness that excess water is just as bad as drought, if not worse. Waterlogging or water saturation of the root zone induces root damage, water uptake difficulties, leaf yellowing, necrosis, defoliation, reduced photosynthesis, and can eventually kill trees (Alben, 1958; Loustalot, 1945; Smith and Ager, 1988; Smith and Bourne, 1989). Trees subject to consistently high levels of soil moisture can also become excessively vegetative in warm climates, especially when coupled with high dosages of nitrogen.

Excess water problems in the field occur for various reasons. One common problem is poor surface drainage in large leveled-border basins consisting of poorly permeable soils with no surface drainage outlet, Rainwater, owing to its low salinity, has difficulty penetrating soils that are slightly affected by sodium and tends to stand for along period. Various soil improvement measures that help mitigate this problem are now available (Miyamoto and Storey, 1995). In addition, if buried pipes equipped with alfalfa valves are used for irrigating leveled borders, the system can be designed to drain the surface water.

Excess water caused by high water tables is a common occurrence in pecan orchards established along river basins. Potential measures for lowering water tables are discussed in Miyamoto and Storey (1995). Drip irrigation used in clay soils also can cause water saturation (along with terrific weed growth) near the emitters, especially when operated continuously. Intermittent application or increasing number of emitters usually alleviates the aeration problem, but the system must have adequate flow rates to make such modifications,

Looking ahead

Water generally is regarded as the most critical element for producing quality nuts, Recent observations indicate that high salinity is also a significant factor in pecans, which are salt-sensitive, Unfortunately, salinity of irrigation water has been increasing in many parts of the southwestern region. There must bean improved understanding of salt effects on tree performance, especially in late season when photosynthesis rates are high and nut-filling demands large quantities of carbohydrates, Once the true nature of salt effects is understood, improved guidelines for water management can be devised.

There seems to belittle doubt that most growers will move toward irrigation systems that combine improved uniformity of water application with minimal labor requirements, Irrigation efficiency then must be enhanced through improved scheduling and understanding of the dynamic process of water and salt transport in the soils. These processes occur differently in each soil, and they affect yields significantly, The importance of understanding what is happening in the soils was briefly discussed with respect to management of large-basin irrigation and drip irrigation, Improved understanding of root development and behavior indifferent irrigated soils and water and salt movements indifferent soils may improve water and salt management and ,ultimately, tree performance,

From a practical perspective, many growers may benefit from implementing tentative guidelines to maintain the soil water suction above saturation but below 30 to 40 cb until shuck opening and soil salinity levels below about 2,5 $dS \cdot m^{-1}$ in the root zone. Irrigation water must be applied to the entire root zone for optimum tree growth and nut production. Implementation will require measurements or monitoring of irrigation quantity, soil moisture, and soil salinity along with tree performance. Due to extreme soil variability existing in irrigated soils of the southwestern region, these guidelines alone are not adequate, Growers may then examine what is happening in the soils with respect to rooting patterns, water penetration, drainage, and salt accumulation and modify irrigation strategies.

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