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Updated Guidelines for Soil Selection and Improvements for Irrigated Pecan Production: Alluvial Soils

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Synopsis

Soil types (texture and profile configuration), soil salinity, sodicity, subsoil drainage, and fluctuating high water tables, have the pronounced effect on tree performance in pecan orchards established in alluvial soils. This paper outlines the soil types and soil properties suited or not suited for irrigated pecan production, using the decades-long experience in the El Paso Valley, Texas. Various ways to improve undesirable soils, such as chiseling, trenching, and soil profile modification are also briefly discussed. The information presented would be useful for planning orchard development in alluvial basins of the West.

Introduction

Pecan orchards have been developed in a wide variety of soils, ranging from sand to clay, shallow to deep, soft to hard, and well-drained to poorly drained. A consequence has been a wide range of tree performance, ranging from excellent to poor. New plantings, stimulated by a favorable market forecast, are coming in with improved soil selection, and more importantly with various ways of improving the soils.

The most significant change in soil selection has been increased uses of soil maps along with improved access to soil type information and presentation through internet. The visual observation of orchards along with the soil type distribution map, such as shown in Fig. 1, provides convincing evidence of soil type influence on tree growth. This orchard was planted in a period of 1971 to 1973, and has undergone thinning in the sections with normal tree growth rates. Note that the trees have grown better in the area mapped as Ha (Harkey loam) and Ga (Gila loam) than in the area of Gs (Glendale silty clay) or Tg (Tigua silty clay). This is an example of the repeated pattern of tree response to soil types developed in the El Paso Valley, and occurs to different degrees, regardless of the orchard locations or the tree management practices used. Alluvial soils developed in floodplains and bottomlands (called Entisols) are usually stratified, and above all, structurally weak, as compared to upland soils. Knowing this pattern of soil type impact, several questions have been raised. First, which soil type provides better growth, and which does not? Second, if certain soils are not suited, what can we do to improve them? These are the questions addressed here for alluvial soils. Soil maintenance is a topic beyond the scope of this paper.

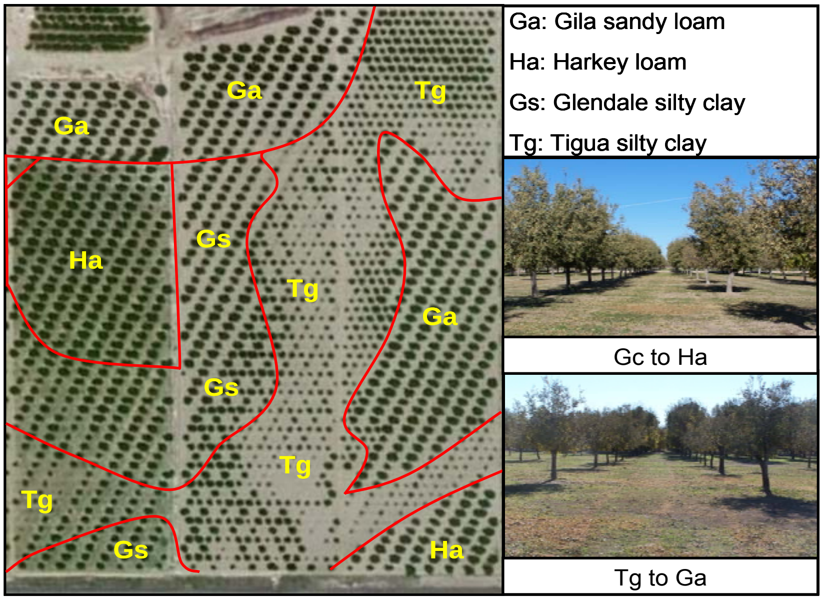

Fig. 1. An aerial and ground view of a pecan orchard (39 years old) consisting of multiple soil types in the El Paso Valley, TX.

Soil Type Dependence

Soil types are the most detailed soil classification and mapping unit, and are based primarily on soil texture and profile configuration. Soil reports prepared by USDA, NRCS (Natural Resources Conservation Service) designate a typical soil profile for each soil type, such as shown in Fig. 2 for selected alluvial soils. It includes Glendale silty clay (Gs) and Tigua silty clay (Tg) which appeared in Fig. 1. The actual depth of the clay layer of Tg can exceed 50 inches, and has a pronounced impact on tree performance. Two other soil types which appeared in Fig. 1, Ha and Ga, are not shown in Fig. 2, but these soils have loam or sandy loam extending about 17 inches, and the depth below consists of loamy sand or other sandy materials. We seldom have had problems for growing pecans in these types of sandy soils.

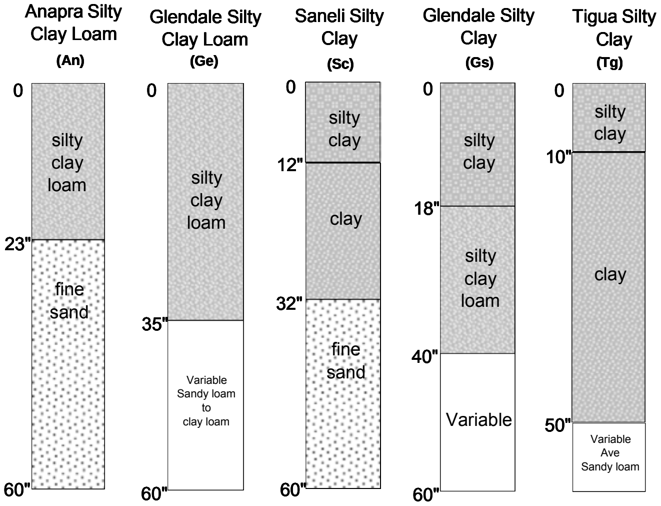

Fig. 2 Typical soil profiles of clayey alluvial soils of the El Paso Valley, TX.

Table 1. General classification of soil types for growing pecans under basin irrigation in the middle Rio Grande Basin.

Suitable without modification	
	Gila sandy loam (Ga), loam (Gc)
	Harkey loam (Ha), silty clay loam (Hk)
Suitable with minor modification	
	Anapra silty clay loam (An)
	Saneli silty clay loam (Sa)
	Glendale loam (Gd), silty clay loam (Ge)
Suitable with major modification	
	Glendale silty clay (Gs)
	Saneli silty clay (Sc)
	Tigua silty clay (Tg)

These observations led to the development of general suitability guidelines for various soil types, and examples are shown in Table 1 for the El Paso Valley. These pecan orchards are basin-irrigated with water from the middle Rio Grande (having salinity of 600 to 800 ppm) and at times supplemented with groundwater of elevated salinity. Since soil types in other areas are likely to be different, it is necessary first to compare the site soils with these sample profiles. Once soil profile similarity is recognized, general suitability of the soils can be assessed by using the classification shown in Table 1. Another option is to utilize the type of visual information shown in Fig. 1, and to establish tree growth as related to soil types for the existing pecan producing area of interest.

Note that Harkey silty clay loam (Hk) is placed under the first category, “Suitable without Modification,” whereas Glendale loam (Gd) is placed under the second category. The soil type Hk has a layer of silty clay loam to a depth of about 12 inches, whereas Gd has a subsoil layer consisting of silty clay loam to a depth of about 40 inches. In addition, clay minerals contained in Hk are nonexpandable and nonsticky, whereas Glendale series, along with Saneli and Tigua series contain expandable clays. In other words, these are the cases where soil profile configuration and clay types, beside soil texture enter into the suitability assessment.

Quality of water to be used for irrigation has an impact on appraisal of soil suitability. Typically, fine textured soils become unsuitable when salinity or sodicity of water to be used for irrigation is elevated. We found that the ratio of soil salinity and salinity of irrigation water (referred to as the salt concentration factor), increases with increasing the clay content of the irrigated soils (Table 2 from Miyamoto, 2010). This includes both Hk and Gd where sod stratification reduces salt leaching upon soil compaction. The projected soil salinity of clayey soils can exceed the soil salinity limit of 2.5 to 3.0 dS m^{-1} when salinity of irrigation water exceeds 1 dS m^{-1} (or less in silty clay or clay) is to be used, unless the clayey soils are modified. This includes both Gd and Hk soil types.

Table 2. Soil textures, the saturation water content, and the typical salt concentration factor, and projected soil salinity in basin-irrigated pecans.

Soil texture	Saturation water content	Salt Concentration factor [1]	Projected soil salinity irrigated with water of		
			1.00	1.5	2 dS m^{-1}
	ml/100g		-------------	dS m^{-1}	-------------
Sandy loam	<30	1.0-1.2	1.0-1.2	1.5-1.8	2.0-2.4
Loam/silt loam	30-45	1.2-2.0	1.2-2.0	1.8-3.0	2.4-4.0
Silty clay loam	45-60	2.0-3.0	2.0-3.0	3.0-4.5	4.0-6.0
Silty clay/clay	>60	3.0-5.0	3.0-5.0	4.5-7.5	6.0-10

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

Additional Soil Properties

Although soil types play a dominant role of determining soil suitability, there are other soil properties which affect tree performance. The depth to the water table is, for example, an important factor in any river basins and has to be evaluated independently of soil types. Under certain hydrologic conditions, sandy soils are subject to a rapid fluctuation in water table. Pecan trees may tolerate a static water table as shallow as 6 ft or less, but suffer if the table fluctuates during a growing season. When the water table rises, it usually brings up dissolved salts to the root zone. Such incidences have occurred from time to time along the Middle Rio Grande. One incident increased salinity of the top 1 ft to as high as 12 dS m^{-1}, which is high enough to defoliate and kill the trees (Miyamoto 1989). Trees under fluctuating water tables suffer not only from oxygen deficiency, but also from salt effects. When subsoil drainage is poor, excess water in soil profiles can also cause reduced photosynthesis and defoliation (Alben, 1958: Smith and Ager, 1988).

Soil compaction and/or soil strength affect both root growth and water infiltration. This constraint along with the problems of soil particle cementation caused by calcium carbonate and/or gypsum precipitation is common in upland soils, but seldom in alluvial soils. However, there are a few cases where soils were excessively compacted during prior cropping, or due to certain soil forming history. Soil compaction caused by farm equipment is usually limited to the surface 4 to 6 inches. However, vehicle traffic with high axle load can cause subsoil compaction as deep as 40 inches (Håkansson and Reeder, 1994). Plant roots simply can not penetrate through high strength soils as demonstrated by van Zyl (1988) for grapes, and by Unger and Kaspar (1994) for field crops.

Soil salinity is another property which has a pronounced impact on tree performance. Soil salinity in excess of 2 to 3 dS m^{-1} in the soil saturation extract can adversely affect tree growth. Tree dieback occurs when soil salinity exceeds around 5 to 6 dS m^{-1} (Miyamoto, 2006). Mortality of bare root transplants can occur at lower salinity. Soil survey reports may or may not provide a general warning about the presence of saline soils (which has soil salinity greater than 4 dS m^{-1} in the soil saturation extract). The salinity threshold of pecan trees is well below the saline soil limit, thus requiring a separate soil test and assessment.

Soil sodicity, when elevated, causes soil structural degradation, thus reducing water infiltration and soil permeability. Alluvial soils which typically have weak soil aggregates are especially vulnerable to disintegration and dispersion, especially when they come in contact with low salt irrigation water (< 600 mg L^{-1}) or rain runoff. The threshold sodicity which may cause soil structural degradation ranged from 3 to 6 in the exchangeable sodium percentage (ESP), depending on soil types and salinity of water used for irrigation (e.g., Oster and Schroer, 1979). High Na concentrations in soils (> 100 me L^{-1}) can also cause root injury (e.g., Picchioni et al., 1991). The exchangeable Na tends to increase with soil depth along with soil salinity. The impact on water infiltration and soil structural stability is magnified when the Na-affected subsoils are brought to the soil surface through trenching or excavation.

Some soils can contain certain trace elements which are toxic to plants. Boron (B), for example, can be toxic to pecans even when its concentration in the soil saturation extract is as low as 1.0 ppm (Picchioni et al., 1991). If the soils were developed from marine deposits or affected by geothermal activities or disposal of industrial effluent, B should be checked.

Soil Improvements

There has been a notion that it would be difficult to justify spending money for soil improvements at the time of or prior to tree planting. Typically, soil improvements in silty clay loam help reach maturity at least a few years earlier, and help improve the yield of mature trees. In the case of silty clay, soil improvements may have to be assessed against acquiring or trading off with new properties with better soils. As indicated earlier, there is little evidence to indicate that economic production of pecans can be achieved in massive silty clay without major improvements, especially when irrigated with water of elevated salinity. Such an example was shown earlier in Fig. 1. In either case, the justification hinges upon growers' particular situations.

In selecting an option or options described below, it is important to recognize the soil profile characteristics first, then decide what properties you intend to improve. As shown earlier in Fig. 2, the limiting layer for pecan production in alluvial soils is the clayey layer which restricts water infiltration, percolation, salt leaching, aeration and trafficability, especially when exceed about 2 feet in thickness. This profile characteristic is in sharp contrast to upland soils of the Southwest (Aridisols) where clay and calcium carbonate contents are usually increase below 2 feet, and often become impediment to root growth, drainage, and salt leaching. Soil compaction and soil aggregate distraction further compound the problem. Even when the clayey layer does not exceed 2 feet, the soil may not be suitable for retaining adequate quantities of water for infrequent surface irrigation. Typically, the primary targets of soil improvements in alluvial soils are to enhance water infiltration, penetration, salt leaching, and soil water storage and availability. In many instances, the targets include a reduction in soil salinity. It is, however, not easy to lower water tables or soil Boron concentration.

Shallow Ripping: This approach is applicable mainly to silty clay loam. The primary objective is to break off the tight clayey surface soils, and to leach out salts from the previous cropping. The common tool used is curved ripper shanks (Fig. 3a) which penetrate 18 to 24 inches. This type of shank is also used to facilitate land leveling. It has a limited value for improving silty clay with the clay depth exceeding about 30 inches, such as Glendale, Saneli, and Tigua silty clay. Shallow chiseling helps improve water infiltration and salt leaching where the shanks pass (Table 3). In established orchards, the use of ripper shanks brings up large roots, unless a certain distance from tree trunks are maintained. Most growers thus run the shank routinely at the center of the tree row space. Unfortunately, this leaves the majority of orchard floor to be untouched, and has little positive effect on tree performance (Miyamoto, 2010).

Fig. 3. Ripper shank, subsoiling shank, deep chisels, and an excavator used by growers in the El Paso Valley

Minimum-till Subsoiling: One of the inconveniences of shallow ripping is the need to rework the chiseled field, which usually takes more time than the chiseling operation itself. Minimum-till shanks (Fig. 3b) are designed to minimize ripping of the ground surface, but to concentrate on breaking subsoils, typically to a depth of about 30 inches. Soil cracks are essential for water infiltration, penetration and salt leaching in silty clay or clay (e.g., Pandey, 1985). The cracks created by subsoiling are usually filled by dry sand to maintain the elevated level of water infiltration rate, water penetration, and salt leaching. This method can be implemented in a strip along the intended tree rows or in wider strips after tree establishment. If the site contains a clayey surface layer, cross-chiseling after application of a sand layer allows deep sand incorporation between clay

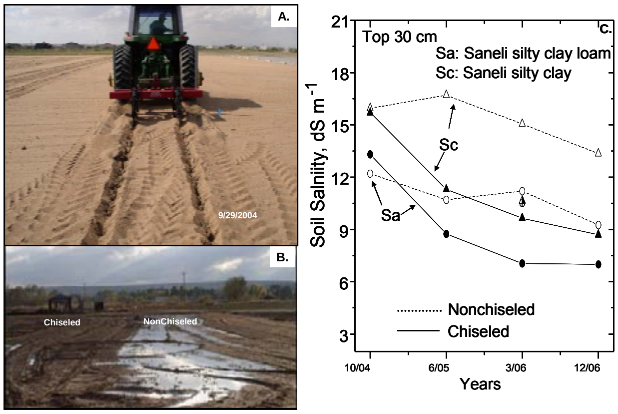

Fig. 4 Sand incorporation into clayey soils with a use of subsoiling chisels (Fig. 4A), improved water infiltration in chiseled areas (Fig. 4B), and changes in soil salinity in Saneli silty clay and Saneli silty clay loam (Fig. 4C).

clods. This method greatly improves water penetration and salt leaching (Fig. 4). The history of using this type of shank in the El Paso Valley is only for about 4 years, but the early results have been largely positive (Table 3), especially in established orchards where a curved parabolic shank can not be used near the trees. Straight shanks are common for subsoiling prune roots, thus allowing soil improvements in the root-zone. Regrowth of the pruned roots usually takes place rapidly with multiple root developments from the pruning cuts. A constraint of this method is high power requirements to pull the shanks, typically 30 to 50 Hp per shank. An associated constraint is its inability to go deeper, unless the number of shanks is reduced. This method is ideally suited for silty clay loam with the layer not exceeding about 30 inches.

Deep Chiseling: Two types of equipment are available. One type is a large single or multiple parabolic shanks which can reach 4 to 5 ft, provided that a tractor has the necessary horse-power and a clearance. This type of shank was originally developed for breaking out the calcic or the gypsic soils prevalent in upland soils. The effectiveness of this method for improving drainage in silty clay extending beyond 30 inches has not been adequately demonstrated. The soft clay layer of Saneli and Tigua silty clay tends to seal back as it becomes water-saturated with heavy irrigation. Wing attachments to breakout the clear boundary between the clay layer and the sandy profile below (Fig. 3c) may reduce this seal-back problem. Once drainage improvement through deep chiseling is confirmed, this method can be combined with minimum-till subsoiling or shallow ripping.

Another type of deep chiseling equipment is referred to as a slip plow, which can reach as deep as 6 ft or more. Because of the large draft, the width of the slip is fairly restricted, usually no more than 15 inches wide. Slip plows break up the horizontal orientation of soil particles, and have been shown to improve permeability and salt leaching in heavy clay soils of the Imperial Valley, California (Kaddah, 1976; Robinson and Luthin, 1968). When tried in the El Paso Valley along the middle of row space, the results were not encouraging. The observations of slip-plowed strip, using the cross trench, has shown no identifiable changes in soil profile, except that wet soils and water-saturated sand present below, has melted back into the original shape with little evidence of upward movement of sandy soil into the clayey layer above. The experience of using slip plows for orchard establishment is limited in the El Paso Valley, and no definitive conclusion can be drawn. In California, slip plowing is used successfully for establishing grape orchards. However, recent attempts to use it for almond orchards irrigated with drip or microjet systems seem to have resulted in little tree response. The effectiveness of slip plowing appears to depend on soil and crop types, plus irrigation methods used.

Deep Trenching: Trenching along the dripline of one side of tree rows with a backhoe was originally introduced as a means to deal with stunted young trees planted in silty clay loam and silty clay. The recommended depth of the trench has been twice the depth of the clayey layer which allows mixing of clay and loamy or fine sand at a ratio of 1:1, which yields a texture of loam. The width varies, ranging from a few feet to as wide as 4 ft, depending on the type of backhoes available. The effect of trenching is basically confined in the trenched strip, and there is little indication that it helps leach salts beyond the trench (e.g., Miyamoto and Gobran, 1983), unless combined with chiseling. This method usually helps improve the growth rates of young trees in both silty clay and silty clay loam. Increasing numbers of growers are now adapting this method prior to planting. In deep clay loam or silty clay soils, trenching can be combined with chiseling, especially minimum-till chiseling with sand topdressing. Trenching is to be made at a depth sufficient to dig out sand. An alternative is to fill up bottom portion of the trench with sand for improved drainage along the original land contours, combined with chiseling in a perpendicular direction along the slope of the original topography. Trenching is a slow process, and requires some allowance for a settling period.

Table 3. Examples of salt leaching after various soil improvement measures.

Methods	Frequency	Depth	Soil Salinity ($dS\ m^{-1}$)	
Soil Types[1]	years	ft	Treated	Untreated
Shallow Chiseling (17"- 20")				
Ha	annually	0-1	2.0 a	2.9b
		1-2	2.5 a	4.8b
Ge	annually	0-1	1.5 a	2.2 b
		1-2	1.4 a	3.4 b
		2-3	1.5 a	4.0 b
Gs	annually	0-1	2.0 a	3.5 b
		1-2	4.9 a	5.7 b
		2-3	4.5 a	5.1 b
Minimum-Till surface chisel (7")				
Hk	annually	0-1	2.4 a	2.3 a
		1-2	4.0 a	5.2 b
		2-3	4.2 a	8.8 b
Minimum-Till deep chisel (30")				
Ge	once 2007	0-1	1.1 a	2.6 b
		1-2	1.1 a	2.9 b
		2-3	1.0 a	3.9 b
Sc	once 2007	0-1	1.8 a	2.6 b
		1-2	3.4 a	5.5 b
		2-3	4.8 a	5.6 b
Excavation				
Gs	once 2008	0-1	1.8 a	4.1 b
		1-2	1.6 a	5.6 b
		2-3	1.6 a	7.1 b
Tg	once 1993	0-1	2.0 a	4.5 b
		1-2	6.2 a	6.6 a
		2-3	7.0 a	7.1 a

[1] For identification of soil types, refer to Table 2.

[2] Numbers followed by the same letter are not significantly different at a 5% level

Excavation: This method is the extended version of trenching covering essentially the entire orchard floor using a large excavator if implemented prior to tree planting. When implemented after planting, excavation is usually performed every other row first, then the skipped rows a few years later after salt leaching and some regrowth of tree roots in the excavated rows. In the case of small trees or trees which experienced dieback, excavation is made on both sides of the trees. The mixing ratio of 1:1 for clay and loamy sand is usually a target, but the actual ratio is often dictated by the depth of the clay layer, and the availability of equipment and budget. When mixed with sand, it helps salt leaching (Table 3). If the sand is not incorporated or the excavation does not reach the sandy layer, this method does not provide the satisfactory results, because of the waterlogging at the bottom of the root zone. Although this method is very effective, it is costly and requires a period of settling and leveling after excavation. Excavated soils also require maintenance, such as decomposition, and periodic soil leaching, especially when sand mixing was limited. There are cases where excavated fields have undergone the secondary salinization, when sand mixing was limited (Table 3).

Water Table Control: Various methods have been tried to lower elevated water tables, including deep trenching, subsurface drain, besides open drains. Deep trenching (18 ft deep plus) seems to have evolved with the notion that a clay layer must be present below the water table, and breaking the layer should help lower it. However, the outcome has been mixed, as much as the assumptions involved. Subsurface drains have been used successfully in the Lower Rio Grande Valley, but not in the middle Rio Grande. This type of drain is designed to remove ordinary drainage water resulting from irrigation, and can not handle large influx of seepage, either from the river or from irrigation canals or wash (e.g., Miyamoto, 1989). It requires a special design. In some cases, the perched high water table is developed due to the presence of deep clay soils in the direction of subsurface water flow, which may be present beyond the boundary of pecan orchards. Canal seepage and river flow leakage are common sources, but strict control of these sources can reduce groundwater recharge. Because of the complexity involved, water table control is often beyond the resources of individual growers. It may be addressed appropriately as a part of groundwater management plans at a district level.

Chemical/Biological Methods: Soil application of chemical amendments, such as gypsum and sulfuric acid following trenching or excavation was found effective in promoting water infiltration and salt leaching. Without any amendment, the soil dug from deeper depths can seal due to high exchangeable sodium, unless sufficient quantities of sand are present in the surface layer. Although it is not a chemical amendment, a thin layer of sand (about 1 ½ inches) placed on severely sodium-affected soils has apparently increased water infiltration (Acharya and Abrol, 1976). The sand layer reportedly helped reduce dispersion. Gypsum and polysulfide application to undisturbed soils were found to have no measureable impact on water infiltration and salt leaching in the El Paso Valley (Helmers and Miyamoto, 1990; Miyamoto and Storey, 1995). However, water-run application of chemicals seems to be helping water infiltration after saline groundwater or reclaimed municipal effluents are used to supplement irrigation, especially in excavated orchards with clean floor management. The sodium adsorption ratio (SAR) of the reclaimed water is between 8 and 9, and that of the Rio Grande is around 3.5. Although successful uses of water-run chemicals are reported in sandy loam soils of California (e.g., Wildman et al., 1988), elevated salinity of irrigated water used in pecan producing areas of west Texas along with its highly variable soil type distribution often limit its effectiveness. There are many other chemicals which have been marketed to improve soils for many years. Growers may wish to have check plots, and test soil salinity, besides tree response. Lowering soil salinity usually means improved soil water movement and/or reduced evapotranspiration, if irrigation is kept the same. It is also a consideration to reduce soil erosion at the water checking point as it generates suspended particulates which plug soil pores at the soil surface. Water-run chemicals are mainly for soil maintenance, but usually not for soil preparation for orchard developments.

Planting of reclamation crops, such as sorghum and oats, is another way to condition sodic soils prior to tree planting. Sorghum is known to help reduce the exchangeable Na by solubilizing $CaCO_3$ through intensive respiration (e.g., Robins 1986). According to a study in Idaho, one cropping with sorghum removed the exchangeable sodium in an amount equaling a 5 tons/acre rate of gypsum application. Incorporation of crop residue from sorghum also helps increase soil organic matter and soil aggregation. There are indications that planting of oats or bromegrass may help in water infiltration (e.g., Prichard et al., 1990). These crops are known to be reclamation crops or soil builders, and are usually planted one year ahead of tree planting after soil profile modification or, occasionally for intercropping. Planting of reclamation crops or sodding of orchard floor is especially effective in stabilizing excavated fields.

Soil Maintenance

Soil improvement activities should be followed by appropriate soil maintenance practices. It involves soil aggregate maintenance, decompaction and occasional salt leaching irrigation. Some of these practices are described in separate articles (Miyamoto, 2010; Miyamoto and Storey, 1995).

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