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by

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Introduction

Pecans, along with Almonds and Walnuts, are among the salt sensitive tree crops currently grown under irrigation. Yet, many growers are not convinced that salts are affecting yields, probably because symptoms of salt-affected trees are difficult to differentiate from those of water-stressed trees.

Salt problems usually appear when salinity of water used for irrigation exceeds about 500 mg L^{-1}, and the orchard consists of clayey soils or has a shallow water table. Pecans are especially sensitive to sodium (Na) and chloride (Cl) ions (Miyamoto, et. al., 1985). In other words, salt damage tends to be greater when irrigated with Na-dominated water than with gypsum or Ca-rich water. Salt problems are not wide-spread, but are common in areas irrigated with salty ground water or salty irrigation returnflow.

Recent drought in the Southwest and northern Mexico has also accentuated salt problems as the supply of the fresh project water has dwindled. The shortfall is usually supplemented with ground water which may have elevated salinity. Salt problems also appear when soil and irrigation management practices are out of order.

This short article outlines ways to diagnose and manage salt problems. Readers who are interested in technical details should refer to separate publications listed at the end of this article.

Diagnosis

Symptom

The loss of tree vigor is the first symptom of salt-affected trees. During spring months, budbreak of salt-affected trees is delayed by as much as a week, and leaf and shoots develop slowly. By mid-summer, salt-affected trees have small leaves with slight leaf-

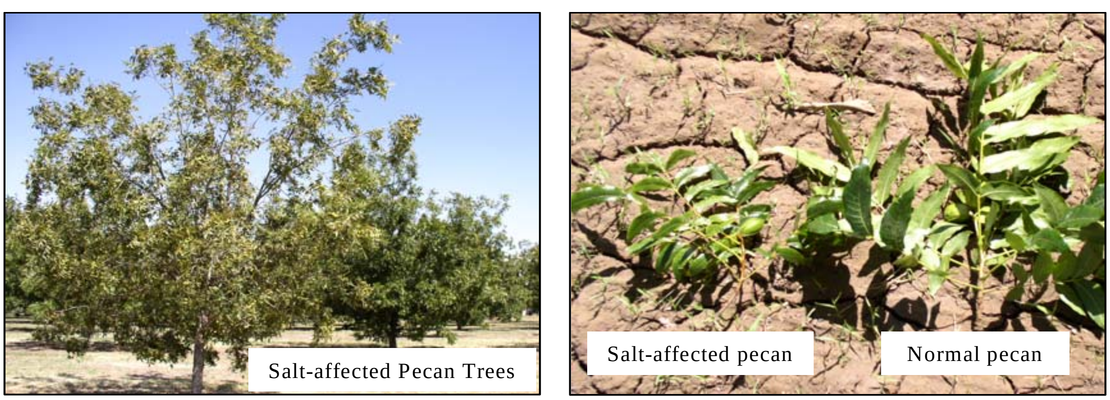

Fig. 1. Symptoms of salt-affected trees.

tipburn, which often progresses to a length of ¼ to ½ inch by the end of irrigation seasons (Fig. 1). If trees are affected by Cl, leaf injury is more extensive. These trees defoliate sooner than others. The second most frequent symptom of salt-affected trees is a smaller nut size and increased sticktight. Typically, salinity has greater impacts on nut size than on percent kernel (Miyamoto et al., 1986).

Pecan trees sustain leaf injury when tree leaves are wet with sprinklers. In these cases, salts are being absorbed directly through the leaves. This problem is frequently noted with young transplants irrigated with sprinklers, and can be readily corrected through modification of the sprinkler systems.

Saline Tolerance

As noted earlier, pecan trees are sensitive to salts, especially to Na salts. Growth of trees decreases almost linearly with increasing soil salinity or Na concentrations (Fig. 2). The data were obtained in a pecan orchard in the El Paso Valley (Miyamoto et al., 1986). The onset of a significant growth reduction is 2.5 to 3.0 dS m^{-1} in the soil saturation extract or a concentration of Na about 20 meq L^{-1} (460 ppm) measured in the saturation extract. When soil salinity increases to a range of 6 to 8 dS m^{-1} (or Na concentrations of 50 to 60 meq L^{-1}), tree branch die-back usually occurs.

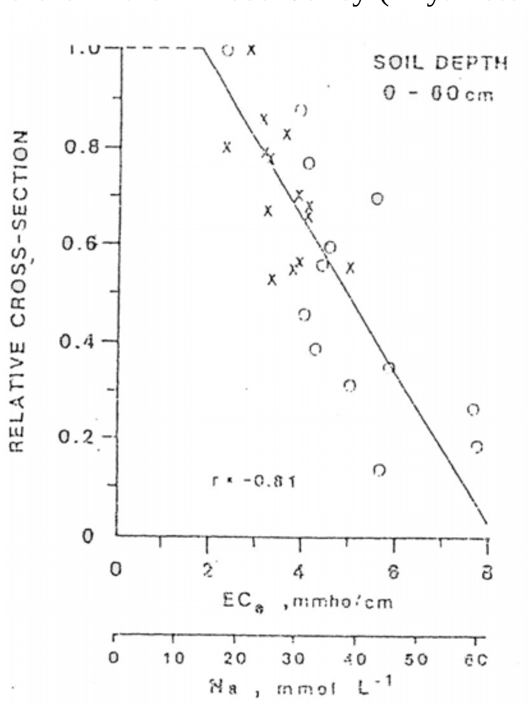

Fig. 2. Trunk cross-section as affected by salinity or Na concentrations in the soil saturation extract (Miyamoto, 1986).

There seem to be a significant difference in salt tolerance among pecan varieties. "Wichita" is, for example, known to be more sensitive to salts and other stresses than "Western Schley". Little is known about the effects of rootstock on salt tolerance. Experiences seem to indicate that 'Riverside' is fairly salt-tolerant, and less adsorptive of Na than 'Burkett' or 'Apache' (Miyamoto et. al., 1985). Certain rootstock varieties used in East Texas may not tolerate salts (personal observation).

Soil Salinity Tests

Testing soils for salinity is among the most reliable methods of diagnosing salt problems. Soil samples should be collected from the main feeder root zone, typically 50 to 80 cm deep. They should be collected on the basis of soil type, if available using a soil map (Miyamoto, 1988). It is important to look for a soil testing laboratory which uses the saturation extract method, an official method of soil salinity testing (Rhoades and Miyamoto, 1990). Many commercial soil testing laboratories use a fixed soil to water ratio for preparing the aqueous extract. Tolerance of pecan trees to soil salinity is given by salinity of the saturation extract, and can not be compared against salinity of the aqueous extract made at a fixed soil to water ratio.

Make sure to ask for the data on the water content at saturation. The saturation water content, if determined correctly, provides the valuable information on soil texture and the potential for salt accumulation (Table 1). The potential for soil salinization is expressed by the salt concentration factor (SCF).

$$SCF = C_e / C_w \qquad [1]$$

where C_e is the soil salinity measured in the saturation extract, and C_w salinity of irrigation water. The greater the SFC, the higher the probability of soil salinization.

Table 1. Soil textures, the saturation water content, and the typical salt concentration factor in surface-irrigated pecans.

Soil Texture	Saturation Water Content	Salt Conc. Factor [1] -
	ml / 100g	
Sandy loam	< 30	1.0 - 1.2
Loam/Silt loam	30 - 45	1.2 - 2.0
Clay loam	45 - 60	2.0 - 3.0
Silty clay/clay	> 60	3.0 - 5.0

[1] - Salt concentration factor = soil salinity / salinity of irrig. water

Water Testing

Although water quality testing alone is not sufficient to appraise salt problems, the information on salinity, cation and anion concentrations is useful. The cation concentrations can be used to estimate the sodium adsorption ratio (SAR), a measure of sodicity.

$$SAR = Na / (Ca + Mg)^{½} \qquad [2]$$

where the concentrations of Na, Ca and Mg have to be expressed in mmol / liter by dividing mg L^{-1} by their respective molecular weights (Na = 23, Ca = 40, Mg = 24). As noted earlier in Table 1, the extent of soil salinization caused by the use of irrigation water with elevated salinity varies with soil types. The tentative criteria for water quality suitability for irrigation are shown in Table 2 (Miyamoto, 2002). If quality of water approaches or exceeds any of these suggested criteria, a detailed assessment for suitability for irrigation is recommended. These criteria are for the situation of the long term uses, and water of poor quality may be acceptable for a short-term use.

Table 2. Tentative water quality criteria for irrigated pecans (Miyamoto, 2002).

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

[1] - Larger numbers apply to Aridisols and smaller numbers to Entisols

Note that SAR is for assessing the impact of Na on soil structural stability and water infiltration. When the SAR of water is lower than the range of limits shown, soil structural degradation is unlikely. The SAR is approximately equal to the exchangeable Na percentage (ESP) of the surface soils. If the SAR is 3, for example, approximately 3% of the exchange sites of the surface soil is occupied by Na ions under proper soil and irrigation management. The actual ESP can be somewhat higher due to salt accumulation.

Management

The target of on-farm salinity management is to maintain soil salinity at or below the threshold level described earlier. This may be achieved by improving water quality and/or improving salt leaching, depending on the given circumstances. Since soil and water properties vary widely depending on locations, soil and water management to control soil salinity or sodicity is also highly site-specific.

Improving Water Quality

Blending or Dilution: Two or more sources of water can be mixed to manipulate irrigation water quality. This strategy is used widely during drought by blending saline well water with fresh project water. Blending is used not only for lowering salinity, but also for lowering sodicity as well as boron concentrations to the permissible levels noted in Table 2.

If the farm operation involves field crops, besides pecans, blending may not be the best strategy. The water of best quality should be allocated to tree crops. Likewise, blending may or may not be the best option if an orchard consists of multiple soil types. Water of the best quality should be allocated to orchard blocks consisting of clayey soils. Potential soil salinity can be estimated by using the SCF shown earlier in Table 1. The best quality water may also be set aside for production blocks with high nut loading.

Chemical Additives: Calcium compounds and acidulants have been used to lower sodicity. These practices are usually effective for promoting water infiltration when salinity of water is lower than 1 or 1.5 dS m^{-1}, and the SAR of the water exceeds the limits shown in Table 2 (Miyamoto, 1998). Water-run application of ammonium fertilizers (but not ammonia) is just as effective as applying Ca compounds for reducing sodicity (Fig. 3). The oxidation of NH_4 to NO_3 at the soil surface provides hydrogen ions (H^+), thus solubilizing Ca from $CaCO_3$ which is usually present in the soils of the arid region (Miyamoto and Ryan, 1976). Ammonium polysulfide is another compound used for many years. The oxidation of NH_4 and elemental S yields H+, and releases Ca from $CaCO_3$. The effectiveness of these measures tends to decrease with increasing salinity of water, and is most consistent and reproducible in alluvial soils under clean cultivation. Leave check plots for evaluating their effectiveness.

Fig. 3. Simultaneous application of sulfuric acid and ammonia gas to fertilize trees and to condition irrigation.

There is a notion that Na can not be leached without adding chemicals. When the SAR of irrigation water is below the suggested limits, only a small fraction of the soils cation exchange sites is occupied by Na. In that case, Na leaching takes place by the passage of water alone. This situation applies to gypsic water rich in Ca and SO_4. This type of water is found in the Pecos River Basin as well in southern Chihuahua.

Desalting: The cost of desalting has declined significantly, but is still not low enough to be economical for pecan production. Desalted water, mostly through reverse osmosis is, however, used for public water supply as well as for watering putting greens in golf courses.

Increasing Salt Leaching

Irrigation Scheduling and Management: The basic equation which describes the salt balance in the root zone is

$$LF = (D_I - ET) / D_I$$
$$= C_W / [(n + 1)C_c - nC_W] \qquad [3]$$

where LF is the leaching fraction needed to maintain soil salinity below the threshold value of C_c, ET the evapotranspiration, D_I the depth of irrigation, C_W the salinity of irrigation water, and n a matching factor to compute the mean salinity of the feeder root zone; n = 1 for clayey soils and n = 2 for sandy soils.

Table 3 shows the target leaching fraction (LF) required to control soil salinity below 2.5 dS m^{-1} for sandy or clayey soils. The table includes the LF for surface-irrigated orchards where soil salinity distribution varies within an irrigation unit. With increasing salinity of irrigation water, the leaching required increases, in many cases to the levels which can not be readily obtained without creating standing water for several days.

Table 3. The target leaching fraction (LF) to control soil salinity below 2.5 dS m^{-1} in the saturation extract.

Irrig. Water salinity		LF (Uniform)		LF (30% CV)[1] -	
		sandy	clayey	sandy	clayey
dS m^{-1}	ppm	-------- % -------			
1.0	680	8	11	11	15
1.5	1020	11	18	18	24
2.0	1360	18	25	27	35
2.5	1700	25	33	---	---
3.0	2040	33	43	---	---

[1]- Apply to spatially variable alluvial soils

The target leaching fraction given above is the theoretical value, and it may or may not be achieved, especially in clayey soils or compacted soils which have low permeability. In these cases, it is difficult to leach salts in the middle of summer. The best time to leach salts is when the evapotranspiration rate is lowest. In other words, irrigation during the dormant period is most effective for leaching salts. It is also important to maintain good water infiltration and penetration during a growing season, even if the target LF may not be attained. Improved soil and floor management is among the options to maintain or improve water infiltration and penetration.

When irrigated with sprinklers, a caution should be taken not to under-irrigate. Frequent and light irrigation commonly used with sprinklers can lead to salt accumulation when the depth of water penetration decreases. Both the depth of water penetration and soil salinity should be checked periodically, and irrigation scheduling should be adjusted accordingly.

Soil Management: Chiseling and trenching are two of the most frequently used methods of improving water infiltration. Deep chiseling (90 cm) helps improve water infiltration and salt leaching in silty clay loam and coarser textured soils (e.g., Helmers and Miyamoto, 1990: Kaddah, 1976). Trenching is more suited in clay or silty clay, especially when stratified, as it helps mix soil profile (Miyamoto and Storey, 1995). Chiseling and trenching also work well with the soils containing caliche. The effect of deep chiseling usually lasts for many years, and that of trenching is nearly permanent. When trenching is used along a tree row, the area beyond the trench should be deep-chiseled so as to equalize water infiltration between trenched and un-trenched areas.

Soil compaction and soil aggregate break-down are two of the most challenging tasks of soil management. Sodded floor usually provides better soil structure and water infiltration than the floor under clean cultivation or treated with herbicides (e.g., Florenso et al., 1992). Table 4 shows an example obtained in a mature almond orchard established on sandy loam in Stanislaus Co. CA, (Prichard et al., 1990). Water infiltration increased by having clover as a cover by as much as 26 to 96 %. Resident vegetation (weeds) as well as Bromegrass also helped improve water infiltration towards the end of the season. However, both residence vegetation and clover increased water consumption by 14 to 17 %. The water consumption by the floor vegetation could have been greater if the orchard were young. The test orchard had 70 % ground shade. Bromegrass did not affect the water consumption during the period of the measurement, April 10 through the end of September. Bromegrass is a cool season grass. Overall, the improvement in water infiltration exceeded the increase in water consumption, but the effect on soil salinity is unknown as it was not measured. A separate field test conducted in a citrus orchard shows improved salt leaching under mulch.

Table 4. Consumptive water use and infiltration depth into the floor of almond orchard (Prichard et al., 1990).

	Water use (Apr - Sept)		Infiltration	
			May	Aug
	inch	%	cm/2 hrs	
Resident Veg.	32	117	5.2	5.5
Clover	31	114	6.7	6.3
Bromegrass	27	100	5.3	6.5
Herbicide	27	100	5.3	3.2

[1]- Mature orchard with 70 % shading

Our ongoing experiments using potted silty clay loam soils in a double ring infiltration system show that soil compaction substantially lowers the rate of water infiltration. Planting Oats, but not Buffalograss, in the compacted soils helped improve water infiltration as the season progressed. This difference can be attributed to the difference in growth rate and root mass; Oats are the fast grower, and Buffalograss is not. The fastest infiltration, excluding the uncompacted treatment, resulted when the compacted soil was cut vertically to a depth of 7.5 cm and was planted to Oats. It is entirely possible that the slots are filled with plant roots.

The above result points to the possibility that the rate of water infiltration into orchard soil could be improved by providing the vertical cuts into sodded floor. We are currently testing a minimum-till surface chisel to cut and loosen compacted surface soils with minimal disturbance to the sod cover (Fig. 4). This equipment has been marketed to maintain water infiltration into pasture with extensive livestock foot traffic, and the shank penetrates to 15 to 17.5 cm in soil depth. The passage of the shanks was found to cause extensive cracking of the surface soil if the soil is dry or moist (Fig. 4). This results in improved water infiltration as well as reduced growth of resident vegetation. After one year of experimental use by several growers in the El Paso Valley, all reported by

Fig. 4. A minimum-till surface chisel being tested for alleviating soil surface compaction in pecan orchards.

visual observation some improvements in water infiltration over disking. Disking, when used for extended periods, is known to develop a compacted layer at the disking depth, but also exposes soil aggregates to slaking, both of which are not helpful to water infiltration and salt leaching.

Reclamation

If soil salinization continues, it may require more potent measures. The specific measures required depend on site conditions, especially soil texture and water tables, and at times chemical properties of the soils.

Site Investigation

Site investigation for reclamation should include soil texture, profile configuration, and the depth to the water table. It is essential to identify the soil horizon which is likely restricting water movement and salt leaching. Soil samples, along with irrigation water samples, should be collected and be analyzed for salinity and sodicity. The record of irrigation is also useful and should be collected. If the water table is less than about 150 cm from the ground surface, water table monitoring wells should be installed (Miyamoto, 1989).

Reclaiming Clayey Soils

If the entire orchard consists of silty clay or clay, and salinity of irrigation water can not be lowered below 600 to 800 ppm, it may be advantageous to transplant the trees into more suitable sites. If clayey soils appear in small portions, trenching may help (Miyamoto and Storey, 1995). If the orchard consists of silty clay loam or clay loam, deep chiseling may help improve salt leaching (Helmers and Miyamoto, 1990). Some of the new subsoilers are equipped with a tripping device, and can be used to deep chisel mature orchards with large roots (Fig. 5).

Fig. 5. Spring-loaded subsoiling shank penetrating 70 cm deep.

If the soil test shows that the exchangeable Na exceeds 10 or higher, and that the soil is dispersed, the use of chemical amendments such as gypsum and sulfuric acid can help reduce soil sodicity and speeds up reclamation, especially in alluvial soils which have weak soil structure (Miyamoto, 1998). Chemical amendments should be applied after chiseling or trenching, and there is no need to incorporate them into the soil. Once chemicals are applied, leaching irrigation has to be made in order to leach salts, usually by applying two consecutive deep irrigations during the dormant period. The first portion of the leaching process can be made by using salty well water or drainage water, if available. If trees are damaged extensively, they should be pruned.

Reclaiming Gypsic Soils

Many soils in the gypsic basin, such as the Pecos River Basin, contain gypsum, and permeability is reduced due to pore plugging by gypsum. The use of sulfuric acid or gypsum in gypsic water simply compound soil pore plugging by gypsum precipitation. In gypsic water situations, deep chiseling followed by leaching irrigation is sufficient to improve salt leaching, provided that the depth of the gypsic layer is reachable with the deep chisel.

Reclaiming Soils with High Water Table

There are places where high water tables hinder salt leaching. Even there is a tile drain in such fields, the quantity of water applied to salt leaching can exceed the capability of the drain system. Under such circumstances, a special leaching technique should be considered. One method is to set two borders along the tree rows, then irrigate only within the strips (Fig. 6). This leaching technique helps lower drainage load, and store salts between the tree rows, which can be leached when the water table recedes after an irrigation season (Miyamoto, 1989). However, this method would be less effective in close spaced mature orchards. The quantities of leaching water required vary with soils and salt levels, and typically 30 to 50 cm. Once salt leaching is completed, sodding will help develop soil structure.

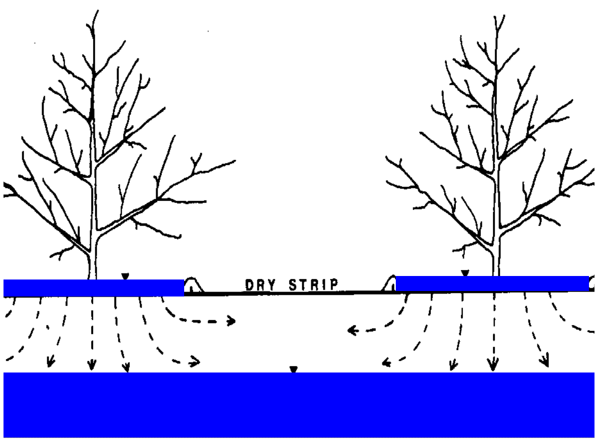

Fig. 6. Strip leaching of salted orchard with a high water table.

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