Effectiveness of Soil Salinity Management Practices in Basin-irrigated Pecan Orchards

Seiichi Miyamoto^{1,3} and Monte Nesbitt²

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SUMMARY. Soil salinity management is a factor for successful production of pecan (*Carya illinoensis*) in arid southwestern United States. An exploratory study was performed to evaluate the effect of various soil management practices on salt leaching in basin-irrigated orchards developed on alluvial soils (Torrifluvents, Entisols) of the middle Rio Grande Basin. The practices evaluated were ripping, minimum-till chiseling, and soil profile modification. For ripping, parabolic shanks were passed through the center section (4 to 8 ft wide) between each tree row to a depth ranging from 18 to 36 inches. Minimum-till chisels included 7- and 30-inch shanks, equipped with coulters to reduce break up of the ground surface. Soil profile modification consisted of trenching with a backhoe and profile mixing with a large excavator. The effectiveness of these methods was evaluated by measuring soil salinity and moisture in treated and untreated zones at 17 test sites. Both ripping and minimum-till deep chiseling helped improve salt leaching, and the effectiveness of salt leaching increased as working depths approach the thickness of the clayey layer. However, annual ripping of the center section of each tree row space may not provide wide enough zones to alleviate salt stress to the trees. Straight shanks prune but do not lift tree roots, thus appearing to be better suited for chiseling closer to tree rows. Soil profile modification was highly effective in leaching salts. From the view of minimizing soil aggregate destruction and of maintaining a leveled floor, minimum-till deep chiseling, followed by the use of sand-topdressing and minimum-till shallow chisels for maintenance may prove to be more desirable than conventional ripping, especially in soil types consisting of silty clay loam.

Pecan is among the most salt-sensitive tree crops currently grown in the southwestern United States. The threshold soil salinity in the main root zone for tree growth appears to be around 2.0 dS·m⁻¹ in the soil saturation extract when sodium (Na) is the dominant cation (Fig. 1). Tree growth decreases after soil salinity exceeds the threshold, and it essentially ceases at soil salinity of 4 to 5 dS·m⁻¹ or Na concentrations of about 30 mmol·L⁻¹ in the soil saturation extract, and branch dieback begins at about 5 to 6 dS·m⁻¹ (or 50 mmol·L⁻¹ of Na) or higher

(Miyamoto et al., 1986). High salinity also reduces shoot and leaf growth, nut size, and yields (Miyamoto et al., 1986). Although pecans are susceptible to acute effects of chloride (Cl) ions, the long-term effect on tree growth is associated more often with Na (Miyamoto et al., 1985).

Neither salinity nor sodicity of the irrigation water from the Rio Grande is exceptionally high (Table 1). In fact, salt-sensitive crops have been grown successfully in the Mesilla Valley located above the El Paso Valley. Quality of groundwater in the upper reach is usually as good as the river water, and the level of salt accumulation is only modest, 2 to 3.5 dS·m⁻¹ in the saturation extract, except in limited cases (Picchioni et al., 2000). In the El Paso Valley, reclaimed municipal effluent

(Table 1), returnflow, and/or salty groundwater are blended into the river water, especially during drought years, thus raising salinity of the irrigation water and irrigated soils. Salts often accumulate in clayey soils, which have low permeability (Miyamoto and Cruz, 1986). Figure 2 illustrates the typical profile of soil types in the study area, which are prone to soil salinization. Salinization is usually pronounced in deep silty clay and has been reported even in field crop production involving annual chiseling and plowing (Miyamoto and Cruz, 1987). Soil salinization is potentially exacerbated in orchard soils, mainly as a result of soil compaction imposed by equipment traffic. Soil compaction reduces soil permeability as well as root growth (Shafiq et al., 1994; Sillon et al., 2003) and can reach as deep as 3 ft under high axle load (Håkansson and Reeder, 1994). Experienced growers recognize the need to minimize salt accumulation in clayey portions, especially during or after the temporary use of saline groundwater.

There are two basic approaches in reducing salt accumulation. One is to apply an ample amount of water at each irrigation for salt leaching, usually using the steady-state salt balance equation as a guide (e.g., Rhoades, 1974). While this approach is conceptually valid, it is unlikely to leach salts from the clayey portion unless low permeability is improved. Otherwise, irrigation water applied to a basin percolates preferentially through permeable portions of the basin (Miyamoto, 1990). The use of control borders to hold ponded water in place can help, but is rarely practiced as water stands in the clayey portion for an extended period. Pecan trees cannot tolerate standing water during summer months (e.g., Kallestad et al., 2007).

Another approach is to improve permeability and drainage in the clayey portion of the basin. Various methods

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¹Professor and Soil Scientist, Texas AgriLife Research Center at El Paso, Texas A&M University, 1380 A&M Circle, El Paso, TX 79927.

²Extension Program Specialist, Texas AgriLife Extension Horticulture Sciences, Texas A&M University, Mailstop 2134 College Station, TX 77843.

³Corresponding author. E-mail: s-miyamoto@tamu.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
1	%	g/100 g	1
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.6093	mile(s)	km	0.6214
1	mmho/cm	dS·m ⁻¹	1
1	ppm	mg·L ⁻¹	1

Fig. 1. The relative trunk cross-section of pecan trees relative to those of the same age grown under no salt stress as related to the EC of the soil saturation extract (EC_e), in the main root zone depth of 0–24 inches (Miyamoto et al., 1986); 1 inch = 2.54 cm, 1 $dS \cdot m^{-1}$ = 1 mmho/cm, 1 $mmol \cdot L^{-1}$ sodium (Na) = 22.9898 ppm Na.

Fig. 2. Typical soil profiles (in inches of depth) of the soil types prone to salinization in the pecan study area (U.S. Department of Agriculture and Texas Agricultural Experiment Station, 1971); 1 inch = 2.54 cm.

are used to improve permeability and include ripping, subsoiling, slip plowing, soil profile modification, and chemical amendments (e.g., Miyamoto and Storey, 1995; Wildman et al.,

1988). Ripping employs parabolic shanks to break up the soil to various depths, whereas subsoiling with straight shanks creates soil cracks without ripping the ground surface. Slip

plowing, also a form of subsoiling, was once used extensively for row crop production, especially in California (Kaddah, 1976; Robinson and Luthin, 1968), but seldom in pecan orchards. Sodded floor management has also been reported to improve soil permeability (e.g., Folorunso et al., 1992; Prichard et al., 1990). However, the data needed to evaluate the effectiveness of these methods for leaching salt in pecan orchards are limited, except for ripping (Helmers and Miyamoto, 1990). The present study was conducted to determine the effectiveness of various management practices for lowering soil salinity in basin-irrigated pecan orchards established on alluvial soils. Results, largely exploratory, may be useful for developing soil management strategy in basin-irrigated orchards with similar soil characteristics.

Test sites and methods

Five orchards located within a 12-mile distance in the Lower El Paso Valley, TX, were examined for this study (Table 2). The primary consideration for selecting test orchards was to cover a broad range of soil types and soil management practices. An additional consideration was to include trees with leaf-tip burn. The extent of leaf-tip burn (a salt-stress indicator) was observed by measuring the length of browned tips in Oct. 2010, using 10 middle leaflets per tree (Table 2). Included in Table 2 is the tree trunk size measured at 2 ft above the ground, using five to six trees per soil sampling site.

The orchards examined were planted with 'Western Schley' at various time periods, laser-leveled, and irrigated using large basin methods with high flow gates. The irrigation water used came from the Rio Grande (Table 1). Orchard E and, to a lesser extent, Orchard B blended saline groundwater (3 to 4 $dS \cdot m^{-1}$) into the river water to supplement the shortfall. Orchard E has also used reclaimed water and returnflow mainly during fall and winter months for leaching salts. Reclaimed water has elevated sodicity (Table 1) and was treated on-site with sulfuric acid (Miyamoto and Storey, 1995). The area studied has the network of open drains, and the water table ranged from 6 to 9 ft deep during summer months and falls during the nonirrigation season.

Mature trees in the study area are typically basin-irrigated once per

Table 1. The mean concentrations of dissolved salts in the middle Rio Grande at American Dam and reclaimed municipal effluent, both reported monthly during 2009 and 2010.^z

Water sources	EC (dS·m ⁻¹) ^y	TDS (mg·L ⁻¹) ^y	SAR ^y	Sodium (mg·L ⁻¹)	Calcium (mg·L ⁻¹)	Magnesium (mg·L ⁻¹)	Chlorine (mg·L ⁻¹)
Rio Grande (El Paso, TX) ^z							
Winter (returnflow)	2.3	1440	9.1	332	117	27	280
Summer	1.0	630	3.6	122	60	15	96
Reclaimed effluent							
Northwest plant	2.1	1120	9.8	350	45	5	325
Bustamante plant	1.9	1090	8.3	277	60	15	346

^zRio Grande at the entry into El Paso, TX, in 2009 and 2010. Water salinity in the Lower El Paso Valley is higher by 50 to 200 mg L⁻¹ due to blending of reclaimed effluent and/or return flow.

^yEC = electrical conductivity, TDS = total dissolved salts, SAR = sodium absorption ratio; 1 dS·m⁻¹ = 1 mmho/cm, 1 mg·L⁻¹ = 1 ppm.

Table 2. Soil types, tree trunk sizes, leaflet sizes, leaf injury, and floor management practices used at the pecan test orchards.

Orchard code	Site code	Soil type ^z	Tree age (years)	Tree space (ft × ft) ^y	Trunk diam (inches) ^y	Leaflet length (inches) ^y	Leaf injury ^x	Soil salinity (dS·m ⁻¹) ^w	Floor management
A	1	Ha	32	32 × 34	15	—	—	2.3	Clean, disk
	2	Ge	19	40 × 40	9	3.9	H	2.8	Clean, ripping
B	2	Gs	37	32 × 36	8	3.4	M	3.5	Grass, ripping
	19	Gs	37	32 × 36	9	3.0	H	5.2	Grass, ripping
	16	Gs	37	32 × 36	11	3.5	H	4.2	Grass, ripping
C	1	Ha	48	32 × 32	14	—	—	3.2	Grass, herbicide
D	352	Hk	43	32 × 32	15	3.4	L	1.9	Clean, MTSC ^v , ripping
	372	Ge	43	32 × 32	12	3.0	H	4.9	Clean, MTSC, ripping
	351	Gs	43	34 × 34	13	3.2	H	3.8	Clean, MTSC, ripping
	5	Gs	13	17 × 40	7	3.8	H	4.9	Clean, MTSC, ripping
	132	Hk	17	17 × 34	10	3.5	H	4.0	Clean, MTSC, ripping
	3	Gs	16	32 × 34	10	3.7	H	5.0	Clean, MTSC, ripping
	133	Tg	17	17 × 34	6	3.0	M	4.0	Clean, MTSC, ripping
E	29	Ge	13	30 × 30	8	3.6	M	2.7	Grass and herbicide
	55	Sc	52	34 × 54	8	3.6	H	4.1	Grass and herbicide
	552	Tg	50	30 × 46	11	3.1	M	2.6	Grass and herbicide

^zFor soil profile identification, refer to Fig. 2; Ha is similar to Hk.

^y1 ft = 0.3048 m, 1 inch = 2.54 cm.

^xLeaf-tip burn as percent of leaflet length: L = low (<5%), M = medium (5% to 10%), H = high (>10%).

^wSalinity of the saturation extract made from 0 to 2 ft from untreated zones; 1 dS·m⁻¹ = 1 mmho/cm.

^vMTSC = minimum-till surface chisel.

month during March through May and twice a month during June through September with a season total of 11 to 12 irrigations. A typical irrigation depth is 4 inches per application, except for the first irrigation. However, Orchard B, consisting of Glendale soil series, has used 6 inches of irrigation every 3 weeks during summer months. Orchard E was irrigated at less than 2-week intervals and has practiced off-season irrigation. The main root zone of pecan trees in this valley is rather shallow, typically ranging from 18 to 36 inches (Miyamoto, 1983).

Floor management practices varied with orchards. Orchard A used

clean cultivation using a ripper and a cultivator. The ripping operation was performed in one direction at two sites using three shanks spaced 40 inches apart at a width of 7 ft to a depth of 18 inches. The first site consisting of Harkey loam (Ha) had no history of ripping, and the second site on Glendale silty clay loam (Ge) had been ripped once per year. Ripping was followed by a cultivator (8-inch deep, five shanks spaced 12 inches apart equipped with a spike roll to break clods) in both directions throughout the orchard floor. This orchard had been irrigated with river water, supplemented with well

water of low salinity (1.4 dS·m⁻¹) as needed.

Orchard B had initially adopted clean cultivation using a ripper and a disk and then was converted to mowed floor management for 5 to 6 years until 2003. Well water with elevated salinity (conductivity of 3.4 dS·m⁻¹) was used during the drought of 2003, resulting in significant salt damage, including tree dieback. Soil profile modification was then implemented in every other tree row in the center 12 ft to a depth twice the thickness of the clay layer 3 years before soil sampling. Unexcavated rows were ripped using five shanks

spaced 15 inches in one pass covering a 7-ft strip in the center to a depth of 36 inches. The entire floor was then disked in two directions and leveled.

Orchard C used a cultivator and a mower in the center and herbicide along the tree rows to control floor vegetation. In 2004, a minimum-till shallow chisel (MTSC) equipped with 8-inch shanks spaced 15 inches apart was introduced (Fig. 3A). The chisel was used in one direction, two passes covering a total of 18 ft, once in April, then in June to a depth of 7 inches. Soil samples were collected in July from three zones: chiseled, mowed, and herbicide-treated strips.

Orchard D used a disk to control floor vegetation and ripping in the center to a depth of 17 inches since planting. The MTSC was introduced in 2004 and has been used in the center 18-ft strip in one direction with two passes after each irrigation until June. In 2008 (2 years before sampling), the ripper was replaced with deeper curved shanks; a set of five shanks spaced 20 inches apart. The ripper was passed once in one direction at 6 ft wide to a depth of 36 inches at the beginning of each irrigation season. In some blocks of Orchard D, the projected tree rows were trenched before tree planting 16 to 17 years ago, 9 ft wide every 34 ft to a depth sufficient to mix the two layers at a 1:1 ratio. Trees were then planted along the center of the trenches at a spacing of 17 ft to form hedge rows. The area that was not trenched was chiseled with the MTSC in two passes in one direction (18 ft wide) and with the ripper along the middle (7 ft wide to a depth of 36 inches).

Orchard E used a mower to control vegetation for many years. After the drought of 2003, minimum-till deep chiseling was introduced as a means to break up the compacted floor. The equipment with a four-shank

assembly (Fig. 3B) with a width of 9 ft was pulled by a 250-horsepower tractor in two passes at a total width of 18 ft between tree rows, leaving 7 to 8 ft to the tree trunks in Mar. 2008. It was followed by topdressing with dry loamy sand to a depth of about 1 inch. (Loamy sand is locally available along the edge of the floodplains or below the clay layer.) The dry sand filled soil cracks, which measure up to 3/4 inch wide, and covered the ground lightly. Soil samples were collected from unchiseled and chiseled zones 2 to 3 years later.

Soil samples from three depths (0–1, 1–2, and 2–3 ft) were collected at five to six holes per soil type per treated and untreated zones. According to a previous study (Miyamoto and Cruz, 1986), salinity of soil samples collected in this manner is expected to yield the mean value with a deviate range of 15% from the true mean. Soil samples collected were air-dried, passed through a 2-mm screen, and the saturated paste was prepared as described in Rhoades and Miyamoto (1990). The moisture content of the saturated paste and salinity of the saturation extract were determined gravimetrically and with an EC meter, respectively. The effect of soil treatments on these properties was assessed with the split-plot analysis of variance, using the depth as the main plot and the soil treatment as the subplot (Little and Hills, 1975), followed by the Duncan's multiple range test at a 5% level.

Results and discussion

RIPPING. The use of 18-inch ripper in Harkey loam (Ha) section of Orchard A resulted in a significant reduction in soil salinity in the ripped zone, especially at a depth of 1–2 ft where salts had been accumulated to the level of $4.8 \text{ dS}\cdot\text{m}^{-1}$ (Table 3). Soil salinity readings below 2 ft were lower

than at 1–2 ft, as a result of oversaturation, which occurs in loamy sand. The ripping operation also resulted in significantly higher field soil water contents (Table 3). Annual ripping of Glendale silty clay loam (Ge) at the second site in Orchard A caused nearly complete leaching of salts from the ripped zone (Table 3). However, the soil moisture content below 1 ft was lower in ripped zones, probably as a result of a greater degree of water uptake by the roots, which branched out because of repeated root pruning over the years. Soil salinity of the ripped area was also significantly lower in Glendale silty clay (Gs) section of Orchard B, as reported in Helmers and Miyamoto (1990). Additional data on soil ripping effects on soil salinity are shown in Tables 5–8.

These data show that ripping promotes salt leaching where implemented. However, annual ripping along the middle of row space did not seem to alleviate salt stress to the trees. Although soil salinity decreased to as low as $1.5 \text{ dS}\cdot\text{m}^{-1}$ in the ripped zone, leaf injury at Orchard A, for example, remained at an elevated level. Likewise, ripping at Orchard D lowered soil salinity significantly, but leaf-tip burn remained high, especially at Sites 351 and 5. The trees seem to be responding to salinity of the unripped zones, as the ripped zone accounts for a small proportion, usually less than 1/4 of the orchard floor, and roots are cut every year.

MINIMUM-TILL CHISELING. Salinity of soil samples collected from chiseled, sodded, and herbicide-treated zones in Orchard C is shown in Table 4. Chiseling was made with the MTSC twice before sampling. There was no significant effect of chiseling on soil salinity at the first depth, but it did lower it at the depths below. The use of the chisel may have helped improve water penetration. Unfortunately, field soil moisture data were not available at this site.

The MTSC used in combination with deep ripping (36-inches deep) at Orchard D did not lower soil salinity, but deep ripping did at the sites consisting of deep clayey soils (Table 5). At Harkey silty clay loam (Hk) site, there was no significant impact of soil treatments on either soil salinity or soil moisture levels. Although the MTSC did not significantly lower soil salinity, the soil moisture level in the chiseled

Fig. 3. (A) Minimum-till surface chisel and (B) deep-shank, both equipped with coulters.

Table 3. The saturation water content (SWC), soil salinity, and field soil moisture content in ripped and unripped (control) zones at pecan Orchards A and B.^z

Depth (ft) ^y	SWC (g/100 g) ^y	Texture	Salinity (dS·m ⁻¹) ^y		Moisture (g/100 g)	
			Control	Ripped	Control	Ripped
Harkey silt loam (Orchard A)						
0–1	45	Silt loam	2.9 a ^x	2.0 b	7.8 a	10.0 b
1–2	30	Loamy sand	4.8 a	2.5 b	5.3 a	6.3 b
2–3	25	Coarse sand	1.6 a	1.1 b	3.0 a	4.1 b
Glendale silty clay loam (Orchard A)						
0–1	56	Silty clay loam	2.2 a	1.5 b	8.7 a	11.0 b
1–2	42	Silt loam	3.4 a	1.4 b	10.8 a	9.6 b
2–3	31	Loam	4.0 a	1.5 b	6.2 a	4.0 b
Glendale silty clay (Orchard B) ^w						
0–1	67	Silty clay	3.5 a	2.0 b	—	—
1–2	59	Silty clay loam	5.7 a	4.9 b	—	—
2–3	51	Siltv clay loam	5.1 a	4.5 b	—	—

^yFor description of Orchards A and B, refer to Table 2.

^y1 ft = 0.3048 m, 1 g/100 g = 1%, 1 dS·m⁻¹ = 1 mmho/cm.

^xNumbers in row followed by the same letter in each parameter are not significantly different via Duncan's multiple range test at $P \leq 0.05$.

^wReported by Helmers and Miyamoto (1990).

Table 4. The saturation water content (SWC), soil salinity in surface-chiseled, mowed, and herbicide-treated zones at pecan Orchard C.^z

Depth (ft) ^y	Texture	SWC (g/100 g) ^y	Salinity (dS·m ⁻¹) ^y		
			Chiseled	Mowed	Herbicide
Harkey silt loam (Ha)					
0–1	Silt loam	55	2.4 a ^x	2.4 a	2.3 a
1–2	Silt loam	46	4.0 a	4.8 b	5.2 b
2–3	Loamy sand	31	4.2 a	6.2 b	8.8 c

^yFor description of Orchard C, refer to Table 2.

^y1 ft = 0.3048 m, 1 g/100 g = 1%, 1 dS·m⁻¹ = 1 mmho/cm.

^xNumbers in rows followed by the same letter are not significantly different via Duncan's multiple range test at $P \leq 0.05$.

zone was comparable to the ripped zone. This observation may indicate that irrigation water has infiltrated in the chiseled zones, but not deep enough to cause adequate salt leaching. It is uncertain whether annual ripping helped reduce salt stress or actually accentuated the problem by letting irrigation water to leak through the ripped strip where roots are cut annually. The salt-stress indicator remained high, especially at Sites 351 and 5 of Orchard D (Table 2).

The minimum-till deep chisel (MTDC) (using 30-inch shanks) caused a major reduction in soil salinity when tested in the Glendale silty clay loam section of Orchard E, but had no impact on field soil water contents (Table 6). The test field was irrigated in October, about 2 weeks before soil sampling, and the field was wet when sampled. The saturation water content of the surface 1 ft was lower than that of the depth below, as a result of topdressing with sand in

both chiseled and nonchiseled areas. The MTDC also reduced salinity in Saneli silty clay loam at Site 55, but not to the same degree as it did in Glendale silty clay loam (Table 6). Note that Saneli silty clay loam, but not Glendale, has an expandable clay layer below 18 inches (Fig. 2), thus making it difficult to leach. The soil moisture data indicate higher soil moisture contents below 1 ft, as compared with those unchiseled zones (Table 6). In Tigua silty clay, which has a deep clay layer (Fig. 2), chiseling did not lower soil salinity as it was already low because of prior excavation. Nonetheless, the saturation water content remained high at Tigua site, indicating that the site was deep-plowed, but probably did not reach the loamy sand layer below. In deep silty clay soils, the MTDC probably needs to be combined with either trenching or deep subsoiling to assure drainage.

Leaf injury remained at a moderate level at Site 29 of Orchard E

consisting of Glendale silty clay loam even though soil salinity in the chiseled zone decreased to as low as 1.0 dS·m⁻¹ (Table 2). The area chiseled accounts for nearly two-thirds of the orchard floor, and the grower reported visible improvements in tree growth along with water infiltration. It is yet to be seen if salt stress will decrease to a low level with time as the roots reestablish themselves in the chiseled area with low salinity. Leaves at Site 552 consisting of Tigua silty clay have also shown some yellowing, a symptom common in wet soils.

SOIL PROFILE MODIFICATION. Soil profile modification conducted 2 to 3 years before soil sampling at Orchard B caused a significant reduction in soil salinity in all cases tested (Table 7). (The data for Site 2 were similar to Site 16 and are omitted for simplicity.) Ripping with the 20-inch curved shanks also helped reduce salinity although not to the same extent as achieved by soil profile modification. The saturation water content has also decreased from 60–70 to 35–45 g/100 g, which corresponded to that of silty clay and silt loam, respectively. The soil salinity data obtained as a function of distance from the end of the excavated strip showed no reduction in salinity with the distance, starting at the first sampling site, which was 3 ft away from the edge of excavation. This finding is consistent with an earlier report that the effect of trenching on salt leaching

Table 5. The saturation water content (SWC), soil salinity, and field soil moisture contents of soil samples collected from unchiseled (control), deep-ripped strips (Rip), and minimum-till surface chiseled (MTSC) zones at pecan Orchard D.^z

Depth (ft) ^y	Texture	SWC (g/100 g) ^y	Salinity (dS·m ⁻¹) ^y			Field moisture (g/100 g)		
			Control	MTSC	Rip	Control	MTSC	Rip
Harkey silty clay loam (Hk), Site 352 ^x								
0–1	Silty clay loam	50	2.1	1.6	1.2	11	10	8
1–2	Silty clay loam	40	1.5	1.4	1.1	7	11	7
2–3	Loam	32	1.5	1.9	0.6	5	6	4
Glendale silty clay loam (Ge), Site 351 ^w								
0–1	Silty clay loam	55	3.3 a ^v	2.9 a	2.8 b	16 a	17 a	17 a
1–2	Silty clay loam	57	6.2 a	6.2 a	3.4 b	18 a	18 a	20 b
2–3	Silty clay loam	47	5.5 a	5.6 a	5.6 a	16 a	14 a	20 b
Glendale silty clay (Gs), Site 5								
0–1	Silty clay	57	5.2 a	4.0 b	3.2 c	7 a	10 b	11 b
1–2	Silty clay	61	6.2 a	4.4 b	3.3 c	7 a	10 b	10 b
2–3	Silty clay	64	6.4 a	4.8 b	3.5 c	5 a	5 a	15 b

^xFor description of Orchard D, refer to Table 2.^y1 ft = 0.3048 m, 1 g/100 g = 1%, 1 dS·m⁻¹ = 1 mmho/cm.^zNo mean separation is given as analysis of variance shows insignificant response.^wData from Site 372 were similar to Site 351 and are omitted for simplicity.^zNumbers in rows followed by the same letter are not significantly different via Duncan's multiple range test at $P \leq 0.05$.**Table 6. The saturation water content (SWC), soil salinity, and field moisture contents in chiseled zone with the minimum-till deep chisel (MTDC) and unchiseled zones (control) at pecan Orchard E.^z**

Depth (ft) ^y	SWC (g/100 g) ^y	Texture	Soil salinity (dS·m ⁻¹) ^y		Moisture (g/100 g)	
			Control	MTDC	Control	MTDC
Glendale silty clay loam (Ge), Site 29						
0–1	54	Silty clay loam	2.6 a ^x	1.1 b	23 a	22 a
1–2	60	Silty clay loam	2.9 a	1.1 b	25 a	27 a
2–3	62	Silty clay loam	3.9 a	1.0 b	26 a	26 a
Saneli silty clay (Sc), Site 55						
0–1	55	Silty clay loam	2.6 a	1.8 b	27 a	18 b
1–2	75	Clay	5.5 a	3.4 b	18 a	28 b
2–3	72	Clay	5.6 a	4.8 b	17 a	22 b
Tigua silty clay (Tg excavated), Site 552						
0–1	61	Silty clay	1.7 a	1.9 a	17 a	16 a
1–2	76	Clay	3.4 a	3.6 a	26 a	18 b
2–3	72	Clay	3.8 a	4.9 a	23 a	20 b

^xFor description of Orchard E, refer to Table 2.^y1 ft = 0.3048 m, 1 g/100 g = 1%, 1 dS·m⁻¹ = 1 mmho/cm.^zNumbers in rows followed by the same letter are not significantly different via Duncan's multiple range test at $P \leq 0.05$.

is essentially confined within the trench (Miyamoto and Storey, 1995).

According to the irrigation supervisor of orchard B, no change in irrigation scheduling (6 inches of irrigation every 3 weeks) was made after profile modification. The site observations indicate that the middle of the excavated strips has settled by as much as 1 to 2 inches. It is possible that salt leaching in the excavated zones was helped in part by the deeper water application in the zone. Sodding of the excavated area may help stabilize the disturbed soil. Trees in excavated

areas began strong regrowth, including compensatory shoot growth upon excavation. However, a modest level of tip-burn was evident.

Trenching implemented 17 years ago before tree planting at Orchard D has shown mixed results (Table 8). The trenched strips (noted as Exca. in the table) showed higher salinity than the zone ripped with the 36-inch shank, especially at depths below 1 ft. This finding is a sharp contrast to the results from Orchard B shown earlier. The data also show that the excavated zone had salinity equal to

or higher than salinity of the MTSC-treated zones and that the field soil moisture content of the excavated zone at Hk and Gs sites was greatly lower than the other zones (Table 8). One possible explanation is that permeability of the excavated soils has decreased over the 17-year period. Indeed, there are many cases where permeability of excavated soils have declined when subsoils affected by Na were brought to the surface (Miyamoto and Storey, 1995). In this case, a more realistic reason seems to be settling in the traffic zones, coupled with deep

Table 7. The saturation water contents (SWC), soil salinity, and field moisture contents of soil samples collected from untreated (Control), ripped (Rip), and excavated (Exca.) strips at pecan Orchard B.^z

Depth (ft) ^y	Texture	SWC (g/100 g) ^y		Salinity (dS·m ⁻¹) ^y			Field moisture (g/100 g)		
		Control	Exca.	Control	Rip	Exca.	Control	Rip	Exca.
Glendale silty clay (Gs), Site 19									
0–1	Silty clay	63	45	2.5 a ^x	2.9 a	1.1 b	13 a	12 a	11 a
1–2	Silty clay	70	41	6.0 a	4.5 b	1.1 c	23 a	22 a	14 b
2–3	Silty clay	68	47	6.9 a	6.2 b	1.2 c	25 a	24 a	16 b
Glendale silty clay (Gs), Site 16 ^w									
0–1	Silty clay	60	43	4.0 a	1.9 b	1.8 b	13 a	15 a	14 a
1–2	Silty clay	69	36	6.9 a	4.0 b	1.7 c	23 a	21 a	10 b
2–3	Silty clay	77	35	7.4 a	5.4 b	1.5 c	25 a	28 a	11 b

^zFor description of Orchard B, refer to Table 2.

^y1 ft = 0.3048 m, 1 g/100 g = 1%, 1 dS·m⁻¹ = 1 mmho/cm.

^xNumbers in rows followed by the same letter are not significantly different via Duncan's multiple range test at $P \leq 0.05$.

^wResults from Site 2 were similar to Site 16 and are omitted for simplicity.

Table 8. The saturation water contents (SWC), soil salinity, and field moisture contents of soil samples collected from untreated rows (control), excavated rows (Exca.), deep-ripped strips (Rip), and minimum-till shallow chiseled (MTSC) zones at pecan Orchard D.^z

		SWC (g/100 g) ^y		Salinity (dS·m ⁻¹) ^y			Field moisture (g/100 g)		
Depth (ft) ^y	Texture	Control	Exca.	Exca.	MTSC	Rip	Exca.	MTSC	Rip
Harkey silty clay loam (Hk), Site 132									
0–1	Silty clay loam	50	42	2.7 a ^x	2.3 a	2.0 b	7 a	10 b	10 b
1–2	Silt clay loam	44	36	5.4 a	5.6 a	3.7 b	9 a	14 b	16 b
2–3	Silt clay loam	38	40	4.4 a	6.2 b	4.7 a	7 a	11 ab	12 b
Glendale silty clay (Gs), Site 3									
0–1	Silty clay	66	63	4.1 a	4.3 a	3.6 b	15 a	20 b	20 b
1–2	Silty clay	75	63	6.1 a	6.1 a	4.9 b	17 a	23 b	26 b
2–3	Silty clay	77	67	6.3 a	5.9 a	5.3 b	16 a	26 b	27 b
Tigua silty clay (Tg), Site 133									
0–1	Silty clay	69	49	2.1 a	4.8 b	2.1 a	14 a	13 a	24 b
1–2	Silty clay	73	47	6.1 a	6.5 a	3.5 b	17 a	32 a	31 b
2–3	Silty clay	76	42	7.0 a	7.1 a	4.2 b	12 a	21 b	32 c

^zFor description of Orchard D, refer to Table 2.

^y1 ft = 0.3048 m, 1 g/100 g = 1%, 1 dS·m⁻¹ = 1 mmho/cm.

^xNumbers in rows followed by the same letter are not significantly different via Duncan's multiple range test at $P \leq 0.05$.

ripping and premature cut-off of irrigation. A field observation indicated that the elevation of the tree row became higher by at least 1 inch over the traffic row where deep ripping was performed.

OVERALL ASSESSMENT. This study indicates that salt leaching can be enhanced through modifying soil structure and/or texture of the clayey layer present above sandy subsoils, a unique feature of Torrifluvents in the study area. It is widely believed that soil compaction (which usually occurs at and near the soil surface) limits water infiltration and salt leaching. If this assessment is correct, decompaction of the surface soils with shallow chisels or cultivators alone should have alleviated water penetration and salt leaching problems. However, these methods

were found to have limited value in soils with a thick clayey layer (Tables 4 and 5) although the field soil moisture was nearly equal to that from the ripped zone. Low permeability of the clay layer below the surface may have limited the downward movement of soil water and salt leaching. There are other observations, which seem to support this hypothesis. First, soil salinity tends to be higher with increasing thickness of clay layer (Tables 5–8). The most extensive leaching was observed when the clayey layer was modified to its full extent through profile modification (Table 7) or by deep ripping (Table 5).

It has been suggested that the presence of a high water table is the cause of soil salinization in the study area. Although the water table is indeed elevated (6 to 9 ft from the ground

surface) during summer months, no correlation was found between soil salinity and groundwater levels. The steady-state analysis of the upward capillary flow (e.g., Gardner, 1957) indicates that the upward flow becomes significant when the water table becomes shallower than 4 to 5 ft, but not below 6 ft. Nonetheless, the high water table probably affects the permeability of clay in the capillary fringe, but not of sandy subsoils, thus reducing salt leaching in clayey soil types.

The presence of roots has to be an important consideration in selecting the method to be used. Soil profile modification certainly offers an effective option in soils with deep clay subsoil, such as Saneli and Tigua series, but cuts off roots. Fortunately, pecan trees have remarkable ability to

reestablish the root system. Pruning of roots helps develop multiple fine roots from the cut, which extend by 2 to 3 ft per season (Miyamoto, 2010). Ripping is well suited for initial soil preparation (before planting) and in young orchards. Annual use in mature orchards certainly raises some concern over root lifting, reworking of ripped fields as well as its true effectiveness in reducing salt stress as a result of annual root cutting. Reworking of the ripped field involves disking and leveling, which is often more time-consuming than does ripping operation. The MTDC also has the problem of cutting roots although it does not lift the roots or rip the ground surface. It creates numerous soil structural cracks, which are needed for rapid transmission of soil water (e.g., Pandey, 1985), and sand application has shown to help maintain structural cracks and soil permeability. Sand mulch is also reported to reduce aggregate destruction associated with clean cultivation (Acharya and Abrol, 1976). It is unknown at present how long the effect of sand application may last beyond the 3-year experience. The annual use of minimum-till surface chisel, perhaps with sodding, may help maintain permeability and salt leaching. Additional years are needed to make assessment of longevity of chiseled and topdressed orchard floor.

In addition to soil texture and profile factors, irrigation practices seemed to have had a significant effect on salt leaching. Soil salinity of untreated zones of Glendale soil series in Orchard E (Table 5) is, for example, lower than that observed for the similar soil at Orchard D (Table 5) although orchard E has been irrigated with water of higher salinity. This orchard has been irrigated more often and practiced late season irrigation. This study also indicates that flood irrigation has to have the leveled floor for uniform salt leaching. A field study conducted in deep loamy sand using large transplanted trees shows that water uptake was greatest near the tree trunk (Sorensen and Jones, 1999), presumably because the root density of the transplanted trees was highest near the trunk. Root pruning with ripper or subsoiling shanks is likely to yield high root densities along the chiseling lines. It may be advantageous to have the ground slightly tilted toward the shank path if it can be managed.

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