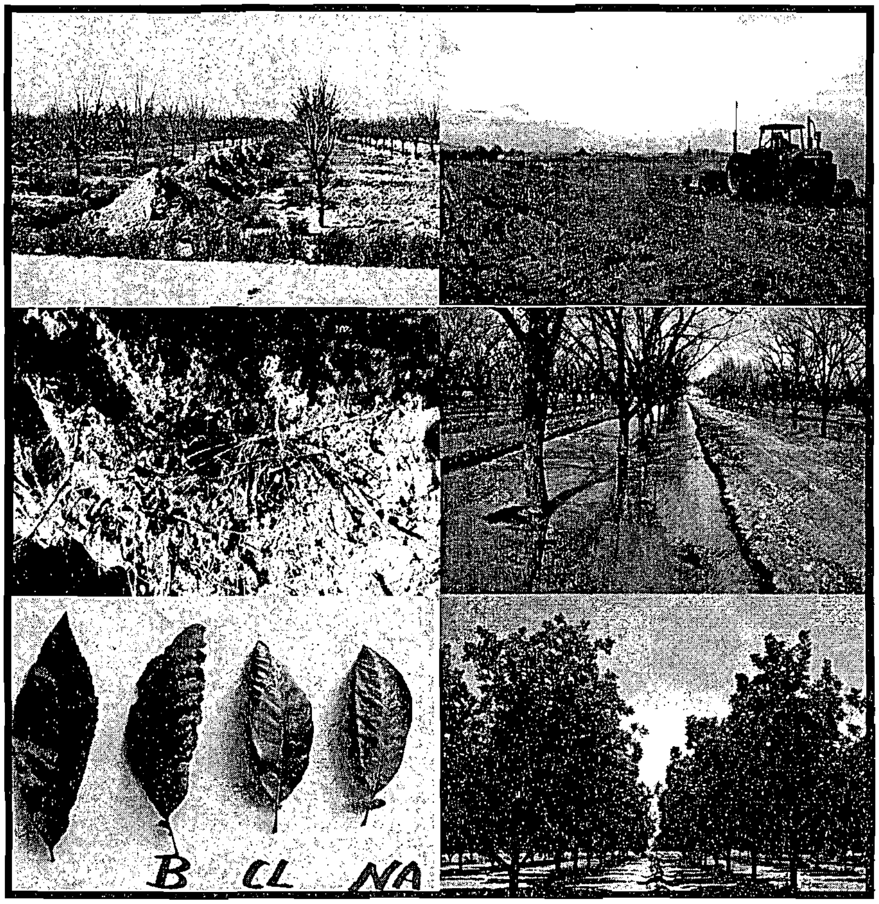
TWRI TR-188
March 2002

Guidelines for Developing Soil and Water Management Programs: Irrigated Pecans



Texas Agricultural
Experiment Station
The Texas A&M University System

Texas Water
Resources Institute
make every drop count

Agricultural Research and Extension Center at El Paso

SYNOPSIS

Existing pecan orchards in the Southwest were established on every soil imaginable, using all types of water. Soil and water management programs are a tool to make the best use of these resources for improved production. A typical step begins with tree performance evaluation, followed by a review of management records for identifying obvious management deficiencies. If these preliminary steps do not yield anything conclusive, it should be followed by soil and water testing and appraisal, and evaluation of soil improvement options. Finally, orchard management practices, such as soil and irrigation management, fertilization and weed control should be fine-tuned. The significance of each measure may be evaluated using the cost and return analyses presented.

CONTENTS

ACKNOWLEDGMENT

Research and Publication of this document was financed in part by the Efficient Irrigation for Water Conservation in the Rio Grande Basin Initiative through the Cooperative State Research, Education, and Extension Service (CSREES-2001-34461-10405), the Texas Agricultural Experiment Station, the El Paso Agricultural Research and Extension Center, and the Texas Water Resource Institute (TWRI).

GUIDELINES FOR DEVELOPING SOIL AND WATER MANAGEMENT PROGRAMS: IRRIGATED PECANS

S. Miyamoto*

Experienced growers have long recognized that soil selection, and soil and water management have major impacts on tree performance and profitability. After all, trees are grown in the soils. Aside from the climate, soil and water quality usually dictates tree growth and yield potentials, whereas orchard management practices affect the actual growth rate, yields and nut quality within each type of soils. The purpose of developing a soil and water management program is to make the best use of soil and water resources for improved production and a greater profit.

When the soil quality or conditions are not ideal, however, it is not easy to develop a soil and water management program. Some orchards, for example, were developed on shallow soils over caliche. Many orchards were also established on alluvial plains where soils can change from sand to clay in a distance of 10 ft (3.3 meters). Some orchards were established on sites with high water tables. These situations are not easy to manage, and may require soil improvement measures prior to imposing intensive orchard management.

Equally important is to recognize that soil changes a great deal with time. Many growers have overlooked subtle changes in soil properties induced by compaction, particle dispersion, and soil salinization. These changes have caused undesirable effects on tree performance, including die-back, and investment losses. Many of these problems can be minimized if we take a time to examine soil and water, and to install an appropriate management program.

The purpose of this paper is to outline the steps toward, and the guidelines for establishing a soil and water management program for irrigated production of pecans in the Southwestern United States, and Northern Mexico.

DEVELOPMENTAL STEPS

Tree Performance Evaluation

Prior to developing a management program, tree performance should be appraised (Chart 1). A soil map or aerial photos are useful for assessing spatial variation in tree growth, and for determining the sites for the performance evaluation. The parameters commonly used for evaluation are tree trunk diameter, shoot growth, nut yield and quality. The tree trunk diameter is a convenient parameter for assessing tree growth rate, and in productive orchards, it usually reaches 8 inches (20 cm) in 10 years, and 10 to 12 inches in 20 years (Fig. 1). The cross-sectional area of tree trunks usually increases at an annual rate of 4.3 to 5.9 sq inch (28 to 38 cm^2) in vigorously growing orchards until the trees are thinned.

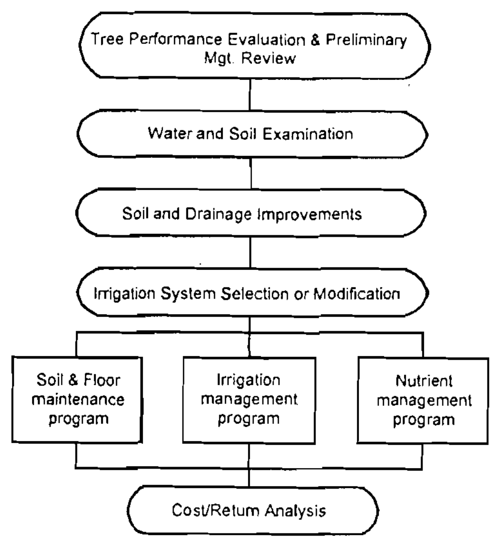


Chart 1. Suggested steps for developing a soil and water management program for irrigated production

Nut yields in high density planting (such as 30 x 30 ft or 32 x 32 ft) can reach under ideal conditions1000 lb/a (1120 kg/ha) by the 10th year, and 2000 lb/a by the

*S. Miyamoto, Professor, Soil & Water Science, Texas A&M University, Agricultural Research Center at El Paso, 1380 A&M Circle, El Paso, TX 79927

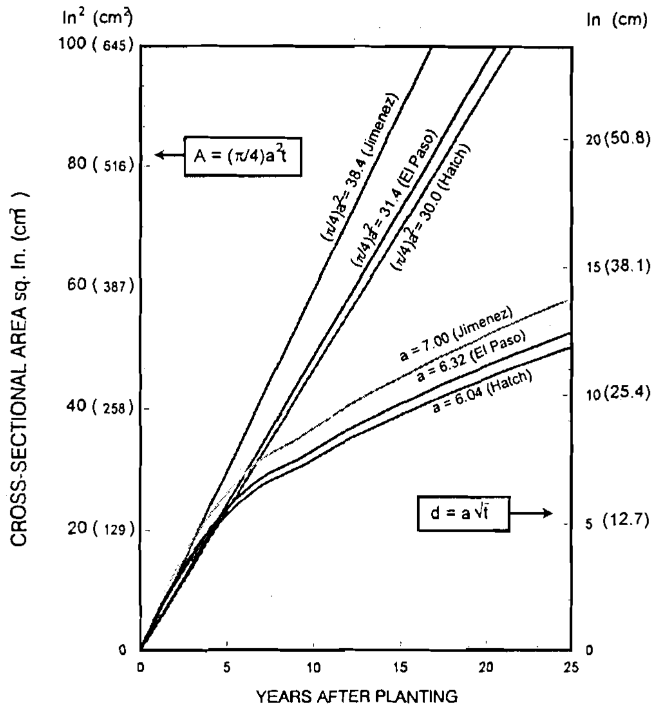


Figure 1. The typical increase in trunk cross-sectional area (A) and trunk diameter (d) of vigorously growing "Western" trees. For details refer to Appendix.

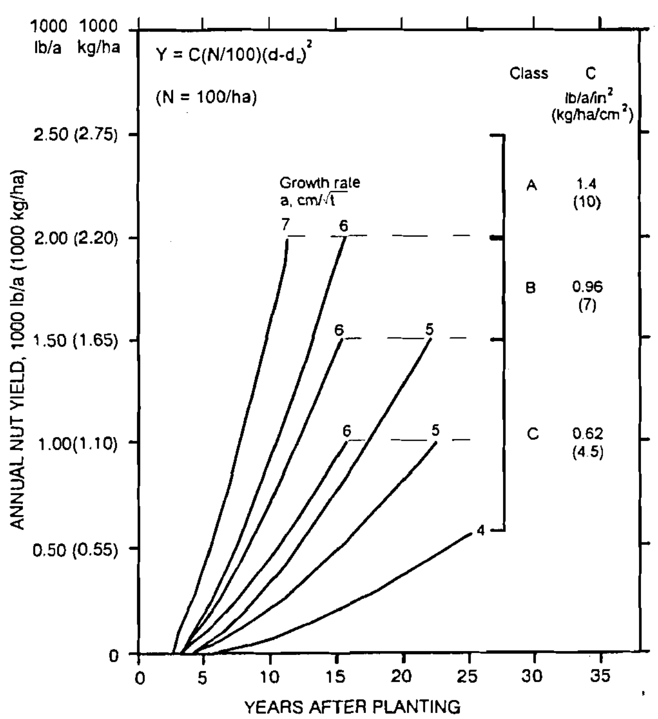


Figure 2. The increase in annual nut yield (Y) of pecans growing at different rates in three classes of orchards. For details, refer to Appendix.

13th or 14th year, then level off or decrease when become crowded (Fig. 2). Yield gains are slowed when tree growth rates are reduced. The potential yields at maturity, as will be discussed later, are affected by soil types and water quality, and the actual yields vary with the orchard management practices employed, usually within each type of soils. Obviously, freeze damage and other weather related factors also affect the actual yields. Tree growth rates are somewhat greater in warm climates, and so are the yield gains. There are indications that the yield curves may increase with improved pruning practices. If irrigated trees do not measure up to the current regional performance expectations, soil, water and orchard management programs should be examined and upgraded.

Preliminary Orchard Management Review

This step is recommended for identifying obvious management factors which may be limiting tree performance. If orchard management records are kept adequately, it is not difficult to analyze the relationship between tree performance and the orchard management practices employed. For example, if the management record shows that the trees were planted in soils with salt levels greater than 2 to 3 dS m^{-1}, soil salinity can be the cause of poor transplant-take (Miyamoto et al., 1986). If young transplanted trees have been irrigated at the full capacity of the water supply, over-irrigation is probably a factor for poor tree performance. Young trees are lost more often by over-irrigation than inadequate irrigation. If mature trees are irrigated lightly only once in September, it can be the cause of poor nut filling and shuck opening. If the orchard floor has not been chiseled for a decade, water infiltration as well as rooting patterns are sure to have changed to a depth shallower than we need. If irrigation scheduling has not been adjusted for growing tree sizes, it is most likely that the deep roots are not receiving an adequate amount of water, and that salts are not leached as much, thus leading to ailing tree conditions. These are just a few examples of obvious management problems that we commonly encounter with irrigated production.

If management records are not kept, it can be an indication of management difficulties. Records related to soil and irrigation management, fertilization, pruning and thinning along with pertinent information on the orchard such as soil types, tree ages and irrigated acreages should be on hand. These records are needed for making appropriate adjustments in orchard management practices. If the management records do not yield anything conclusive, a detailed examination of soil, water and management practices is warranted.

Water Testing and Appraisal

Water supply, both in quantity and quality, should be checked. The quantities of water required to maintain productive orchards vary with tree sizes, time of a year, irrigation efficiency, wetted area, weather, and several cultural factors. Nonetheless, the upper limit of water requirements should not exceed the pan evaporation rate which ranges from 0.27 to 0.47 inch/day (0.70 - 1.25 cm/day) in irrigated pecan producing areas of the Southwestern USA and Northern Mexico (Table 1). Table 1 also shows the water supply capacity needed to meet the evaporative demand in a 100 acre or a 100 ha orchard during summer months with no rainfall for assumed wetted areas of 20 through 100%. These figures can be used as the first appraisal of the adequacy of water supply capacity for irrigation. The actual water use of pecan trees is less during spring months, and decreases with decreasing tree sizes, as discussed in a later section.

Table 1. The maximum rates of water supply needed for growing pecans in 100 acres or in 100 ha in several locations with various wetted areas, assuming no rainfall.

Location	Summer Pan E	Supply rate at wetted area 20	40	60	80	100%
	in day^{-1}	----------- gpm for 100 acres----------				
El Paso, TX	0.45	170	330	500	680	850
Jimenez, Chih	0.38	140	280	420	560	700
Hermosillo, Son	0.36	130	260	400	540	670
Weslaco, TX	0.27	100	200	310	410	510
	cm day^{-1}	--------- L sec^{-1} for 100 ha --------				
El Paso, TX	1.16	27	53	80	107	134
Jimenez, Chih	0.96	22	44	66	88	111
Hermosillo, Son.	0.92	21	42	63	85	106
Weslaco, TX	0.70	16	32	49	65	81

1 ha = 2.2 acres. 1 L/S = 15.6 gpm

Salinity of water used for irrigation should not exceed 1 dS m^{-1} (or 650 to 700 ppm) for optimum production in fine-textured soils (Table 2). If salinity of water exceeds 1.5 dS m^{-1}, every precaution should be taken to avoid salt accumulation in the root zone. The salinity rating of 2.5 dS m^{-1} is currently the upper limit of irrigation water salinity for commercial production of pecans, and this guideline applies only to well-drained sandy soils under surface irrigation (Miyamoto, 1999). Sprinkling of water which has salinity greater than 1 dS m^{-1} directly to tree leaves can cause foliar salt-burn. The extent of damage depends on several factors such as frequency of irrigation and the sprinkler type used.

Table 2. Water quality criteria for irrigated pecans.

Soil Texture	Salinity limit dS $^{-1}$	Sodicity limit SAR	Boron limit ppm
clay, clay loam	< 1	< 3	< 0.5
loam	1 - 2[1J]	3 - 8[1J]	0.5 - 1.0
sand, loamy sand	2 - 2.5[1J]	8 - 10[1J]	1 - 1.5

[1J]Larger numbers apply to Aridisols and smaller numbers to Entisols.

Sodicity of irrigation water, which is commonly expressed by the sodium adsorption ratio (SAR), affects soil structural stability. Soil structural deterioration can begin at a SAR as low as 3 in alluvial clay or clay loam, and usually becomes a practical problem when it exceeds a range of 3 to 8 (Table 2) in some soils (Miyamoto, 1998). The soils developed in floodplains (Entisols) are prone to soil structural degradation more so than upland soils with a high content of calcium carbonate which acts as a cementing agent.

Boron (B) causes phytotoxicity at a concentration as low as 0.5 ppm in irrigation water. Cultivar, 'Wichita' is especially sensitive to B (Picchioni et al., 1991). When B concentration exceeds about 1 ppm in irrigation water, potential B toxicity should be expected. Boron toxicity appears as brown spots, then develops to the leaf margin burn. Boron is, however, an essential element needed for transport of carbohydrates from leaves to nuts.

If drip irrigation is to be used, water should also be analyzed for suspended solids, hardness, and silica (Si). All of these tend to clog drip emitters. High concentrations of Si (>80 ppm) make soil very hard.

Soil Examination and Appraisal

Irrigated pecan orchards in the Southwest and Northern Mexico had been established on a wide range of soils (Miyamoto and Helmers, 1988). Therefore, soil examination is the most critical aspect of establishing soil and water management programs, and provides a foundation to develop soil-type based orchard management programs. Since many different soils are usually present in an orchard, it is essential to subdivide the orchard according to soil types. A soil map is the best guide, but if not available, an aerial photo is useful for identifying the approximate boundaries of different soil types.

Soil examination is usually conducted by making soil pits for each of the applicable soil types to a depth of 4 to 6 ft (120 to 180 cm). The examination is essentially a diagnostic process and includes identification of soil profile characteristics, texture, structure, hardness, moisture, and the presence of a hard pan, a clay layer or a water table. It is also recommended to check soil salinity and sodicity, especially when the soil has a high water table or a clay layer. Finally, rooting patterns or root damages should be noted.

If the soil examination reveals the widespread presence of clay or silty clay, soil texture should be viewed as the primary constraint for growing pecans. If the soil profile contains hard pans or a high water table, soil profile modification and/or water table monitoring must be considered. If the soil profile contains a compacted layer which limits water penetration, soil maintenance programs must be examined. If the soil analysis reveals the presence of soluble salts in excess of 2.5 or 3.0 dS m^{-1} or the sodium adsorption ratio (SAR) greater than about 8 in the saturation extract, salt and/or sodium leaching must also be considered (Miyamoto et al., 1986, 1995). If dead roots are encountered, the depth of water penetration should be monitored, instead of jumping into fungicide applications. Poor soil conditions, especially shallow soil over caliche or inadequate water penetration weaken roots. This, in turn, makes the roots susceptible to fungus infection. Soil profile examination can also yield other useful hints for improving soils.

The most difficult part of soil appraisal is to make a projection on yield potentials for the given soil type. Figure 3 shows the projected cumulative yields in different classes of orchards. Even though there are exceptions, orchard classes are usually related to soil types. As a rule, loamy sand and sandy soils provide Class A, loamy soil, Class B, and clay and silty clay soil Class C. Class A orchards can potentially yield 2000 lb/a (2200 kg/ha), and Class B orchards no less than 1500 lb/a at maturity (Fig. 2). Soil selection will have a long-lasting impact on nut production and yields.

Soil stratification as well as quality of water used also affect orchard classes. If water quality is excellent, e.g., salinity less than 400 to 500 ppm with low sodicity, local experiences show that orchards consisting of silty clay loam can be classified as Class B, especially when trees are young. Orchard management practices affect the yield gain curves, usually within each class. In other words, improving orchard management practices can do only so much in bad soil cases, unless the soil is improved first. The cumulative yield projection for individual orchards is possible if the records of tree trunk growth and nut yields are available for more than 1 year. For further details, refer to Appendix at the end of this article.

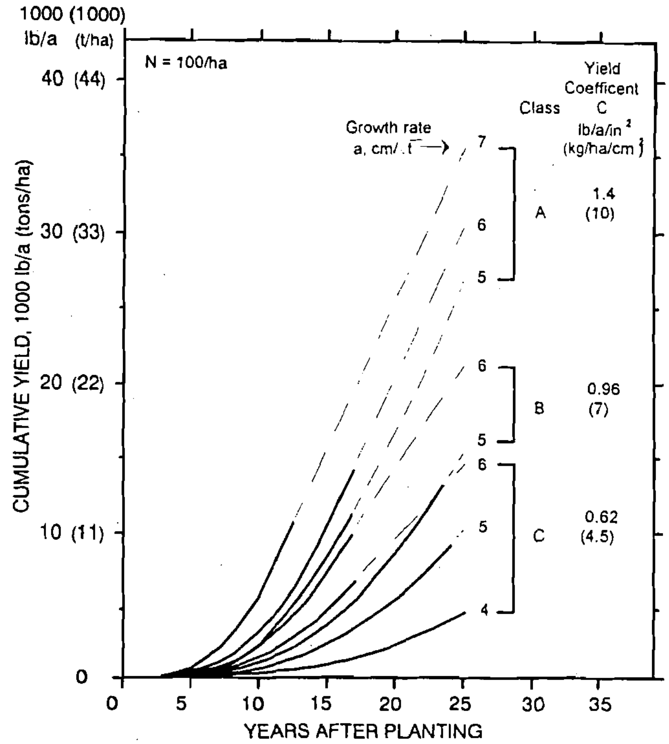


Figure 3. The cumulative nut yields (Y) for different tree growth rates in three classes of orchards.

Soil and Drainage Improvement

Soil improvement programs should be implemented as soon as feasible to minimize the negative cash flow caused by the unsuitable soil conditions. The measures which may be adopted depend on the type or the nature of soil problems (Table 3). Shallow soils developed over caliche can readily be made productive through heavy duty subsoiling. Likewise, the soil consisting of

Table 3. Appropriate soil improvement measures

TYPES OF SOILS	SOIL IMPROVEMENT MEASURES
1. Deep clay	Transplanting, excavation or mixing
2. Clay or clay loam over sand	Pitting or trenching
3. Shallow soil over caliche	Heavy duty subsoiling
4. Salt or Sodium-affected soils	Leaching/Chem. amendments
5. Boron-affected soils	Acid treatment
6. Excessively sandy	Clay incorporation or sprinklers/drip
7. High water table - clay	Stay out or transplant
others	Interception or source control Open or subsurface drains

clay loam to a depth of 2 to 3 ft (60 to 90cm) over a layer of sand can be turned into productive loam, simply by soil profile mixing to a depth of about 120 cm (4 ft). When the alluvial soils contain high levels of exchangeable Na (> 10 ~ 15%), chemical amendments may be needed after chiseling or trenching.

One of the most popular methods used to improve orchard soils with inadequate permeability is trenching along the tree rows (Fig. 4). This method works well in stratified soils with a clay layer (<3ft) on the top of sandy soil or sand. The area beyond the trench should be deep-chiseled. Otherwise, the soil outside the trench could stay dry, while the disturbed soil in the trench become excessively wet. Additional details on various soil improvement measures are discussed elsewhere (Miyamoto and Storey, 1995).

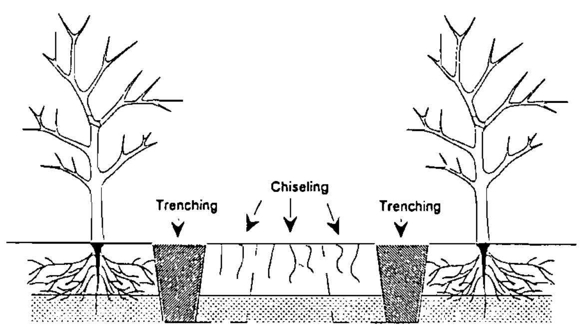


Figure 4. A sketch of a trench treatment used to improve stratified clay soils.

If the land consists of a layer of deep clay, transplanting the trees to better grounds or alternative land uses should be considered. It will take a nearly equal volume of sand to transform clay to acceptable textures, such as sandy clay loam (Table 4). Hauling sand to the extent is usually not cost-effective, unless it appears as a small spot, or generates other benefits, such as an increase in commercial property value.

The control of high water table begins with monitoring of its depth (usually for one full-year), plus conducting a detailed subsoil survey. The monitoring data are used to determine the level of water table fluctuation as well as the direction of the subsurface flow. It is usually unwise to jump into any particular methods of drains, until the survey is completed, and the likely source of water identified. There are cases where hasty installation of drainage measures has resulted in poor drain performance. At the same time, undue waiting on drainage measures can cause

Table 4. Change in soil texture caused by sand addition to silty clay or silty clay loam.

Initial soil texture thickness	Sand addition thickness		Texture after mixing
Silty clay	Sand	%	
40 cm	10 cm	20	Clay loam
40 cm	20 cm	33	Sandy clay loam, loam
40 cm	30 cm	43	Sandy loam
60 cm	20 cm	25	Clay loam
60 cm	40 cm	40	Sandy clay loam, loam
90 cm	60 cm	40	Sandy clay loam, loam
Clay loam	Sand	%	
30 cm	10 cm	25	Loam
40 cm	10 cm	20	Loam
60 cm	20 cm	25	Loam

Silty clay contains about 10% sand and silty clay loam up to 20% sand. The ideal texture for most tree crops is sandy loam and loam.

shallowing of root systems, soil salinization, poor nut quality, and possibly negative cashflow. Water table control must be considered when the table approaches within 4 to 5 ft (120 to 150 cm) from the soil surface, and it does not remain stationary and/or has elevated levels of salinity.

Surface drainage is as important as subsurface drainage. Pecan trees cannot function when the ground is covered with standing water for an extended period, especially during hot summer months. Water ponding shuts off the supply of oxygen which is needed for water uptake by pecan roots (Smith and Ager, 1988). Measures should be provided to drain surface water, including ponded water after rains, if possible, within a day or two during hot summer months. During the dormant period, pecan trees tolerate water ponding for weeks (Smith and Bourne, 1989).

Irrigation System Selection or Modification

Irrigation systems should be selected or modified after considering the rate and cost of water supply, and soil properties, including slope, water intake rate, and water holding capacity (Table 5). The availability of capital as well as the cost and quality of irrigation labor also enter into this decision. When the water supply rate is high and the water prices are low, large-basin irrigation is the industry standard, mainly because of its proven performance and low labor requirements. A water supply rate of 4000 gpm (250 l/sec) can, in theory, supply 3 inches (7.6 cm) of water over a 10acre area (4 ha) in a matter of 3 ½ hours. This rate of flow is sufficient to irrigate 500 acres (200 ha) of mature pecans at an application efficiency of 80% plus, provided that the basin is well-leveled. The real acreage which can be irrigated at once as well as the individual basin size depend primarily on soil permeability or water intake rates, and usually range from 5 to 20 acres (2 to 8 ha). The use of large basins can result in uneven water infiltration and uneven salt leaching due to spatial variation in soil type within the large-basin, especially in alluvial soils (Miyamoto, 1990). The capital cost to level the ground and to construct irrigation ditches capable of carrying the large flow does not come cheap.

Table 5. Appropriate methods of irrigation.

Water Supply	gpm	L/S	Soils	Typical methods	Initial cost	Labor cost
High>	3000	190	clay	Large Basin*	M*	L
			sandy	Small Basin*	M	M
Medium	1000	64	clay	Small Basin*	M	M
	~3000	~190	sandy	Border	M	H
Low	<1000	<64	deep	Border	L	H
			deep or shallow	sprinkler	H	L
			deep	Drip	M	L

*Large Basin > 10 acres (4 ha), small Basin 5 to 10 acres (2 to 4 ha).
*H, M, L: High, Medium, Low

When the water supply rate is in the range of 1000 to 3000 gpm (63 to 189 l/sec), the size of the basins is typically reduced to a range of 0.5 to 5 acres (0.2 to 2 ha). The supply rates of 1000 and 3000 gpm are sufficient to irrigate, respectively, 125 to 375 acres (50 to 150 ha) at an assumed application efficiency of 80%. The capital cost per land area tends to be lower than the large basin- irrigation, and irrigation efficiency can be higher due to lower soil variation within each basin. The drawback is considerably higher irrigation labor costs.

When the rate of water supply is less than 1000 gpm (63 l/sec), irrigation borders have to be placed at almost every tree row. This border setting requirement, coupled with the slow supply of water, makes border irrigation labor consuming. The flow rate of 1000 gpm (63 l/sec) provides a water depth of 3 inches (7.6 cm) over a one acre area in 1 hour 20 min. or it will take a week to deliver 3 inches of water over 125 acres. The excessive labor requirement and water application control can be improved somewhat with the use of gated PVC pipes (usually 8 to 10" in diameter) equipped with adjustable slot valves.

An alternative to border irrigation is sprinklers, which are especially advantageous when the land slope is steep or the soil is sandy or shallow. The initial cost of sprinkler irrigation systems is comparatively high, but there may be a cost-share program. Many growers faced with low flow and low efficiency of border or basin methods have made successful conversion to sprinklers. It should be kept in mind that the consumptive use does not decrease with the use of sprinklers, and may even increase somewhat. The use of sprinklers can improve water application efficiency, especially in sandy fields, shallow soils, or slopped ground. It also saves irrigation labor, as long as the tractor does not mow down sprinkler heads. If the system is to be converted to sprinklers, soil improvement projects, especially subsoiling should be completed prior to pipe installation. Water ponding, upon the conversion to sprinklers, is not uncommon in clayey soils or compacted soils.

Microjets are popular for irrigating young trees. However, terrific weed growth associated with frequent water application can increase weeding costs as well as the incidents of poor water application. In some cases, microjets attracted bees and ruminants, resulting in poor water application or breakdown of the spray nozzles. Growers should also be aware of foliar salt damage from direct spraying when irrigation water has salinity in excess of 1 dS m^{-1}. Sprinkler irrigation is effective in leaching salts from the soil once tall weeds are controlled, and this feature is a definitive advantage over subsurface drip irrigation.

Drip (trickle) irrigation has been used effectively in supplemental irrigation areas of the Southeast as well as young orchards in the Southwest. When used in mature trees, it should be kept in mind that pecan roots, once surface-irrigated, usually develop a shallow lateral pattern, In contrast, the wetting pattern from an emitter is typically vertical, especially in gravelly sandy soils. This causes the problem of coverage and comparability with the rooting patterns, unless a large number of emitters is used. In addition, excess water near emitters can deter root growth when used in clay soils. Salt accumulation above emitters is also a concern. Nonetheless, a recent report shows that several driplines (equipped with in-line emitters) placed between tree rows have provided good coverage and good tree growth (Henggeler and Word, 1995). A recent survey of drip-irrigated orchards in Texas also indicates that drip methods provide a significant labor saving, but the performance is highly dependent of soil types (personal observation). In general, the best performance is found in deep sandy or silty soils, and it is questionable in shallow or clayey soils. Irrigation system conversion in mature orchards should be approached with caution.

Soil and Floor Maintenance

Orchard soils are subjected to severe compaction due to increased uses of heavy equipment and soil packing performed prior to mechanical nut harvesting. Soil compaction leads to reduced water infiltration (Fig. 5), increased water stress, reduced salt leaching, feeder root die-back, and eventually loss of tree vigor. An exception applies to an orchard subirrigated with a drip method. Compacted soils should be regularly loosened by chiseling or spiking. Chiseling may be implemented in alternate rows in one direction to reduce shock to the trees through root cutting (Fig. 6). If this system is adopted, it will take 4 years to complete one round of chiseling. The depth of chiseling needed depends on the depth of soil compaction, which usually extends from the surface to the disking layer. Once the first round of deep chiseling is completed, shallow chiseling (less than 4 to 6 inches or 10 to 15 cm) may be employed under the tree canopy, and deep chiseling away from the trees. If an irrigation block consists of multiple soil types, chiseling should be performed to equalize water intake rates as much as possible within the irrigation block.

Soil particle dispersion induced by sodium (Na) is another soil maintenance item. This can be reduced by sodding, sand topdressing or with chemical amendment (Table 6). Application of chemical amendments often helps maintain water intake, especially when conducting salt leaching irrigation (Miyamoto, 1998). When clay or clay loam layers are involved, however, salt leaching cannot be achieved due to low permeability. Such soils usually require trenching or profile modification before the salts can be leached. Standing water may be reduced by improved leveling or grading or by pitting or trenching as discussed earlier in a section dealing with soil improvements.

Table 6. Appropriate soil and floor maintenance measures.

TYPES OF PROBLEMS	SOIL MAINTENANCE MEASURES
1. Compaction	Chiseling, spiking
2. Dispersion	Sodding, Sand topdressing Chemical amendments
3. Salinization	Chiseling or spiking and Periodic leaching
4. Water standing	Leveling & grading, Chiseling, Pitting Sand wedging & Sodding
5. Loose sand & gravel	Sodding, Mud irrigation

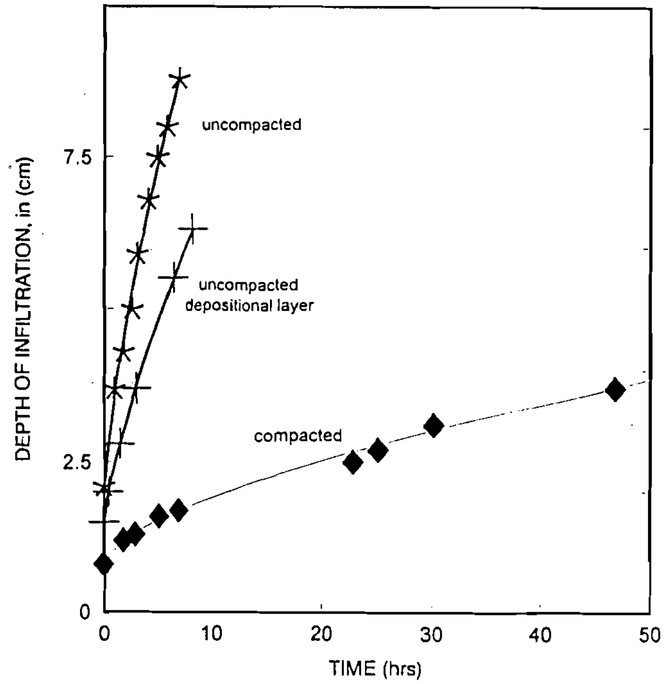


Figure 5. The depth of water penetration into alluvial soils after soil compaction to cause 5 mm of settling or the use of irrigation water containing suspended solids to make a 2 mm layer of deposition (Miyamoto, 1989).

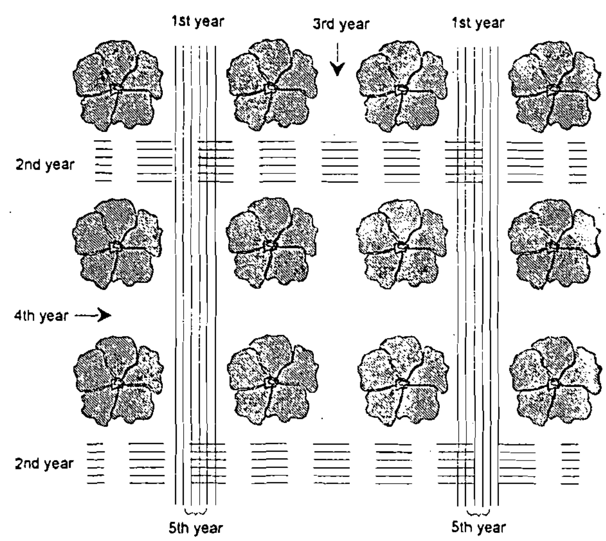


Figure 6. A system of soil chiseling implemented in a 4 year cycle. A new round of chiseling begins at the 5th year with a reduced width of chiseling strips.

Orchard floors should be kept free of sods or weeds until soil fertilization is completed. Otherwise, growing weeds absorb fertilizers faster than do tree roots. Fig. 7 shows several examples of NO_3 - N present in soil solutions with and without sods. The presence of warm-season grass on half of the ground area caused a 30%

reduction in available nitrogen (N). The addition of clover, a cool-season ground cover, also lowered available N, mainly through uptake during spring and early summer months. During this period, growth rates of clover far exceed that of deciduous trees, and it presented severe competition for N. Sods and weeds should be controlled, especially in young orchards. Once fertilization is completed, weeds can be mowed so as to provide a stable sodded floor for nut harvesting and to allow decomposition of sod clippings prior to the spring of the next growing season. In addition, sodding improves soil aggregation. In warmer climates of Mexico, sodding is often viewed as essential for controlling the spread of Texas root rot. Additional discussion on soil and floor management is given elsewhere (Miyamoto and Storey, 1995).

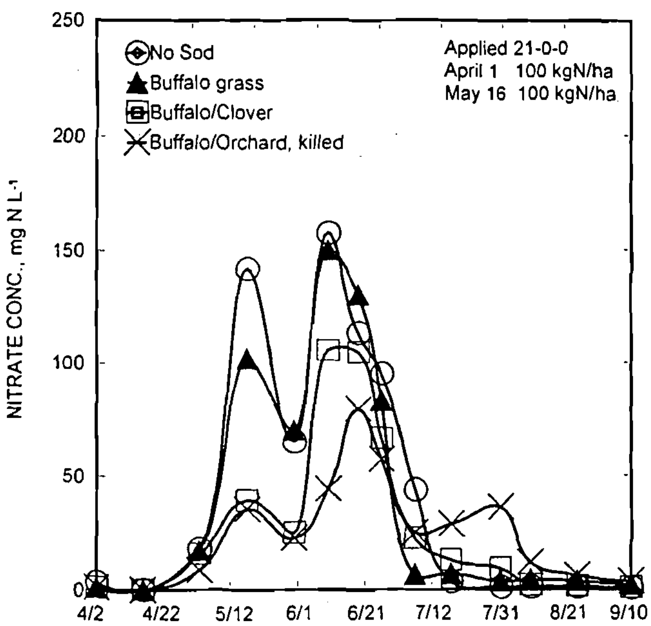


Figure 7. **Nitrate N concentrations in soil solutions following two applications of ammonium sulfate to sodded or nonsodded soils under surface irrigation (unpublished data, this laboratory).**

Irrigation Management

Irrigation management must deal with the question of how much, when and what portion of the orchard floor should be irrigated. The answer to the last question is straight forward; irrigate all of the ground where tree roots are present for optimum growth (Henggeler and Roark, 1992). Pecan tree roots usually extend to about twice the tree canopy. This guideline is in sharp contrast to the guideline for supplemental irrigation areas where microjet or drip irrigation is placed to cover as little as 25% of the rooting area.

The quantity of irrigation per application should ideally equal the quantity needed to wet the entire depth of the root zone. The rooting depth and the water holding capacity are soil-specific, and should be obtained for each soil type. The depth of main feeder roots varies widely from 18 inches (45 cm) to as deep as 60 inches (150 cm). Typically, sand holds no more than 2 inches (5 cm) of water readily available to trees in an assumed root zone of 3 ft (90 cm). Soils may hold 2 to 4 inches (5 to 10 cm) of water readily available in an assumed root zone depth of 2 ft (60 cm). These figures are rough estimates, and the actual storage can be affected significantly by soil stratification. Checking the water penetration depths after irrigation is a practical way to assess if the quantity of water applied is appropriate.

The depth of water penetrated into dry soil after the first irrigation yields the information necessary to compute the water holding capacity, provided that the depth of water applied is known. The depth of water penetration should also be checked in August and September prior to the nut filling stage. If the depth of water penetration is found to be inadequate, soil permeability and/or water application practices have to be modified.

It is not easy to determine the timing of irrigation, because pecan leaves do not show a visible sign of water stress until it is too late. Most growers seem to use a prefixed irrigation calendar based on the daily consumptive uses and irrigation amounts (Table 7). However, yearly fluctuation of weather and rainfall patterns make the use of such a calendar somewhat uncertain. In addition, neither the quantity of irrigation nor soil water holding capacity is known with certainty, especially under surface irrigation. For these reasons, monitoring of soil moisture is recommended, for example, using tensiometers, at least until the workability of such irrigation calendar is established. Alternatively, a computerized system of irrigation scheduling is also available (e.q., Miyamoto 1984).

Irrigation scheduling becomes critical in mid-July through mid-September. Nut sizes increase to the full-size by the end of August, and nut-filling continues until the beginning of October or later, if early summer temperatures, especially of May and June were low enough to encourage vegetative growth. It will be followed by shuck opening usually in October. Water stress in any of these periods is known to reduce nut size, nut-filling, or shuck opening. Moist soil, but not dry soil, is essential for shucks to open. Irrigation during nut filling and shuck openings stages is critical, especially when the trees are loaded. If nut load is light, experience shows that trees are usually capable of filling nuts under a greater level of water stress.

Table 7. Consumptive water use and typical irrigation intervals*.

Trunk size	Consumptive use				Summer Months Intervals for net Irrigations		
	April	May	June/Aug	Sept.	2"	3"	4"
inch	------------inches/day------------				------days------		
6	.055	.079	.13	.10	15	23	31
8	.067	.10	.18	.15	11	17	22
10	.079	.12	.25	.19	8	12	16
12	.087	.13	.28	.24	7	11	14
16	.091	.15	.34	.29	6	9	12
Pan Evap	.39	.43	.45	.29	-	-	-
cm	----------------cm/day-------------				5 cm	7.5 cm	10 cm
15	.14	.23	.33	.25	15	23	31
20	.17	.26	.46	.38	11	17	22
25	.21	.30	.63	.48	8	12	16
30	.22	.33	.71	.61	7	11	14
40	.23	.38	.86	.74	6	9	12
Pan Evap	.99	1.09	1.14	.74	-	-	-

*Spaced 33 ft x 33 ft.(10 X 10m)

When soil tests indicate soil salinity is greater than about 3 dS m^{-1} in the root zone, salt leaching irrigation is warranted. Leaching irrigation is usually performed during winter or in conjunction with the first irrigation by applying as much as 12 inches (30 cm) of water at once. Soil improvement measures outlined earlier, such as chiseling and soil amendment applications should be completed in advance of leaching irrigation. The best time to leach salts from clayey soil is in the spring when the soil is driest and has cracks. Failure to perform leaching irrigation can lead to salt accumulation and loss of tree vigor, especially in clayey soils. Additional details on irrigation management are given elsewhere (Miyamoto et al., 1995).

Nutrient Management and Water Conditioning

The actual quantity of N application ranges from 100 to 200 lb N/a (110 to 220 kg N/ha), depending on tree size, nut load, soil type, floor management practices, and the potential for freeze, and should be calibrated against leaf tissue analysis and nut loading. High nut loading requires higher rates of nitrogen applications. Field tests performed in a humid area of Georgia indicate that high dosages of N encourage nut setting. A work performed in Arizona seems to indicate that high rates of N application well into the fall may help reduce alternate bearing (Personal Communication, Dr. M. Kilby, Univ. of Arizona). Additional testing of this strategy is warranted.

Soil nutrient management should be coordinated with irrigation and orchard floor management. The first fertilization is usually performed prior to the first irrigation, using 21-0-0, which will not become available until the second irrigation. Although it is rare, phosphorous fertilizer (e.g., 18-46-0 or 11-52-0) is also applied prior to the first irrigation, then is disked. In basin or border-irrigated orchards, the second fertilization is usually made prior to or during the second irrigation, usually using a mixture of 21-0-0 and 46-0-0 or 32-0-0. These first two fertilizations provide nitrogen needed most for shoot and leaf growth during the period of mid-April through the end of May.

Soil fertilization after the shoot and leaf growth period is largely to sustain N and K levels in leaves in order to enhance shuck and nut developments, and to store carbohydrate for the next season. Some recommend to apply N in every irrigation until August or September. Such fertilization strategy can reduce leaching losses of N, but N is likely to be used by sods or weeds if they are not controlled. It could also increase the potential for freeze damage of young trees if carried into the late season. Granule forms of N fertilizers should not be applied to moist or wet soils, as they volatilize rapidly. This is particularly true with urea N, and to a lesser extent with ammonium N.

Most micro-nutrients, especially Zn should be fed through leaves. However, zinc chelate applied through subsurface drip irrigation has been reported to be effective, especially in sandy and neutral soils without calcium carbonate. Otherwise, these elements are fixed in calcareous soils unless acid is injected into the root zone (Fenn et al., 1990). Injection of urea/acid solutions is reportedly effective in fertilizing young trees, while reducing the need for Zn spray.

Irrigation water with low salinity (<500 ppm) tends to disperse soil particles, and can induce water infiltration problems. Water-run application of ammonium polysulfide for the first irrigation may help reduce this problem. Do not apply fertilizers which make water alkaline, such as NH_3 through irrigation water having low salinity (<1dS m^{-1}), as it disperses soil aggregates. When salinity of the water is elevated (> 1 dS m^{-1}), and sodicity exceeds the range of 5 to 8, water application of polyacrylamide (PAM) may prove to be effective in improving water infiltration. Water conditioners do not alleviate soil compaction, and their primary function is to reduce disaggregation of soils at and near the ground surface. A research report addressing comparative effects of water conditioners is currently being prepared at our laboratory. Orchard floor management, upon completion of fertilization, should include sodding, which increases soil aggregation.

INTEGRATING AND BALANCING PROGRAMS

Various orchard management activities should be integrated along the course of the crop development (Fig. 8). Soil improvement and maintenance activities should be completed during the dormant period. It must be followed by the first fertilization and irrigation, ordinarily one to two weeks in advance of the anticipated budbreak, depending partly on the projected nut loads. Foliar application of Zn and other micro nutrients, and if applicable, of insecticides, usually begins upon the green-tip development. In order to facilitate these activities, the ground has to be sufficiently dry. Under the conventional basin or border irrigation, the second soil fertilization begins prior to the second irrigation in late April, and be followed immediately by the second light irrigation to reduce N volatilization as well as leaching losses. The soils prior to the April irrigation are often at or near the field capacity.

Weed control becomes an important task, especially during the period of rapid shoot and leaf growth, which usually takes place in 3 weeks, starting at the end of April and ending by the end of May. Otherwise, weeds take up N faster than do the tree roots. The presence of killed sods also reduces N availability, due to microbial immobilization of nitrogen. The presence of salt-tolerant weeds usually signals soil salinization. These weeds should be controlled, as they increase soil salinity.

Once soil fertilization and early season irrigations are completed, the management target usually shifts to careful water management to obtain the desired nut size, filling and shuck opening. The presence of weeds after leaf growth does not affect tree performance as much, especially in sandy soils. As discussed earlier, late season irrigation has to be managed carefully as it has a pronounced effect on nut filling, shuck opening and nut germination called *Vivipary* (Zertuche, 1982).

Various orchard management activities should be balanced or be put into a proper prospective. If poor tree performance is caused by soil problems, soil improvement activities should be initiated before spending money on water conditioners, fungicides, foliar spray chemicals or expensive irrigation systems. This principle is often ignored. If poor tree performance is associated with poor irrigation systems or poor farm

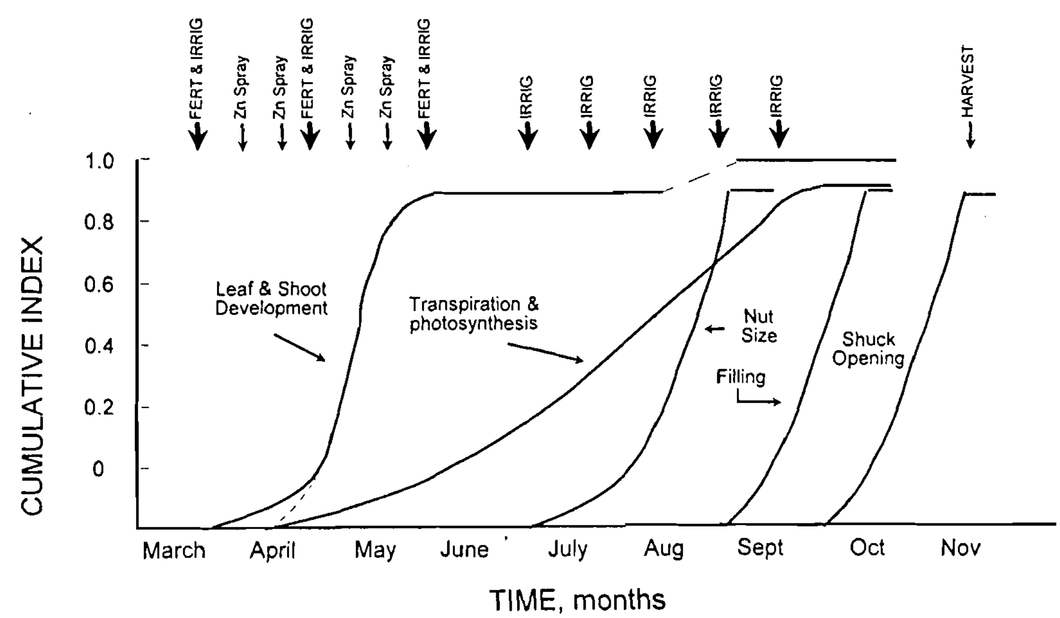


Figure 8. Relative advancements in pecan development and associated management guidelines.

management, system improvements or personal training should receive priority. In most cases, it may prove most cost-effective if soil and drainage improvement programs are initiated before intensive management measures are imposed. Soil improvement programs should also be coordinated with tree pruning and thinning programs. Soil work which results in extensive root cutting, such as trenching, should be performed following tree pruning or thinning, preferably during off-years.

COST AND RETURN ANALYSES

Any attempts to improve soil and water management must follow the principle that the revenue has to eventually surpass the costs. Growers may wish to run a long-term income and cost projection. The income projection can be made by multiplying the anticipated price to the projected yield. The income potential shown in Fig. 9 was estimated by assuming \$1.15 per lb (\$2.53/kg) of nuts with shells. The cumulative cost estimates came from the analysis by Gorman (1990) and Peña (1993) for large orchard operations, and growers may wish to use their own cost figures.

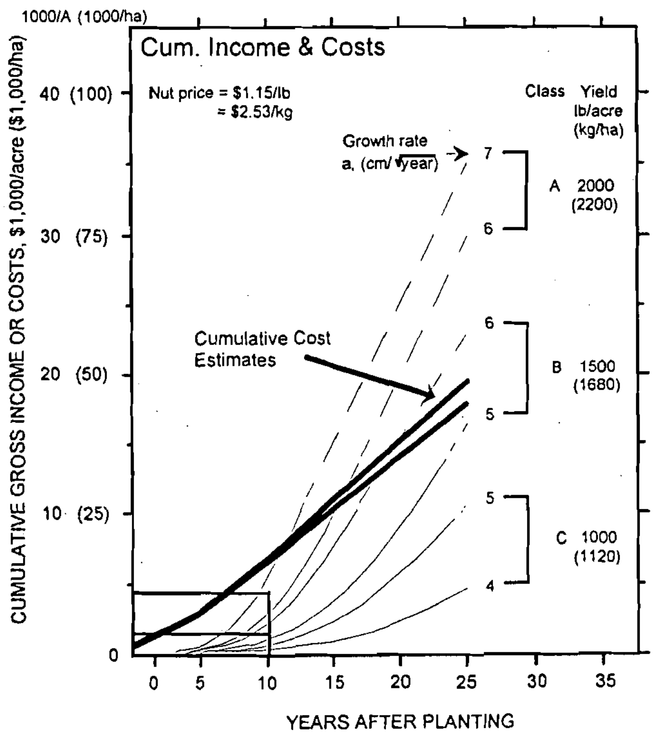


Figure 9. Cumulative gross income for different tree growth rates in three classes of soils, and the estimated cumulative production costs

Typically, the costs of pecan production (excluding the land cost) do not change greatly with soil types, but the income potential does, due to the well-known effect of soil types on tree growth rates and nut yields. If one wishes to recover the investment in pecans as soon as possible, Fig. 9 illustrates that it is necessary to push for early yield gains, preferably at a tree growth rate of no less than 4.6 sq inch (30 cm^2) per year, and the annual nut production of 2000 lb/a (2200 kg/ha). Otherwise, the return from irrigated pecan production becomes closer to or less than the costs for an extended period at the present prices of pecans.

Various orchard management practices should be considered cost-effective and viable only if the tree growth rates and/or yields at maturity are elevated over the increase in costs. Experience indicates that soil maintenance measures, such as chiseling usually help improve nut yields and quality, thus cashflow with a minimal increase in expenses. Likewise, improved irrigation or nutrient management can help cashflow with nominal increases in expenses. Both of these examples are valid only if the soil selected is manageable. If not, the soil or water quality will dictate tree performance.

APPENDIX

Trunk Growth and Nut Yield Estimate

Experience shows that the tree trunk diameter (**d**) increases with time in the following fashion.

$$\mathbf{d} = \mathbf{a}\sqrt{\mathbf{t}} + \mathbf{d}_o \qquad (1)$$

where $\mathbf{d}_o$ is the initial diameter of transplants, **t** is the time in year after planting, and **a** is the tree growth coefficient, which can be determined from the measured trunk diameter (Fig.1). This equation applies to high density orchards until trees are thinned. Frequent hedge prunning can affect the growth coefficient a, but details are not known at present. Eq (1) can be rewritten as

$$(\mathbf{d} - \mathbf{d}_o)^2 = \mathbf{a}^2\mathbf{t}$$

or

$$\mathbf{A} = (\pi/4)(\mathbf{d}-\mathbf{d}_o)^2 = (\pi\mathbf{a}^2/4)\,\mathbf{t} \qquad (2)$$

where **A** is the increase in the cross-sectional area of tree trunk. Once the trunk growth coefficient **a** is determined, **A** can be computed by Eq (2).

Mathematically speaking, nut yields can be expressed as a function of tree size, tree density, and nut production efficiency.

$$Y = C(N/100)\ (d - d_c)^2 \qquad (3)$$

where **Y** is the nut yield, **C** the nut production efficiency, **N/100** the tree population density coefficient, and d_c the tree trunk diameter above which trees produce a harvestable quantity of nuts, which is usually about 4 inches (10 cm). Note that **C** may decrease when the orchard becomes crowded, or the soil is not properly maintained. Pruning practices also affect **C**. Graphic illustration of Eq (3) is shown in Fig. 2 of the text.

Note that the tree population density coefficient is calculated for a 10 x 10 m spacing as a reference (which yields 100 tree per ha). The nut production efficiency **C** must be expressed in kg/ha/cm^2 if the **N** is expressed in trees per ha. The coefficient **C** can be calibrated using the actual nut yield, preferably averaged over a two-year period. Once **C** is determined, nut yields can be projected for different years by using Eq (2) and Eq (3).

ACKNOWLEDGMENT

Many ideas presented in this guideline came from my association with two pomologists who have retired from Texas A&M University; Dr. Benton Storey and Dr. Sammy Helmers, and Mr. Joseph Henggeler who left the Texas A&M University to this home state.

REFERENCE

Fenn, L.B., H.L. Malstrom, T. Riley, and H.L. Horst. 1990. Acidification of calcareous soils improves Zn absorption of pecan trees. J. Amer. Soc. Hort. Sci. 115:741-744.

Gorman, W.D., 1990. Pecan orchard establishment costs, investment analysis, and annual expenses and returns. Cooperative Extension Service, New Mexico State University

Henggeler, J.C. and R. Roark, 1992. The effect of orchard floor wetted area on pecan growth. Texas Agr. Ext. Serv. Dist. 6, Ft. Stockton.

Henggeler, J.C., and J. Word, 1995. The use of closely-spaced subsurface drip irrigation tape on pecans. Texas Agr. Expt. Serv. Dist. 6, Ft. Stockton.

Miyamoto, S., 1984. A model for scheduling pecan irrigation with micro-computers. Trans ASAE 27:456-463.

Miyamoto, S., 1985. Water consumption: Growers need to know this to plan irrigation. Pecan South May Issue p 8-13.

Miyamoto, S., G. Picchioni, and B. Storey, 1986. Salinity: A major factor of poor tree performance in irrigated pecans. Pecan South July/August Issue p14-17.

Miyamoto, S., and S. Helmers, 1988. Selecting soils for irrigated pecan production. Pecan South 22(2):8-12.

Miyamoto, S., 1990. A model to estimate salt accumulation and crop yields in surface-irrigated orchard. Proc. Nat. Irrig. Conf. Phoenix, AZ p384-389.

Miyamoto, S., and Benton Storey. 1995. Soil management in irrigated pecans in the Southwest. Hort Tech. 5:219-222.

Miyamoto, S., J. Henggeler and Benton Storey, 1995. Water management in irrigated pecans in the Southwest. Hort Technology. 5:214-218.

Miyamoto, S., 1998. Use of acid and acidulants in alkali soils and water. In "Handbook of Soil Conditioners" Wallace and Terry (Eds). Mercel Dekker INC., New York.

Miyamoto, S., 1999. Water quality guidelines for optimum production of surface-irrigated pecans: Salinity and Sodicity. Proc. Nat. Pecan Workshop Conf 106-112.

Peña, J. 1993. Orchard Economics; Establishment, Development and Management. In Texas Pecan Handbook. Texas Agr. Ext. Serv. p X-13-X-26.

Picchioni, G., S. Miyamoto, and B. Storey, 1991. Growth, boron uptake of five pecan cultivar seedlings. Hort. Sci. 26:386-388.

Smith, M.N. and P.L. Ager, 1988. Effects of soil flooding on leaf gas exchange of seedling pecan trees. Hort. Sci. 23:370-372.

Smith, M.W., and R.D. Bourne, 1989. Seasonal effects of flooding on greenhouse-grown seedling pecan trees. Hort. Sci. 24:81-83.

Zertuche, M.I., 1982. The effect of various irrigation treatments and levels of nitrogen and potassium upon *vivipary* of pecans. MS thesis. Texas A&M University, College Station.

Unit Conversion

Length

1 mm	= 0.1 cm	1 inch	= 2.54 cm
	= 0.001 m		= 0.083 ft
1 cm	= 10 mm	1 ft	= 12 in
	= 0.01 m		= 30.5 cm
	= 0.394 in		= 0.333 yd
1 m	= 100 cm	1 yd	= 91.4 cm
	= 0.001 km		= 36 in
	= 1.094 yd		= 3 ft
1 km	= 1000 m	1 mi	= 1.61 km
	= 1094 yd		= 5280 ft
	= 0.621 mi		= 1760 yd

Area

1 m^2	= 10000 cm^2	1 ft^2	= 929 cm^2
	= 1550 in^2		= 0.111 yd^2
	= 1.196 yd^2		= 144 in^2
1 ha	= 10000 m^2	1 acre	= 4047 m^2
	= 0.01 km^2		= 0.405 ha
	= 2.47 acres		= 43,560 ft^2
1 km^2	= 100 ha	1 mi^2	= 259 ha
	= 247 acres		= 2.59 km^2
	= 0.386 mi^2		= 640 acres

Volume

1 L	= 1000 ml	1 ft^3	= 28.32 L
	= 0.264 gallons		= 7.481 gallons
1 m^3	= 1000 L	1 AF	= 1233 m^3
	= 35.31 ft^2		= 325,900 gallons
	= 1.309 yd^3		= 43,560 ft^3

Mass

1 g	= 0.0353 oz	1 oz	= 28.35 g
1 kg	= 1000 g	1 lb	= 453.6 g
	= 35.27 oz		= 0.4536 kg
	= 2.205 lb		= 16 oz
1 ton	= 1000 kg	1 short	= 907.2 kg
	= 2204 lb	1 ton	= 2000 lb

Flow

1 L/s	= 86.4 m^3/day	1 gpm	= 0.0631 L/s
	= 15.9 gpm		= 1440 gpd
	= 0.070 AF/day		= 0.00442 AF/d
1 m^3/s	= 1000 L/s	1 mgd	= 43.8 L/s
	= 15,900 gpm		= 3785 m^3/day
	= 22.8 mgd		= 694 gpm
	= 35.3 cfs		= 1.55 cfs
	= 70 AF/d		= 3.07 AF/day
			= 36.84 A-in/day