

Improving Permeability and Salt Leaching in Irrigated Sports Fields: Exploratory Testing

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TWRI Technical Report 310

February 2008

Acknowledgment

The work reported here was supported in part by the Cooperative State Research, Education, Extension Service, U.S. Department of Agriculture under Agreement No. 2005-34461-15661, and was carried out in cooperation with El Paso City Parks and Recreation Department, and El Paso Water Utilities. The purpose of this program is to help conserve water, while improving the turf conditions of irrigated sports fields. Document preparation was assisted by Jessica White, Technical Assistant II at the Research Center, along with David Tirre, Engineer Associate at El Paso Water Utilities. Irazema Rojas, Manager of Water Reclamation and Biosolids at El Paso Water Utilities helped facilitate matching funds. Richard Garcia with the Parks and Recreation Department provided administrative support to conduct field testing.

Contents

Summary	1
Introduction	2
Nature and Distribution of Problematic Soils	3
Compacted Soils.....	3
Clayey Soils.....	4
Stony Sediments.....	5
Caliche.....	5
Observation Sites	6
Sandy Alluvial Sites.....	6
Clayey Alluvial Sites.....	7
Stony Sediments.....	7
Indurated Caliche.....	7
Equipment Used	8
Procedures and Results	10
Sandy Alluvial Soils.....	10
Clayey Alluvial Sites.....	12
Stony Sediments.....	21
Indurated Caliche.....	22
Discussion	24
Diagnosis of Salt Accumulation.....	24
Assessing the Need for Soil Improvements.....	24
Soil Improvement Measures.....	25
Tasks Ahead.....	28
References	29
Attachments	30

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The name of equipment manufacture or distributor is mentioned here solely for an informational purpose, and does not imply endorsement by the authors or affiliated institutions. Readers should be aware of the facts that the performance of any implement varies with soil conditions.

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SUMMARY

Many sports fields developed in the El Paso Valley and some in uplands became salinized when irrigated with water containing 800 to 1,200 mg/L of dissolved salts. The soil types, which were salinized, include compacted soils, clayey Entisols, stony sediments along foothills, and some areas containing an indurated calcic horizon. Salinity of these soils was initially less than 3 dS m^{-1} in the saturation extract, and has increased over a decade or two in excess of 10 dS m^{-1} , sufficient to deter growth of most turf grass species. The study reported here was performed for evaluating various mechanical means of improving soil permeability for enhancing salt leaching. Observation included two municipal parks consisting of sandy alluvial soils, five sports fields consisting of clayey alluvial soils, sports fields consisting of topdressed stony alluvial soils or developed on an indurated calcic horizon through topsoiling. The equipment tested included a rotary tiller, a vibratory spike, aerifiers, a minimum-till surface chisel, a subsoiler, a backhoe, and a front-end loader. Field management practices were left to discretion of cooperators. Soil salinity and photo records of turf response were used as the primary means of the treatment impact.

The most significant reduction in soil salinity was found when stratified silty clay was either inverted to the new profile sequence of loamy sand over the fractured silty clay clods or mixed with the loamy sand layer below. Replacement of clays with sandy soils in a corrugated surface to permit lateral drainage was also highly effective in salt leaching in deep clay. Subsoiling of Glendale and Saneli silty clay loam followed by topdressing with a thin layer of sand also resulted in good salt leaching, especially when flood-irrigated using the Rio Grande water. The subsoiling shanks penetrated 20 to 30 inches deep, or almost to the full extent of the clay layer. It is uncertain if salt leaching can be improved when used in deeper clay, such as Tigua silty clay. The use of minimum-till shallow chisels provided an excellent fracturing of the surface clay layer (6 to 8 inches deep), but salt leaching was limited due to internal drainage impairment. The use of aerifiers did not improve salt leaching, at least at our test sites. Nonetheless, surface implements, especially minimum-till shallow chisels can be used advantageously for renovation or for sustaining high use fields consisting of loam. These preliminary test results are consistent with an earlier finding that soil salinization problems are closely tied with clayey soil textures. Test results also indicate that drainage impairment caused by the clay layer is probably as common as the difficulties with water intake for leaching salts.

Since soil improvement measures to be used depend upon soil type, the field should be surveyed for soil type and its distribution prior to planning soil improvement activities. Irrigation systems and scheduling should also be checked. The primary goal of soil improvement activities is to improve soil permeability, water movement and salt leaching, and must be complemented by prudent turf management practices to obtain turf response. There is a need to examine the existing codes or specifications for construction of new fields for improved salt leaching. The current construction codes for sports fields emphasize soil strength and stability, but not salt leaching.

INTRODUCTION

Sports fields (mainly football and soccer fields) are among the fastest growing public facilities in urban communities of the Southwest. The demand for this type of facility is driven by the rapid increase in young population. In order to meet these demands, many communities have converted public parks and land-holding into sports fields, and some have constructed a multi-million dollar sports complex. Unfortunately, this type of land use conversion has been made without adequate consideration to soil suitability.

Since sports turf is subjected to extensive foot-traffic, rapid re-growth from its use is essential. Irrigation, along with fertilization, is an essential management tool to enhance turf growth and recovery. However, irrigation adds large quantities of salts, besides water, to the soils. Potable water in the Southwest, for example, contains dissolved salts around a ton per acre-ft. of water. This means that 3 to 4 tons of salts will be added annually to an acre of turf at a typical annual water application of 36 to 48 inches. Reclaimed water used for irrigation usually contains greater quantities of salts, as much as several tons per acre-ft. in some cases (Table 1). When this type of water is used for irrigation, irrigation water must be able to infiltrate, penetrate, and a portion of it must drain out of the soil. If one of these processes is too slow, the soil can become droughty or soggy, salty, and eventually affecting turf growth and vigor.

The first documented case of soil salinization in the El Paso Valley (Table 2) appeared many years ago in clayey soils of the Valley irrigated with potable water with a dissolved salt concentration of 800 mg L⁻¹ (Miyamoto et al., 1997). The reported soil salinity levels, reaching well above 10 dS m⁻¹, were high enough to deter growth of most turf species, including bermudagrass which is salt-tolerant (Miyamoto et al., 2004). The records of soil salinity measured shortly after facility construction has shown initial soil salinity levels of less than 3 dS m⁻¹. These increases have occurred since 1978 or over the time span of two decades, since irrigated farmlands were converted to school yards and municipal parks. Following this report of 1997, the El Paso City Parks and Recreation Department (EPCPRD) began using various types of aerifiers, but with mixed results. Water Utilities considered that little can be done from the water supply side, as they are providing drinking water for irrigating these parks.

Starting around year 2000, the growth of El Paso accelerated to the North

Table 1. Salinity and annual salt loading from irrigation using potable or reclaimed water.

Water Sources	Salinity	Salt Load ¹ -
	mg/L	tons/acre
Potable		
Upper Valley	550-650	2.4-2.8
Lower Valley	800-850	3.5-3.7
Reclaimed		
Haskell	900-950	3.9-4.1
Northwest	1150-1200	5.0-5.1

¹ Assessing the annual water application of 42 inches.

Table 2. Salinity of soil samples collected from recreational turf areas located on different soil types: Irrigation water salinity of 600 to 800 ppm (Miyamoto et al., 1998).

Soil Series	Texture	Salinity ('78)	Salinity ('97) ¹ -	
		means	means	max.
-----dS m ⁻¹ -----				
Bluepoint	loamy sand	0.6	1.5	2.6
Canutillo	sandy loam	--	1.6	3.3
Hueco	sandy loam	0.9	1.8	3.3
Delnorte	gravelly loam	0.9	1.7	2.5
	Caliche	--	3.8	11.1
Turney	silty clay loam	0.8	3.9	6.9
Harkey	silty clay loam	2.8	11.1	18.4
	High water table	--	27.0	32.0
Glendale	silty clay	2.7	36.9	45.7

¹ Soil salinity is expressed by the electrical conductivity of the soil saturation extract. Growth of Bermudagrass curtails significantly at soil salinity of 6 dS m⁻¹.

(the Upper Valley and the Westside), and to the East. The Upper Valley has high water tables (about 30 inches from the ground surface), and several sports fields were salinized even when irrigated with potable water. Several upland sites have also undergone salinization after the source of irrigation water has changed to reclaimed water with salinity of 1,150–1,200 ppm.

Salinization of sports turf is rarely recognized by landscape architects, sport field contractors, or by maintenance professionals. Unlike golf courses, low-end sports fields which include parks and schools are constructed using various guidelines and standards. Many of the existing guidelines emphasize soil strength and stability, but not necessarily salt leaching. Neither construction nor maintenance professionals seem to recognize that when there is no drainage under the high evaporative condition of west Texas, soil salinity of sports fields irrigated with reclaimed water can increase to the salt tolerance limit of bermudagrass in a matter of months.

This paper reports the nature of soil salinization and exploratory testing of various mechanical measures on salt leaching. The treatments involve the use of conventional as well as specialized equipment to loosen compacted soils, alter the soil profile of stratified soils or deep clay, and to facilitate drainage from poorly permeable caliche. This project was conducted in cooperation with the El Paso City Parks and Recreation Department and El Paso Water Utilities from 2002 to 2007.

NATURE AND DISTRIBUTION OF PROBLEMATIC SOILS

Four types of soils were identified, which are prone to salinization: compacted soils, clayey alluvial soils, stoney sediments, and indurated caliche. Clayey soils (clay loam and clay) are distributed in the Rio Grande floodplain below El Paso (commonly referred to as the Lower Valley) as well as in the floodplain above downtown El Paso (the Upper Valley). Stony sediments and shallow soil containing indurated caliche layers appear along the western foothills of the Franklin Mountains, and are included in the mapping units, U-4 and U-5 shown in an attached soil map (Attachment I). Soil salinization is seldom reported in the soil mapping unit U-1 (which occupies Northeast El Paso) or in U-2 and U-3 (which occupy East El Paso).

Compacted Soils

Soil compaction is an inevitable consequence of using soils for athletic turf or pasture for livestock. Compaction slows water infiltration and percolation (Shafiq, et al., 1994), increases water evaporation from the soil surface (Sillon et al., 2003), and water runoff when sloped. However, not all the compacted soils have water infiltration problems. Sandy soils (mapping units V-1, U-1, and U-2 of Attachment I), even after extensive compaction, can maintain necessary infiltration, unless it is sloped. In clayey soils (Units V-3 and V-4), modest compaction can reduce water infiltration and develop standing water. Standing water is subjected to high rates of evaporation, nearly half an inch per day, thus leading to soil salinization. Soil compaction caused by foot traffic is also a common cause of water runoff in sloped-turf. The depth of soil compaction varies, typically 2 to 6 inches in high foot-traffic area, and rarely exceeds 8 inches, even in the case of machine traffic. The depth of compaction increases with increasing soil moisture (Sillon et al., 2003). Aerifying equipment is designed or intended to break the compacted layer.

Clayey Soils

Clayey soils (commonly referred to as 'dobe') appear in alluvial plains of the Rio Grande Valley. According to the soil survey report (USDA/TAES, 1972), clayey soils occupy 70% of the Lower Valley and are included in the soil mapping units V-3 and V-4 (Attachment I). These soils include Glendale silty clay loam or silty clay, Saneli silty clay loam or silty clay, and Tigua silty clay. For details, readers may refer to a separate article on soils (Miyamoto, 2000). The clay contents of these soils are too high to allow for adequate water infiltration and percolation. This problem is compounded by soil compaction, and at times by soil aggregate break-down caused by the exchangeable sodium (Na). Irrigation water or rainfall tends to stand at the surface (Fig. 1a). To avoid ponding, irrigators reduce irrigation depths per application, thus the depth of water penetration and salt leaching are reduced (Fig. 1b).

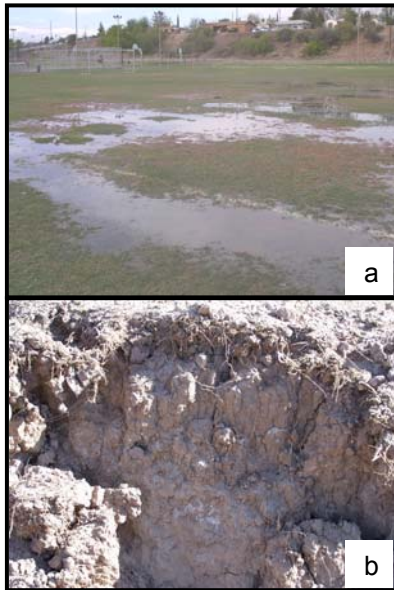


Fig. 1 Water ponding caused by poorly permeable clay (1a) and salt accumulation in the clay layer (1b).



Fig. 2 Poor water infiltration into sports fields developed on clayey soils.

penetration and salt leaching are reduced (Fig. 1b).

Rainfall usually can not infiltrate once clayey soil is salinized, because sodium (Na) ions cause aggregate breakdown. If one attempts to leach salts by applying a large quantity of water, it can stand for days. Bermudagrass usually continues to grow, as it responds favorably to ample amounts of water and nitrogen application. However, the clayey ground can become a muddy area (Fig. 2a). When dried, the soils become hard. These are not ideal features for athletic activities.

A conventional method of dealing with this type of soils is to reseed and apply gypsum (Fig. 2b). Gypsum application to disked and pulverized clay can help improve water infiltration into the pulverized soils (e.g., Miyamoto and Enriquez, 1990). However, if subsurface drainage is impaired, usually the case in deep clay, gypsum application has limited or no impacts on salt leaching.

Some clayey soils, such as Anapra, Harkey, and Saneli series, are stratified with a clear boundary (Fig. 3a). Soil stratification becomes a concern when a layer of clay rests on sand. When a clayey layer is present above a layer of sand, water penetration is deterred until the clay layer is saturated.

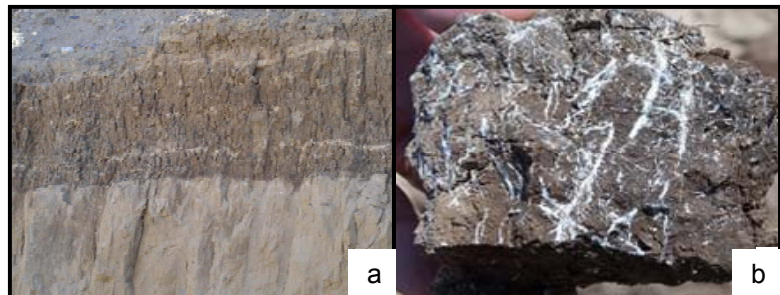


Fig. 3 Soil profile of stratified soils (3a), and salt accumulation in old root channel in the top layer (3b).

In sports fields irrigated with sprinklers, no drainage is likely to result beyond the boundary between the two horizons, unless deliberate leaching irrigation is practiced. This leads to salinization of the clay layer as exemplified in Fig. 1b as well as Fig. 3b. Salt leaching from stratified soils is possible only when the clayey soil has sufficient permeability. Silty clay and clay usually do not fall into this category.

Since the movement of soil water ceases at the boundary, plant roots are rarely found in the sand layer. This observation led to a false notion that the sand is not good for plants. Actually, this sand layer is better suited for growing turfgrass. Mixing or inverting two layers can create better soil for grass growth.

Stony Sediments

Stony or gravelly sediments are represented by mapping unit U-4, and consist mostly of Canutillo series, and Augustin series. No detailed soil map is available for the upland area, and Canutillo series are mapped together with Del Norte series as Canutillo – Del Norte Association. These soils are rated in the soil survey report as being excessively drained with the estimated permeability of 0.63 to 2.0 inches per hour for Augustin series, and 2.0 to 6.3 inches per hour for Canutillo series. The high permeability, at least it was thought to be, is due to high fractions of the stone and gravel fraction (around 50%).

For the last several years, dozens of city parks and school sports fields have received reclaimed water with dissolved salt contents of 1,150 to 1,200 mg/L with the sodium adsorption ratio of 9. So far, several sites consisting of these soils and graded to nearly flat had been salinized within a year and a half after the conversion. The subgrade is topsoiled by sandy soils, typically loamy sand. Excavation of some of these sites revealed that the surface of the subgrade consisting of either Augustin or Canutillo series became impervious or nearly impervious (Fig. 4). The reason for this unusual soil behavior is yet to be investigated. In some cases, we found the sediments filling between the stone and gravel are made of gravelly clay, instead of gravelly loam. In some occasions, we found gravelly loam is affected by Na. In other instances, we observed neither clay nor Na, but there was a lightly cemented calcic horizon. It is possible that heavy equipment traffic over the subgrade has also caused plugging of the pore space with dispersed soil particles.



Fig. 4 Examples of stony sediments in the Canutillo soil series, and poor drainage upon topdressing.

Caliche

The term ‘caliche’ seems to be used to designate all types of soils which are difficult to manage. Strictly speaking, caliche is upland soil containing a layer or layers of calcium carbonate (CaCO_3), which is referred to as the calcic horizon by soil scientists. The majority of caliche is permeable. Some calcic horizons, however, contain distinct horizontal plates which are indurated and have very low permeability (Fig. 5b). The thickness of the plate or the layer ranges from less than an inch to as thick as several feet. The materials

between these plates or layers can be any texture, but are usually sandy. Del Norte soil series is an example of this type of soils (Fig. 5a and 5b).

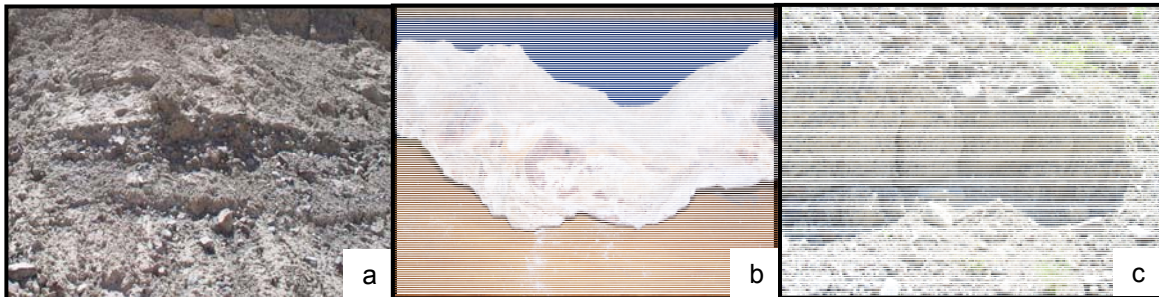


Fig. 5 Example of the Delnorte soil series containing the calcic horizon.

The slope of the caliche layer affects drainage. When the surface of the caliche layer has an appreciable slope, and the calcic horizon has cracks, there would be natural drainage as the percolating water travels along the surface of caliche layer until finding a crack (Fig. 5c). The drainage problem appears when the calcic layer is graded to a minimum slope, and the calcic horizon has no cracks or is sealed during construction. Even when topdressed (typically to a depth of 6 to 8 inches), salinization can occur when the subsoil (calcic layer) does not have sufficient permeability. The subgrade slope needed for appropriate drainage has not yet been determined, and would vary depending on the hydraulic conductivity of the topsoil, the distance to the crack, as well as irrigation management.

OBSERVATION SITES

Nine sites were selected based primarily on soil types for observation. All the sites were planted to either common or hybrid bermudagrass, and have been irrigated with sprinklers, except at the practice field adjacent to William Surratt Elementary School in Clint where both sprinklers and flood methods have been used. The soil types at the observation sites were determined through profile examination, and the results are shown in Attachment I. The sources of irrigation water used are shown in Table 3 (page 10).

Sandy Alluvial Sites

Two small parks (Estrella – Rivera and Mary Webb) consisting of sandy alluvial soils were selected for observation. Estrella – Rivera Park (consisting of Gila sandy loam) had two sections; one area was flat with a decent turf cover, and another area was sloped and had poor grass cover. Soil salinity in the good cover area was 4.2 dS m^{-1} in the soil saturation extract, and 9.6 dS m^{-1} in the poor grass cover area. The annual water application was estimated at 26 inches based on water meter readings and the area of irrigated land. This water application rate is well below the annual allotment of 48 inches and was said to be used to minimize runoff from the poor turf area with a considerable slope. In addition, construction activities are said to have disrupted normal irrigation scheduling. Soil samples were collected from four sites in the salted area, and additional four sites in the area with a good turf cover.

Mary Webb Park, consisting of Harkey silt loam, also had two different zones, one receiving extensive foot traffic and another, an open park area. The first area has been used for practicing football, and the middle section of about a 10-ft. strip was void of turf, due to overuse. The remaining area had good growth of hybrid bermudagrass. Five soils

samples were collected from the ten-ft. strip area, and five additional soil samples were collected from the park area outside of the practice field.

Clayey Alluvial Sites

The first site (Lomaland Park) consisted of Harkey silty clay loam which extends 17 to 19 inches over loamy sand. The second site, Shawver Park, consists of Harkey silt loam, Anapra silty clay loam, and Saneli silty clay loam, or silty clay. The silty clay loam layer in Anapra series extends no more than 24 inches whereas in Saneli series, it extends to a depth of 30 to 34 inches. Site inspection, however, indicated that the top clayey layer extends only 24 to 28 inches at this site. The third site (a practice field in Clint) consisted of Glendale silty clay loam and silty clay, which extend an average of 30 inches over loamy sand. The fourth site (Pavo Real Park) consists of two sections, and the South section consists of Saneli silty clay loam, whereas the North section consists of Tigua silty clay with the clayey layer extending 40 to 50 inches over loamy or medium sand. The fifth site (Valley Creek Park) had multiple soil types: Harkey loam, Harkey silty clay loam, Saneli silty clay loam and silty clay with the clay layer extending 32 to 34 inches. The sketch of the typical soil profile is shown in Attachment I.

Stony Sediments

The area, which consists of stony sediments, extends from the foothill to the transition to the valley floor of the Upper Valley (Attachment I). One site was selected, Galatazan Park developed on Canutillo gravelly loam. The site soil is referred to as sediment because the top soil was removed during grading, and there seem to be no clear indication of soil development in the remaining material, except for slight calcium carbonate coating in the soil material (Fig. 6a). In some areas, the indurated layer seems to be a thin layer of a petrogenic calcic horizon. The prevailing condition was water ponding over the subgrade, which seemed to be sealed (Fig. 6b and 6c). This park had been maintained successfully with potable water. When the source of irrigation was converted to reclaimed water with salinity around 1,150 mg/L, soil salinity increased to nearly 10 dS m⁻¹, and turf (hybride Bermuda) became thin. This field had a slope of 2 to 3%.



Fig. 6 A typical Canutillo gravelly loam and water ponding over the subgrade.

Indurated Caliche

Three Hills Park, located on the Del Norte soil series, contained a huge slab of caliche in one-fifth of the soccer field. When visited, the sprinkler systems and topsoil were already placed. The concern that this layer may limit drainage prompted a quick measure to improve drainage without significant modification to the construction design.

EQUIPMENT USED

Rotor Tiller: This piece of equipment has been used commonly for soil preparation for reseeding (Fig. 7a). The depth of rotor blade penetration is adjustable, typically up to 6 inches.

Vibratory Spikes: This piece of equipment (Fig. 7b) marketed as “Agrivator” has a mechanism to vibrate spikes. It is constructed in a fashion similar to a traditional solid tine aerifier, except for the vibratory mechanism. The implement is attached to a mid-sized tractor (60 Hp), and is among the few that can loosen compacted dry hard soils.

Turf Shaper: This equipment has short chisels and rotors to loosen turf anywhere from 1 to 6 inches deep and is commonly used to level elevated turf (Fig. 7g). The short chisels are to break the ground surface, and the teeth, which rotate back and forth, are to break clods.

Minimum-till Shallow Chisel: This group of implements was originally developed for maintaining pasture that is subjected to compaction by the foot traffic of livestock. Some units are a category of a vertical slicer, which makes slots using a combination of coulters and thin shanks (Fig. 7c). Others have various shoe attachments for changing the level of shattering and lifting of the compacted soils. The actual shattering depends primarily on soil moisture, and when the soil is dry, it may provide extensive shattering to a depth of 6 to 7 inches. Disruption of the ground surface or turf is minimal when used in moist soils. The power requirement is 10 to 15 Hp per shank at a chiseling depth of about 6 inches.

Subsoiler: Subsoilers typically have vertical shanks with a wing-tip shoe at the end to uplift soils, and a coulter in front of each shank to minimize the disturbance of the surface layer (Fig. 7d). The shoe point and shatter wings come in different shapes and sizes. The shank shown in Fig. 7d has a narrow raised-center point for shattering hard clay. The depth of penetration varies with models, but typically ranges from 20 to 30 inches. A shear bolt is a standard feature for implement protection, but some models come with an auto-reset mechanism or compressed spring-load release. The power requirement is rated at 30 to 50 Hp per shank at a chiseling depth of 24 inches, but this depends on the hardness of clay, and the type of shoe attachment. The equipment shown in Fig. 7d was tested at the practice field in Clint, Valley Creek, and Pavo Real, South. A four-wheel tractor used was rated at 180 Hp, and pulled two shanks.

Vibratory Chisel: The shank is designed in the shape of subsoiler, or a straight knife, and can cut through stony soils or stony caliche using vibratory motion, but very slowly. The shank is thin, and the working depth is less than 3 ft. They are marketed as vibratory plows or lawn plow (Fig. 7e). When used in caliche containing stone larger than 6 to 8 inches, vibratory shanks can push the stone towards the ground surface, and at times, cause bulging. Topdressing with dry sand allows penetration of the sand into the crack. When used in very hard caliche, the blade may not be able to cut through. The performance of this type of equipment is highly soil-dependant.

Backhoe: Backhoes (Fig. 7f) are used to dig a trench for improving drainage in hard caliche. In the case of indurated caliche, a backhoe equipped with special teeth is available. The surface of the caliche layer must be sloped to cause lateral drainage into the trench. A backhoe was also used to mix the soil profile or to dig a deep trench into a sandy layer through a layer of clayey soils at Pavo Real Park, South.

Front-end Loader: This piece of equipment is commonly available, and used for loading soil and soil materials. A smaller unit is a skid-loader (bob-cat) which is suited for small areas. A large unit was used to invert the soil profile at Shawver Park, West, and for excavation (Fig. 7h) at Pavo Real, South.

Topdresser: The topdresser used was essentially a truck equipped with rotating fins, which push out sand from the flat bed (Fig. 7i). It can spread sand ¼ inch to one inch deep.



a) Rotor Tiller



b) Vibratory Spikes



c) Shallow Chisel



d) Subsoiler



e) Vibratory Chisel



f) Backhoe



g) Turf Shaper



h) Front-end Loader



i) Topdresser

Fig. 7 Some of the equipment needed for testing.

PROCEDURES AND RESULTS

The soil improvement measures tested are summarized in Table 3, and details are given in the text. The annual irrigation records were obtained from meter reading records, and may or may not apply to the specific test areas.

Table 3. Equipment and irrigation water used during or following the soil treatments.

Locations	Equipment Used	Irrigation Water Used inches/year	Sources ⁴ -
Estrella-Rivera	Rotary cultivator	2004 (26), 2005 (37), 2006 (21)	P→R1
Mary Webb	Shallow chisel	2004 (73), 2005 (61), 2006 (57)	P→R1
Lomaland	Vibratory spike, Shallow chisel	2003 (60), 2004 (36), 2005 (32)	P
Shawver, East	Vibratory spike, Turf shaper	2005 (25), 2006 (38), 2007 (30)	P
Shawver, West	Front-end Loader	2005 (25), 2006 (38), 2007 (30)	P
Clint	Subsoiler	2003(-), 2004(-)	P-Rio
Pavo Real, North	Shallow chisel	2004 (42), 2005 (30), 2006 (26)	P
Pavo Real, South	Subsoiler, Excavator	2006 (36), 2007 (45)	P
Valley Creek ² -	Subsoiler, Topdress	2004(-), 2005 (52), 2006 (42)	P
Galatazan Park	Backhoe, Vibratory Chisel	2001 (67), 2002 (70), 2003 (80)	P→R2
Three Hills Park ² -	Backhoe	2006(-), 2007 (77)	R2

¹ - Rainfall in 2006 reached 17.5 inches for the year.

² - These parks are new construction.

³ - Yellow-shade indicates the year of treatment.

⁴ - P: Potable

R1: Reclaimed, Haskell

R2: Reclaimed, Northwest

Soil salinity measurements (Rhoades and Miyamoto, 1990) were used as the primary means of evaluating the performance of various measures imposed. An earlier study has shown that the coefficient of variability of soil salinity within a sports field ranges from 15 to 35% in Entisols (Miyamoto and Chacon, 2006). The coefficient of variability for field soil moisture content is lower, averaging 10%. The sampling requirement for soil salinity in a typical sports field ranges from three to eleven samples in order to obtain the mean within a 20% deviate range at a 95% confidence level. In the current study, the number of soil samples collected ranged from four to six samples per area of the concerns. At the coefficient of variability of 25%, the deviate of average salinity determined by using 6 samples is within 20% of the true means. If the coefficient of variability was 20%, the deviate range of the means of four samples is within 20% of the true mean. The deviate range of the measured soil moisture content is lower, typically 15% of the true mean.

Sandy Alluvial Soils

Estrella - Rivera Park: In the spring of 2005, the entire park was rotor-tilled by the park maintenance and irrigated daily for a week. Soil samples were collected five each from the sloped area, and five each from the flat area to a depth of 0 to 8 inches and 8 to 16 inches, prior to and after the treatment. Soil salinity decreased from 9.6 to 2.0 dS m⁻¹ in the top 8 inches, and from 10.5 to 2.7 dS m⁻¹ in the depth of 8 to 16 inches (Table 4). Since no control section was left, it is difficult to assess if rotor-tilling helped salt leaching. The park maintenance personnel believed based on their experience that irrigation water would have run off if not tilled. In any case, this example indicates that salt leaching is not difficult in sandy soils through a simple method of tilling and ample irrigation. By the summer (June of 2005), common bermudagrass covered most areas (Fig. 8c). The park maintenance was considering to topdress the sloped area with sand.



Fig. 8 Estrella-Rivera Park (Gila sandy loam) before and after salt leaching treatments.

Mary Webb Park: Mary Webb Park consists of Harkey silt loam, and had good stands of hybrid bermudagrass, except in the middle section of a football field and a path leading to the field (Fig. 9). Soil samples were collected from two areas; high traffic area (which includes the football field and the walking path), and low traffic area (the open park area). Soil test results indicate initial soil salinity was 3.2 dS m^{-1} in the top 8 inches in the compacted area and 1.4 dS m^{-1} in the noncompacted area. In February of 2005, the shallow chisel shown in Fig. 7c was pulled by a 100 Hp four-wheel drive tractor. The shanks, spaced 11 inches apart penetrated 6 to 7 inches. The entire test area was broadcast with loamy sand to a depth of about $\frac{1}{2}$ inch.

Table 4. Soil salinity before and after the treatment at Estrella-Rivera Park.

Depth	Texture	SWC	Before		After	
			Before	After	Ctr.	Trt.
inches		g/100g	----- dS m^{-1} -----			
Salted Area						
0 - 8	loam	37	9.6 a	-	2.0 b	
8 - 16	loamy sand	28	10.5 a	-	2.7 b	
Nonsalted Area						
0 - 8	loam	33	4.2 a	-	2.3 b	
8 - 16	loamy sand	29	6.2 a	-	4.0 b	

¹ Numbers followed by the same letter are not statistically different.



Fig. 9 Mary Webb Park (Harkey silt loam) before and after shallow chiseling treatments.

The use of the minimum-till ripper improved salt leaching in the high traffic area, but not in the low traffic area (Table 5). In the low traffic area, soil salinity in the treated area was slightly higher than the untreated area, although the difference between them was not statistically significant. The reason is unclear, but it is possible that separation of the chiseled layer (discussed later in Fig. 15) may have limited water penetration and salt leaching. A new roller and weight bars were attached to the unit (Fig. 10) in order to press down the chiseling lips and the sod layer lifted by the action of the chisels. Also note that soil salinity of the control section has increased, especially in the high traffic area where turf cover was poor. This is probably related to the conversion of irrigation water from potable (0.9 dS m^{-1}) to reclaimed water with higher salinity (1.3 dS m^{-1}). In any case, soil salinity

measured was well below the threshold soil salinity for growing bermudagrass, except for a few readings in the high traffic area.

Since soil salinity is below the threshold value, there may be no need to use aerifiers for the purpose of salt leaching in sandy or loamy soils. However, uniformity of soil salinity readings obtained may suggest that this type of chisels can provide uniform turf (Fig. 9c).

Clayey Alluvial Sites

Lomaland Park: Lomaland Park, consisting of Harkey silty clay loam, has had a chronic problem of standing water, as shown earlier in Fig. 1a. This park has been used extensively, and turf has been always worn out. The vibratory spikes and the minimum-till shallow chisel were tested with a control plot in the mid-April of 2004 (Fig. 11). Unfortunately, there was nearly one inch rain two days prior to the test. The soil moisture condition was too high for the optimum performance of the vibratory spikes or the chisel. The minimum-till chisel did not fracture the soil as much as it does when the soil is dry or moist. Upon these treatments, the entire area was topdressed with loamy sand to a thickness of about ¾ inch.

Table 5. Soil salinity before and after the treatment at Mary Webb Park.

Depth	Texture	SWC	Before		After ¹ -	
			g/100g	dS m ⁻¹	Ctr.	Trt.
High Traffic Area						
0 - 8	loam	35	3.2	4.2 a	2.1 b	
8 - 16	loamy sand	36	3.5	5.1 a	3.2 b	
Low Traffic Area						
0 - 8	silt loam	33	1.4	2.3 a	2.9 a	
8 - 16	silt loam	36	3.7	3.1 a	3.5 a	

¹ - After the treatment and conversion of reclaimed water.



Fig. 10 Modifications made by Mr. Sam Calhoun to the initial chiseling unit: packing roller and weight bars.



Fig. 11 Lomaland Park (Harkey silty clay loam) before and after the shallow chiseling treatments.

Approximately one month after the treatments, the strip which was chiseled has shown a visible response (Fig. 11b). However, there was no significant effect of the treatments on soil salinity when measured four months after the treatments (Table 6). The soil samples were collected from 0 to 6, and 6 to 12 inches at twelve locations (four sites per treatment).

Table 6. The saturation water content and soil salinity four months after treatments at Lomaland Park.

Depth	Texture	Saturation Content	After ¹ -	
			g/100g	g/100g
After ¹ -				
			Ctr.	Chiseled Spiked
			dS m ⁻¹	dS m ⁻¹

0 - 6	silty clay loam	61	5.1 a	4.9 a 4.1 a
6 - 12	silty clay loam	60	7.3 a	6.7 a 7.4 a

The condition of grass may have improved in the chiseled section, probably because of improved aerification. The chiseling operation lifted the ground by ½ inch or so, and prevented water from standing (Fig. 11b), while the check plot as well as the strip treated with the vibratory spike often had standing water and yellowing turf. Harkey silty clay loam does not shrink or swell, and permeability is very low, once it is compacted. The visual improvement in turf condition in the chiseled strip lasted throughout the summer, but disappeared in the fall (Fig. 11c).

Shawver Park: Because of the presence of Saneli soil series; this park was regarded as a problematic park by the park maintenance. When initial soil samples were taken in the winter of 2006, however, we found that this park consists of multiple soil types: Harkey and Anapra on the east side and Saneli on the west side. The initial soil test also indicated unusually low soil moisture contents, which indicate inadequate irrigation (Table 3).

In the spring of 2006, a vibratory spike (Fig. 7b) was used in the soccer fields consisting of Harkey silt loam, Anapra silty clay loam, and a turf shaper (Fig. 7g) was used in the area consisting of Saneli silty clay loam. The fields consisting of Saneli silty clay have been rarely used for athletic activities. We could not ascertain what was implemented prior to 2006. After aerification, all fields were said to be irrigated heavily. This activated growth of bermudagrass. In July and August, the area received heavy rainfall (3.2 inches in July, 6.8 inches in August, and 5.0 inches in September). Soil samples were collected in May of 2007 from the treated area and the untreated area, eight samples each or sixteen sites per test area.



Fig. 12 Effects of aerification Harkey silt loam (a), Anapra silty clay loam (b) and Saneli silty clay (c) at Shawver Park.

Results (Table 7) indicate that soil salinity has decreased, but there was no difference between the aerified area versus the untreated area with one exception in the area where the untreated area has a slope and extensive foot traffic. However, the treated area was flat, as it was leveled. There was no visible response of turf to the treatment (Fig. 12). This set of results should be interpreted by considering the fact that these fields, especially the one on Saneli silty clay have not been used extensively for athletic activities, and previous aerification activities are unknown.

Soil profile modification tests began in 2006 in the west end of this park consisting of Saneli silty clay. The silty clay extended 23 inches, which was first removed with a large front-end loader. The loamy sand layer was also removed in the same manner to a depth of an additional two feet. The silty clay layer dug was then pushed back into the trench, and was covered by the loamy sand. This operation essentially inverted the soil profile. The area was seeded in August of 2006. Soil samples were collected in December of 2006 and were analyzed for salinity.



Fig. 13 Effects of profile modification of Sanlei silty clay at Shawver Park, West: Stratified profile (a), after inverting (b), and by May of 2007.

Soil salinity measured in the winter has shown a good deal of salt leaching (Table 7), and bermudagrass in the treated area has shown excellent growth as compared to the growth in untreated areas (Fig. 13).

Practice Field in Clint: A practice field adjacent to William Surratt Elementary School consists of Glendale silty clay loam and, in places, silty clay, and is mostly flood-irrigated with the project water from the Rio Grande. Sprinklers have been used for a few months when the field is used frequently. This field had a thin variable turf cover (Fig. 14a) and in June 2004, deep chiseling (20" to 26" deep, 40" spacing) was implemented using two shanks attached to a 180 Hp tractor (Fig. 7d). Once subsoiling had been completed, the minimum-till surface chisel used at Mary Webb and Lomaland Parks was brought in, but its use discontinued as turf was turning over as the shallow shanks cross the chiseling path (Fig. 15 on the next page). It appears that the surface chisel can shatter the surface layer when the soil condition is good.

Table 7. The saturation water content and soil salinity before and after the treatment (Shawver Park).

Depth inches	SWC	Initial		After	
		Salinity		Control	Treated
Shawver, East (2006 Treatment)					
Harkey silt loam -----dS m ⁻¹ -----					
0 - 8	45	-	-	2.2 a	2.5 a
8 -16	42	-	-	3.5 a	3.3 a
Anapra silty clay loam					
0 - 8	51	9.1	6.5	2.8 a	3.1 a
8 -16	57			5.3 a	4.8 a
Sloped and compacted area					
0 - 8	56	13.7	8.4	9.7 a	3.6 b
8 -16	57			11.5 a	5.0 b
Sanlei silty clay loam					
0 - 8	58	-	-	5.7 a	6.4 a
8 -16	63	-	-	10.7 a	10.1 a
Shawver, West (Soil Profile Modification Treatment)					
Sanlei silty clay loam					
0 - 8	66	10.3	7.4	9.7 a	3.4 b
8 -16	69	13.7	13.2	10.6 a	5.7 b

Upon chiseling, the area was topdressed with Hueco fine sand to a depth of 1 ¾ inches by the Clint school maintenance (Fig. 14b). The test site was flooded 5 to 6 times a year, according to the maintenance personnel. Soil samples were taken on April 20, 2004 prior to the treatment, and June 6, 2005, 14 months after the treatment. The treated area was sampled again in February of 2007 at six locations. No seed was planted, and no Gypsum was applied to this site. Nitrogen fertilization was made at a rate of 50 lb-N/acre three times in 2005. Soil samples were analyzed for the field soil moisture content, the saturation water content, and the soil salinity by the method mentioned earlier.

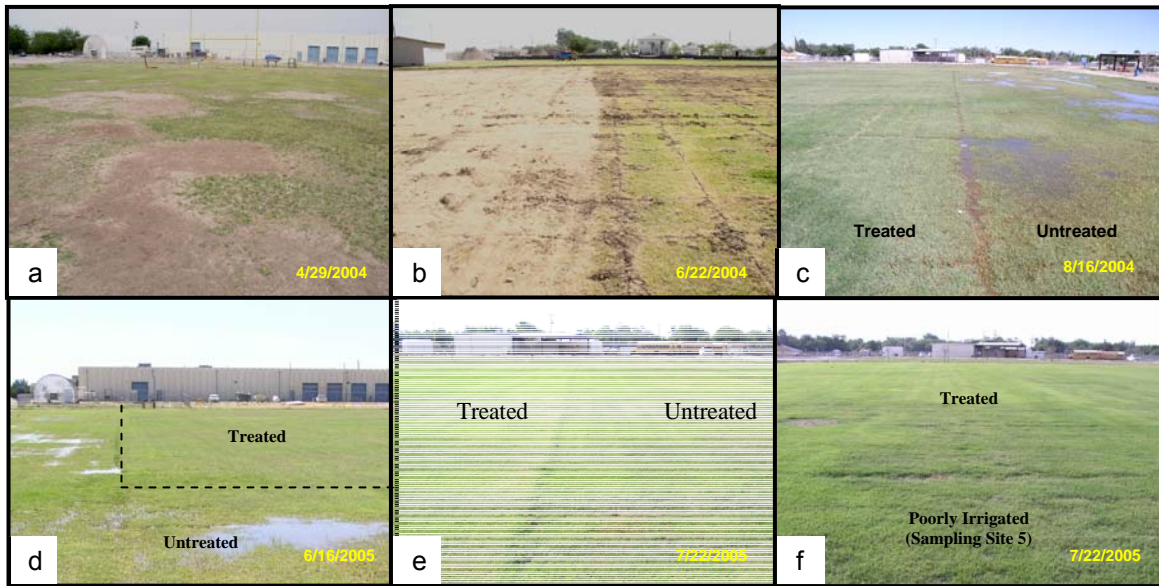


Fig. 14 The transformation of the Clint Practice Field (Glendale silty clay loam) following subsoiling and topdressing.

The progression of the practice field is shown in Fig. 14. Initially, turf conditions towards the tail end of the field (soil sampling locations 5 and 6) were in bad shape (Fig. 14a). Soil salinity in the area exceeded 10 dS m^{-1} in the first 8 inch layer (Table 8). The situation became worse after chiseling, as the topdressing operation extended for several weeks due to manpower shortage. A visible difference in growth of turf appeared in a year. More importantly, a major difference between the chiseled and non-chiseled areas appeared in standing water (Fig. 14c and 14d). In the chiseled area, water from rainfall or flood irrigation disappeared in less than a day or two, whereas in non-chiseled area, it stood for a week. By the end of July of 2005, the chiseled area had attained a good cover of turf, except in the area designated by soil sampling sites 5 and 6 (Fig. 14f).



Fig. 15 A block of top layer flipped over when the surface chisel cross over the subsoiling path.

Soil salinity readings initially ranged widely 4.2 to 11.8 dS m^{-1} . Low salinity readings seemed to be associated with soils with the low saturation water content as well as with the distance from the irrigation ditch. Soil sampling locations were numbered with the increasing order from the ditch. When measured fourteen months after the treatment (June 6, 2005), there was good salt leaching in the area covered by the three sampling sites (1, 2 and 3), which was towards the irrigation ditch. When soil salinity was checked again in February 27, 2007, salts were leached from sampling site 5, but not completely near site 6. The weak portion shown in the last photo of Fig. 14f has also disappeared.

Table 8. Soil salinity, field soil moisture and the saturation water content measured in April 2004 (prior to deep chiseling) and in June 2005 (one year after the chiseling) at a practice field in Clint.

Site	Soil Texture	Saturation Content		Soil Salinity		Field Moisture		
		g/100g	-----	dS m ⁻¹	-----	g/100g	-----	
Soil Depth (0 - 8 inches)								
		6/6/05	4/20/04	6/6/05	2/27/07	4/20/04	6/6/05	2/27/07
1	silty clay loam	55	9.1	1.0	1.3	13	20	19
2	silty clay loam	55	5.1	1.2	1.2	15	19	21
3	silty clay loam	56	4.2	1.4	1.3	13	20	23
4	silty clay	66	11.0	4.5	1.3	15	21	19
5	silty clay	70	11.8	9.8	1.3	16	20	21
6	clay	74	9.8	5.6	3.2	14	21	20
AVG		63	8.5 a	3.9 b	1.6 b	14 a	20 b	21 b
Soil Depth (8 - 16 inches)								
1	silty clay loam	54	13.8	1.5	1.0	15	21	20
2	silty clay loam	57	8.8	2.5	1.3	16	20	23
3	silty clay loam	56	9.8	2.1	1.6	10	23	26
4	silty clay loam	55	9.4	7.6	1.5	16	24	26
5	silty clay	66	13.0	11.9	1.1	19	22	22
6	silty clay	66	11.1	10.4	4.5	19	21	21
AVG		59	11.0 a	6.0 b	1.8 c	16 a	22 b	23 b

The soil salinity data shown in Table 8 do not necessarily prove that subsoiling has facilitated salt leaching. Salinity of soil samples collected along the sideline as a pair at six sites show that salt leaching was definitely enhanced through chiseling (Table 9). Note that the chiseling operation was carried out on the practice field, but not beyond. This data set also indicates that flood irrigation alone can lower soil salinity, but the ground will be wet for a week or longer. We were able to walk through the chiseled and topdressed field in two to three days after flood irrigation, whereas water was ponding in untreated area for five to seven days.

Pavo Real Park, North: This section of the park consists of Tigua silty clay. Water infiltration in high use soccer field was slow, and good turf covers have long vanished. Shallow chiseling (7" deep x 11" spacing) was implemented in April 2005 in dry fields, mainly to break out the ground for reseeding. Once the

surface chiseling operation was completed on April 11, 2005, the clods were crushed repeatedly with a rock rake until pulverized, and the area was topdressed with a mixture of Hueco sandy loam and river sediment from the Jonathon Rogers Water Treatment Plant to an estimated depth of about 1 inch. The field was then re-seeded with common

Table 9. Soil salinity and moisture measured 14 months after chiseling (Clint Practice Field).

	Saturation Water	Salinity		Moisture	
		g/100g	ctr. chiseled	ctr. chiseled	g/100g
	g/100g	-----	----dS m ⁻¹ ----	g/100g	g/100g
Depth (0 - 8 inches)					
1	53	1.8	1.8	14	20
2	58	1.5	1.5	17	24
3	52	2.2	1.0	16	20
AVG	54	1.8 a	1.4 a	16 a	21 b
4	60	5.2	1.6	13	20
5	60	9.6	1.4	17	18
6	77	9.3	2.1	18	25
AVG	66	8.0 a	1.7 b	16 a	21 b
Depth (8 - 16 inches)					
1	53	1.6	1.8	17	19
2	52	1.2	1.3	14	20
3	48	5.7	1.4	19	22
AVG	51	2.8 a	1.5 b	17 a	20 b
4	47	10.1	1.7	19	21
5	47	16.0	2.4	20	21
6	56	13.8	5.1	19	24
AVG	50	13.3 a	3.1 b	19 a	22 b

bermudagrass. This sequence of operation is commonly used for renovation of sports fields. In addition, a small area (35 ft. x 35 ft.) was excavated to a depth of 6 inches, and sandy loam soil was placed. This method was thought to be used near goal posts. Soil samples were collected two days after the initiation of leaching irrigation on May 4, 2005, then again on June 15, 2005, December 20, 2005 and December 20, 2006. These soil samples were analyzed for field soil moisture, the saturation water content and soil salinity of the saturation extract.



Fig. 16 Pavo Real, North: Initial condition (a), after shallow chiseling (b), and by the mid-summer (c).

Results (Table 10) have shown that neither shallow chiseling nor excavation followed by sandy soil placement had caused significant effects on salinity, except for the initial decrease in soil salinity in the chiseled section. Chiseling also increased the soil moisture content initially. It is most likely that low permeability of the soil below the surface impaired drainage and salt leaching.

Table 10. The saturation water, soil salinity and field moisture at Pavo Real, North.

	SWC g/100g	Salinity dS m ⁻¹				Field Moisture g/100g			
		5/4/05	6/15/05	12/20/05	12/15/06	5/4/05	6/15/05	12/20/05	12/15/06
0 - 8 inches									
Control	48 ¹	9.2b	10.5b	7.2a		14.1	15.4	14.0	
Chiseled	59	6.4a	7.3a	7.8a	7.8	18.8	17.4	17.8	20.7
Excavation	33	8.5b	-	7.8a		12.9	-	16.0	
8 - 16 inches									
Control	84	9.7b	10.9b	9.1a		18.8	19.0	19.4	
Chiseled	79	7.9a	9.1b	8.8a	10.2	22.2	23.1	21.2	20.2
Excavation	73	9.7b	-	8.7a		18.7	-	20.0	

¹ - The saturation water content of the first layer is affected by topdressing conducted over the years.

Pavo Real Park, South: This section of the park consists of Saneli and Glendale silty clay. Three test plots were established on Saneli silty clay which has a layer of silty clay or clay from 0 to 24 inches. The first treatment was subsoiling with the same shank placed at the boundary between the clay and the sand layers. However, no topdressing with sand was made after subsoiling. The second treatment involved a mixing of the clay layer and the sand layer below, using a backhoe at a target mixing ratio of one part of clay with one part of loamy sand by volume. The third treatment involved excavation on the clay layer to a depth of 6 inches at one end and 11 inches at the center over the distance of 20 ft. At the center line, a trench was dug to the sand layer. The excavated clay was hauled away, and was replaced by loamy sand. The entire test area was topdressed with a mixture of loamy

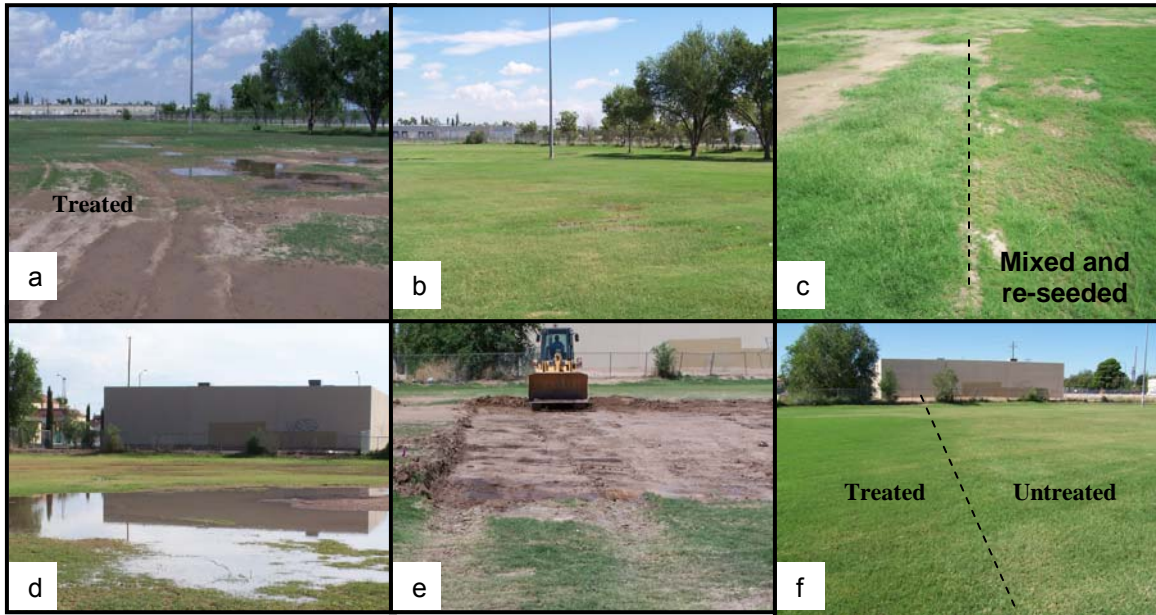


Fig. 17 Pavo Real, South: After subsoiling (a), at the end of the season (b), profile mixing plot after seeding (c), water ponding in the untreated area (d), excavation of clay (e), and turf at the end of the season (f).

sand and sandy loam, leveled, and seeded with common bermuda on April 26, 2007. All of the test areas were adequately irrigated with sprinklers, using 45 inches per year.

The first treatment, subsoiling, provided visible improvements in water infiltration (Fig. 17a and 17b). However, the difference in infiltration became less visible after a month or two. At the end of the growing season, subsoiled strip was not recognizable (Fig. 17b). Nonetheless, soil salinity in the subsoiled strip was lower than untreated strip by 27% (Table 11).

Table 11. Results of three separate tests at Pavo Real Park, South.

	Treatment Mean Comparison			Individual Salinity	
	SWC	Salinity	Field Moisture	Excavation Treatment	Untreated Treated
	g/100g	dS m ⁻¹	g/100g	Sample No.	Salinity
					-----dS m ⁻¹ -----
Subsoiling Means					
Treated	74 a	7.6 a	23 b	1	7.4 (3.1)*
Untreated	81 b	10.4 b	26 b	2	6.1 (2.2)*
Profile Mixing Means				3	6.8 1.5
Treated	44 a	6.2 a	17 a	4	4.3 1.4
Untreated	75 b	9.7 b	23 b	5	6.3 1.4
Excavation Means				6	<u>5.1</u> <u>1.3</u>
Treated	23 a	1.4 a ¹ -	5 a	Means ¹ -	6.0 a 1.4 b
Untreated	65 b	6.0 b	17 b		

¹ Two original data points were excluded due to inflow of saline runoff, shown in parenthesis.

The second treatment, profile mixing, improved water infiltration and provided good establishment of new turf (Fig. 17c). By the end of the season, new turf had completely covered the ground. Soil salinity in the mixed area was lower than the native area by 36%

(Table 11). The texture changes from silty clay to clay loam. No water was ponding in the treated area, while standing water was frequently observed in non-treated areas.

The third treatment, excavation, initially experienced difficulties of establishment, as the irrigation scheduling was set for established grass. However, as soon as this problem was corrected, bermudagrass grew, and covered the entire ground in a season. Poor water infiltration has been a chronic problem at this site (17d). After excavation, water infiltration was improved, and no standing water was present in the excavated area. Soil salinity measured at the end of the season was slightly elevated, and was greatly lower than salinity of the native soil (Table 11). This result is in sharp contrast to the results shown in Table 10 where the excavation which did not provide drainage resulted in no salt leaching.

Valley Creek Park: Valley Creek Park was planned to have two full-sized soccer fields. The first field consisted of four soil types: Harkey loam, Harkey silty clay loam, and Saneli silty clay loam, and Saneli silty clay, and the second field, Saneli silty clay loam, and Saneli silty clay. Both fields had been ripped to 16 inches by a contractor, except at a strip along the sideline where laterals were connected to control boxes. Both fields were disked and leveled (Fig. 18a). At this point, soil samples were collected at three locations per soil type per field to a depth of 12 inches. They were analyzed for the saturation water content and salinity of the saturation extract. On September 20, 2004, the second field consisting of Saneli series was toppedressed with Hueco fine sandy loam to an average depth of 1.5 inches. This was followed by subsoiling at a 40-inch shank space to a depth of 28 inches to draw the fine sand into the chiseling cracks (Fig. 18b). A subsoiler was not used along the sideline with sprinkler boxes. The topsoil was smoothed with a land leveler.

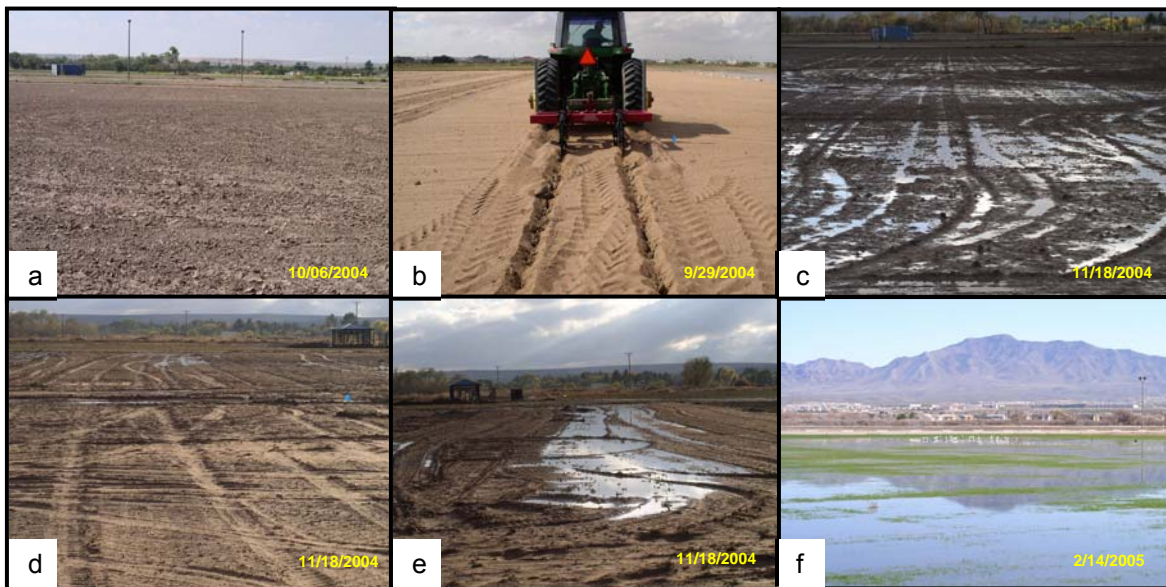


Fig. 18 Soil preparation at Valley Creek Park: Initial ripping (a), deep subsoiling (b), puddling after the first rain (c & e), and standing water after a rain storm (f).

On November 16, 2004, rainfall (3/4 inches) created water puddling in the area not toppedressed (Fig. 18c), as well as the area which was toppedressed, but was not chiseled (Fig. 18e). There was, however, no water ponding in the area toppedressed and subsoiled (Fig. 18d). The entire area was sodded in December of 2004 through January of 2005 using

hybrid bermudagrass over-seeded with ryegrass. Both fields were irrigated every other day using potable water (650 ppm dissolved salts). On February 13, 2005, the area received 1.5 inches of rain, which flooded the field for several weeks (Fig. 18f).

The first soil sampling was conducted in October of 2004. Following the major rain and a good deal of irrigation, soil samples were collected again on June 24, 2005 and March of 2006 to a depth of 12 inches at three sites per soil type. Results shown in Fig. 19a indicate that soil salinity depended on soil type. Note that the second data set is from the irrigation season, while the third set from the non-irrigation season. The water table at the site fluctuates depending on the flow of the river, and usually peaks in September (or at the end of irrigation season). It is entirely possible that the raise in water table brought the salts back the surface layer in the Harkey loam section. The fourth soil sampling took place in December of 2006.

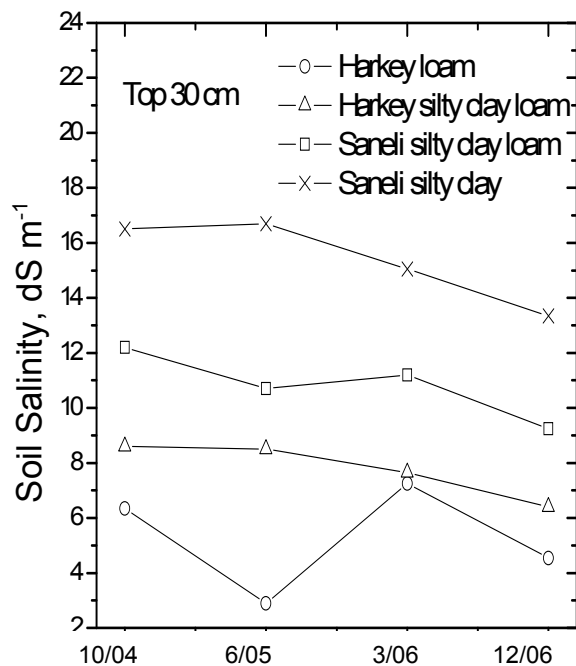


Fig. 19a The leaching of salts from the top 12 inches of four alluvial soils (Valley Creek Park).

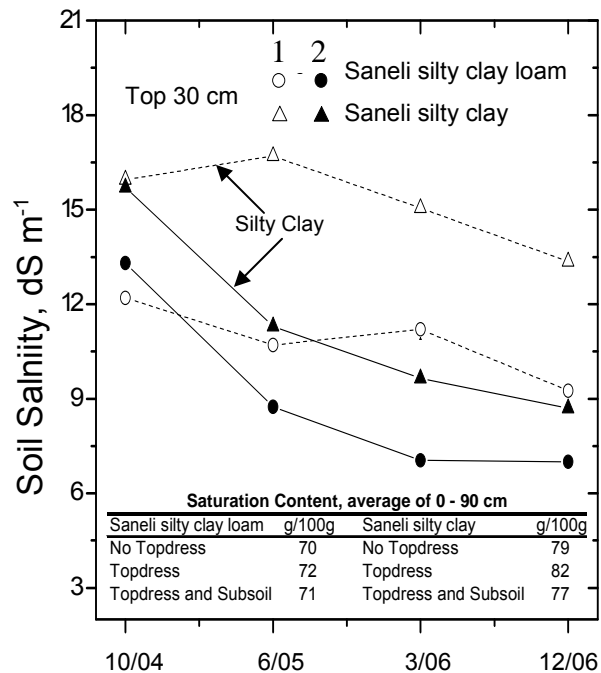


Fig. 19b The leaching of salts from the top 12 inches of four alluvial soils 1: No topdress, 2: Topdress plus subsoil.

Figure 19b shows the changes in soil salinity in the topdressed field, along with the non-topdressed field designated by the dotted lines. Soil salinity in the topdressed and subsoiled section decreased rapidly and has remained stable. The topdressed layer may have acted as mulch, which reduces evaporation and upward movement of water and salts. Soil salinity data from the topdressed, but not subsoiled area were limited to the measurement made in March 2006, in the area consisting of Saneli silty clay loam. Soil salinity readings from the topdressed area were similar to that of the non-topdressed area. This result indicates that thin topdressing alone may not be effective in leaching salts when permeability of the subsoil is low.

Turfgrass has survived the second flood event, which came in August of 2006, except in the area consisting of Saneli silty clay in the non-topdressed area. Some areas in the topdressed area have also lost turf mainly due to prolonged ponding associated with subsidence after the flood.

Stony Sediments

Galatazan Park: This Park, established on Canutillo stony loam, developed a salt problem in about sixteen months after conversion to reclaimed water. The salt problem appeared in the form of browning of turf in early June of 2002 (Fig. 20a). In some areas, turf has turned to dark brown or brownish black, a color characteristic of organo-Na complexes (Fig. 20b). Soil samples were collected at five locations at 20 ft. intervals to a depth of 10 inches down to the subgrade. They were analyzed for soil salinity, and the saturation water content. Results have shown that soil salinity was highly spatially variable and was as high as 15 dS m⁻¹ in some areas (Table 12). Excavation of the site revealed the presence of water at the boundary between the surface of the subgrade and the sandy topsoil placed (Fig. 20c). The subgrade appeared to have been sealed in places.

Table 12. Soil salinity measured upon the first appearance of salt problems on June 8, 2002 and after trenching on August 9, 2002 (Galatazan Park).

Sites	SWC g/100g	Salinity dS m ⁻¹		
		6/5/02	8/26/02	3/27/06
1	33	5.2	3.1	1.6
2	36	15.1	2.6	1.1
3	36	11.6	3.3	1.2
4	32	3.0	1.6	1.2
5	33	4.3	2.0	2.7
AVG	34	7.8 a	2.5 b	1.6 b

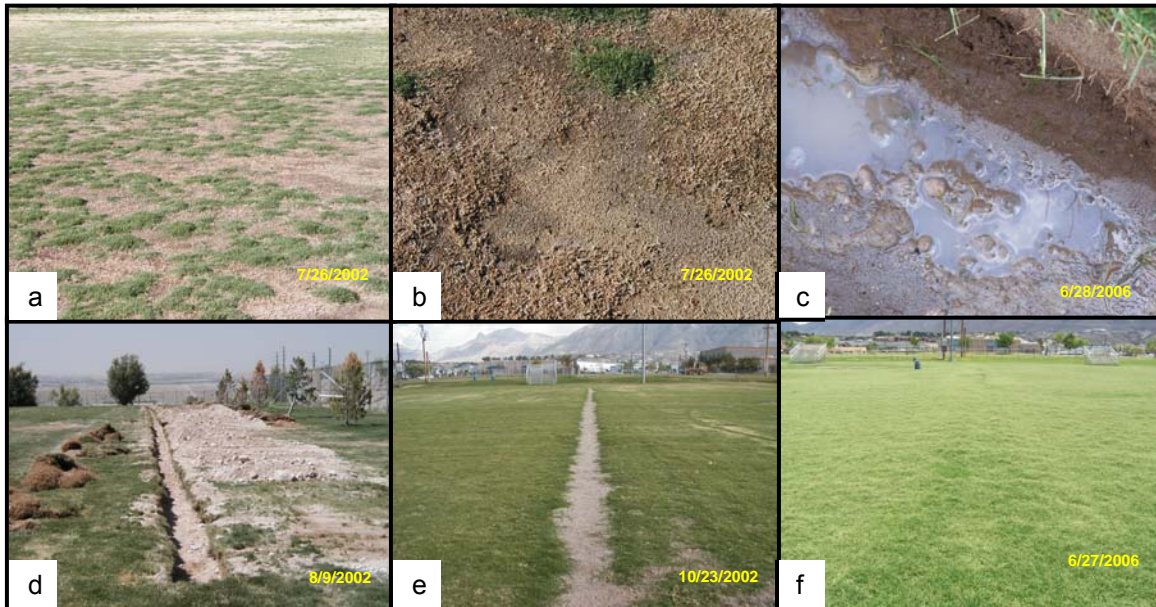


Fig. 20 Galatazan Park; salinized in June and July 2002 (20a & 20b), trenched in August of 2002 (Fig. 20d) and leached (Fig. 20e).

The ground surface of this park had a 2 to 3% slope. A decision was made to trench the field every 60 ft. perpendicular to the slope. The presumption was that the water percolated from the topsoil will move laterally along the surface of the sealed subgrade, and may drain into the trench. The trench was dug with a backhoe 18 inch wide to a depth of 6 ft. (Fig. 7f). The topsoil, about 10 inches in thickness was saved in one side of the trench. The stony loam dug was placed back to a depth of 6 ft., and the top 1 ft. was filled with coarse sand (Fig. 20d), and was finished with the topsoil saved.

Once the trenching operation was completed, the entire field was irrigated for 6 hours using 3 inches of water. Soil salinity was checked again. The area represented by sampling locations 2 and 3 was sufficiently leached. Sprinklers in the poorly leached area

were turned on again for an additional four hours. When soil salinity was checked again on August 26, 2002, soil salinity at all sampling sites were lowered below 3.5 dS m^{-1} (Table 12).

Trenching is a simple operation, yet this system is not efficient in terms of salt leaching efficiency, unless placed much closer. A vibratory chisel was subsequently used on June 29, 2004 to provide cracks in the subgrade at 36 inch spacing to a depth of 30 inches. This piece of equipment does not disturb turf, but did push up a few pieces of stone, 10 inches in diameter towards the surface, thus causing bulging. This test run was then discontinued. Subsequent observations show that there was no water puddling in the chiseled area, while the surrounding area did show ponding. However, we had difficulties of finding chiseling cracks in subgrade. It is possible that the sediment may have settled, causing the chiseling cracks to close.



Fig. 21 A vibratory chisel used at the Galatazan Park.

Indurated Caliche

Three Hills Park: The site consists of Del Norte soil, which contains coarse materials between the calcic horizons. If the caliche slab is sloped, then it is entirely possible that drainage water from the turf area will find an outlet, although there may be a spot or two with poor internal drainage. The EPCPD felt that this park is too important to have soggy spots with poor internal drainage. Heavy duty chisel pulled by a bulldozer were originally proposed, but a risk of hitting the newly installed irrigation lines with the slab ruled out this option. An interception trench or two placed perpendicular to the general slope of the caliche slab was considered an option, mainly for providing a drainage outlet in case salt flushing becomes necessary. This option was also abandoned, because the sprinkler lines were laid in the direction of the slope. The third and not the most favorable option was to trench wherever possible between the irrigation lines, and to increase the topdressing depth from 12 to 18 inches. This plan was implemented in the fall of 2006.

Hybrid bermuda sod was paced in February of 2007, and ample irrigation began. The first soil samples were taken in October of 2007 in a strip where we suspected to have the caliche slab, 9-ft. away from the trench, and right above the trenched area. Five replicate samples were taken from each of these areas.

Results indicate that salinity of the soil samples collected away from the trench averaged 3.4 dS m^{-1} , as compared to 3.3 and 3.5 dS m^{-1} of the samples near or on the trench; these differences were not statistically significant (Table 13). However, soil salinity in the area known to have no caliche has shown the average salinity of 2.1 and 2.2 dS m^{-1} at 0–8 and 8–16 inches deep, which are significantly lower than other cases. The largest difference in salinity appeared in the area showing water stress, mainly due to malfunction of sprinkler heads, including tilting. At this stage, it is not conclusive if the trench made is helping the situation or not in terms of salt control. An early indication seems to be that salt,

if it does accumulate, can be flushed with heavy irrigation, as the distance to the trench is not very far, 15 to 20 ft. at the most. Obviously, it will take another year to learn if salts may accumulate when irrigation rates are reduced to the normal level applicable to established turf. The water application for the first year was estimated to be 77 inches (Table 3).

A troublesome observation was that the area consisting of sandy subsoil without caliche was generally water-stressed, while the caliche area was generally wet. This problem of uneven water retention is likely to persist. As mentioned earlier, sprinkler laterals are placed across several soil boundaries, covering from the poorly permeable calcic horizon to coarse sand.



Fig. 22 Three Hills Park; the calcic horizon (22a), a trenching down to 8 ft. deep (22b), and the turf above the caliche area in June, 2007 (22c).

Table 13. Salinity of soil samples collected from the zones away from, near, and on the trench at Three Hills Park after one growing season, using 77 inches of water.

Samples	Salinity					Means
	1	2	3	4	5	
Caliche Area (0-8")						
Away from the trench (15 ft.)	4.2	3.3	3.2	2.7	3.4	3.4
Near the trench (9 ft.)	2.7	3.6	(4.6) ²	3.1	3.6	3.3
On the trench (0 ft.)	3.1	3.4	3.8	3.7	(5.2)	3.5
Dry area	(5.2)	(4.9)	-	-	-	-
Caliche Area (8-16")						
Away from the trench	4.3	3.5	2.9	3.9	3.4	3.6
Near the trench (9ft.)	3.2	2.7	(4.1)	3.6	2.4	3.0
On the trench (0 ft.)	2.2	2.3	2.9	3.2	(5.0)	2.7
Non-Caliche area						
No trench (0-8")	2.2	2.0	2.2	2.1	1.8	2.1
No trench (8-16")	2.0	2.3	1.7	2.3	2.9	2.2

¹] Note that the zones away from the trench are closest to the sprinkler heads.

²] Numbers in the parenthesis are excluded from the means as they reflect poor irrigation.

DISCUSSION

Diagnosis of Salt Accumulation

A practical way to determine the presence or absence of soil salinity problems is to analyze soils for salinity. It is difficult to diagnose salt problems just by looking at turf, as salts do not cause an identifiable symptom, except for stunted growth and, at times, loss of vigor and color (which can be caused by other reasons beside salts). The threshold soil salinity measured in the soil saturation extract method (Rhoades and Miyamoto, 1990) is around 6 dS m^{-1} for a significant growth reduction of bermudagrass as well as of ryegrass (Fig. 23). Most of the test sites had soil salinity far exceeding 6 dS m^{-1} , reaching as high as 16 dS m^{-1} for the top 20 or 30 cm. Most turfgrass species have a shallower root zone, and can survive soil salinity greater than 6 dS m^{-1} , as long as fresh water is provided frequently. However, bermudagrass in sports field seldom survives when soil salinity exceeds a range of 8 to 10 dS m^{-1} in the depth of 6 to 8 inches.

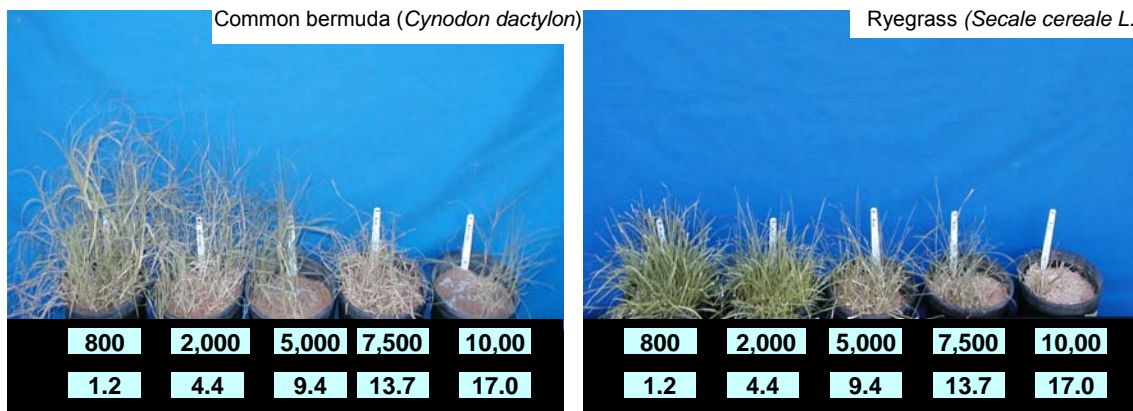


Fig. 23 Growth response of common bermudagrass and ryegrass to soil salinity (Miyamoto et al., 2004); the upper figures are in ppm, and the lower figures in dS m^{-1} in the saturation extract.

Assessing the Need for Soil Improvements

The cause of soil salinization is often associated with inadequate irrigation, including malfunction of sprinklers, or the excessive slope which causes runoff. In other instances, soils just do not have adequate permeability to maintain a favorable salt balance, and these examples were already given in Introduction. Clayey soil series, especially Saneli and Tigua Series, which have a clay subsurface layer are prone to soil salinization and difficult to sustain turf.

A practical way to determine the need for soil improvement is to proceed with irrigation system and management adjustments first. A tentative irrigation scheduling guide is shown in Attachment II. If irrigation water applied to meet the water demand stays on the ground for half a day or more, some forms of soil improvements must be made to improve water infiltration and/or internal drainage. Otherwise, the water applied is subjected to excessive evaporation and an increase in salinity. Ideally, clayey soils should not be irrigated more than two times a week, provided that the irrigation water applied infiltrates adequately. Unfortunately, this is often not the case.

Alternatively, soil salinity levels for different soil textural classes can be estimated by using an empirical equation. Miyamoto and Chacon (2006) found that soil salinity of Entisols (young soils in alluvial plains) is controlled by soil type and turf use characteristics.

$$SCF = EC_e / EC_w = a \text{Exp}[bSWC]$$

where SCF is the salt concentration factor defined as a ratio of soil salinity (EC_e) and water salinity (EC_w), and SWC is the saturation water content. The empirical coefficients a and b vary with turf use categories, and examples are shown in Fig. 24, using the data obtained in the El Paso area when irrigated at a regional estimate of evapotranspiration (which is 40 to 48 inches per year for bermudagrass). The figure contains the mean SCF plus the standard deviation, SD. The relationship between SWC and soil textural class is also shown in the figure.

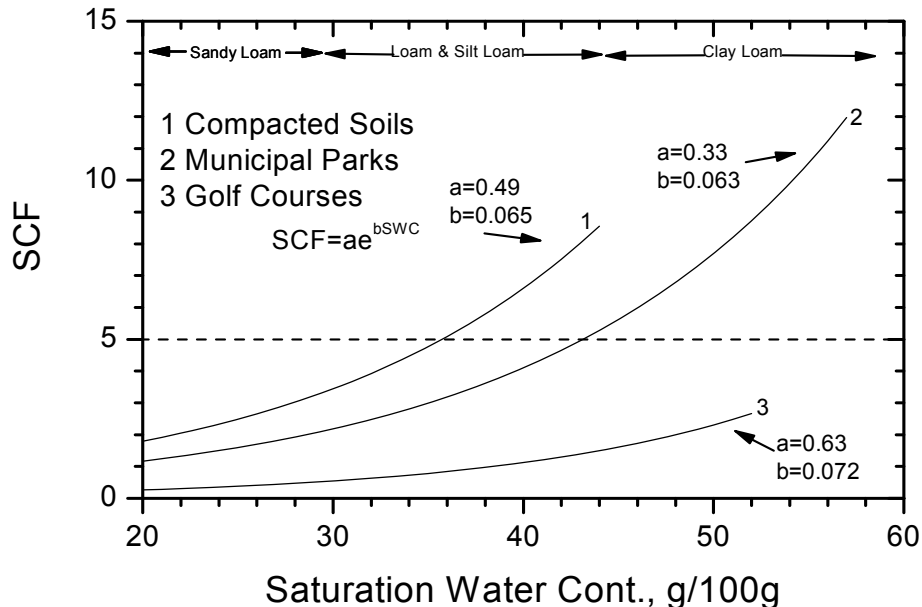


Fig. 24 The empirical relationship between the saturation water content and the mean salt concentration factor (SCF) plus the standard deviation (Miyamoto and Chacon, 2006).

Salinity of potable water in urban communities of the Southwest ranges from 0.5 to 1.2 $dS\ m^{-1}$, and that of reclaimed water 1.0 to 2.5 $dS\ m^{-1}$. The salt concentration factor (SCF) of silty clay loam and silty clay is greater than 5 in sports field, indicating that these soils can be salinized even when potable water is used for irrigation. The clayey soils in Shawver Park West, Pavo Real, and Valley Creek Park all fall into this category. Sandy soils, such as present in Estrella-Rivera and Mary Webb Park should not be salinized unless irrigation is inadequate to leach salts, or the slope of that field is too steep to allow for adequate water infiltration, such as the case at E. Rivera Park.

Soil Improvement Measures

The soils in the El Paso area are highly diverse. This means that the measures used to improve salt leaching must be adjusted to the soil types and conditions.

Leveling: Leveling of the field is ordinarily not considered as a part of soil improvement efforts. When it comes to uniform water infiltration and salt leaching, however, the field has to be leveled. Otherwise, salts accumulate on elevated portions.

Aerification: Three types of equipment have been used to loosen compacted sports fields: slicer, solid tines, and hollow tines (or verti-drains). The effective depth of treatment ranges from 2 to 6 inches. Observations at Lomaland Park and Shawver Park indicate that none of the aerifying equipment, however, has shown a promise in leaching salts, unless the soil is compacted or sloped (Tables 6 and 7). These results do not support the notion that aerification promotes water infiltration, thus salt leaching. The poor response to aerification treatment of Harkey silt loam and Anapra silty clay loam at Shawver Park can be attributed to minimal compaction and/or previous use of similar equipment. The poor response to aerification at Lomaland Park is probably related to poor internal drainage, besides excessive soil moisture at the time of the test run. Aerification may help improve water infiltration if compacted or sloped, but can not improve internal drainage of clayey soils.

Shallow Chiseling or Cultivation: A rotary cultivator used at Estrella-Rivera Park seems to have helped improve water infiltration and salt leaching from the sloped area of Gila sandy loam. However, a turf shaper used in the Saneli silty clay at Shawver Park had no effect on salt leaching, probably because of little soil compaction and drainage impairment caused by the presence of clay layer below. Minimum-till shallow chisels provide good shattering of the surface layer (Fig. 9), which can not be obtained by other aerifiers. However, when used at Pavo Real, North with deep clay, this method did not help leach salts, due to drainage impairments caused by the clay layer below. The best use of the shallow chisel may be limited to the soil textural class of loam or silt loam with surface compaction, but not with serious internal drainage impairment.

Another use of shallow chisel is for renovation. At present, a rotor tiller or a disk is commonly used to prepare soils for seeding. The experiences at the practice field in Clint and Pavo Real Park have shown that re-growth of bermudagrass is much faster from what is left in the ground than from the seed (Figs. 14 and 16). Shallow chiseling encourages re-growth, whereas rotor tillers and disks slow the process.

Subsoiling: Subsoiling to a depth of 20 to 28 inches followed by topdressing with sand worked well in Glendale silty clay loam (a practice field in Clint), and in Saneli soil series at Valley Creek and Pavo Real Parks. The experience at Pavo Real, South seems to indicate that the effect of subsoiling without topdressing with sand can be short-lived.

Although subsoiling is a fast and cost-effective method of improving salt leaching, there are many questions yet to be answered. In deep clayey soils, such as Tigua silty clay, this method may or may not be effective for leaching salts, unless combined with trenching for drainage. Drainage is likely to be impaired by the clay layer below. The same type of concern applies to clayey soils with a high water table, such as Saneli silty clay site at Valley Creek Park. In these cases, drainage which leaches salts would be curtailed.

Another uncertainty about subsoiling is its effectiveness when used in relatively shallow stratified soils, such as Anapra silty clay loam, and Harkey silty clay loam. In those cases, the depth of chiseling if conventional subsoilers with a shank length of 28 to 32 inches are used, enters into the sand layer. For shallow stratified clayey soils, light-duty subsoilers or minimum-till chisels with the penetration depth of 17 to 24 inches with a reduced shank space may prove to be more efficient. These shanks can be pulled with a tractor of less than 180 Hp.

Profile Modification: Soil profile mixing has been used for controlling soil salinity in pecan orchards in the El Paso Valley (Miyamoto, 2000). With a large excavator (4 to 5 ft. wide bucket), an experienced operator can mix one acre in a few days. The test results from

Saneli silty clay (Pavo Real, South) show rapid salt leaching and a good turf establishment, although there is a need to better define the mixing ratio. This method is time-consuming, but is easy to implement, and may be considered in high use sports fields or high use zones within a field, such as near the goal line of soccer fields or the center strip of football fields.

Soil profile modification involving flipping of a clay layer with a sand layer was attempted mainly to simplify the operation. Mixing the soil profile with a backhoe requires experience. In addition, it is a slower process than using a large front-end loader, although this may not be the case if a backhoe with a large capacity is available. As long as sand is placed between large clay clods to allow drainage, profile inverting appears to be satisfactory. In some cases, however, the sand layer may consist of coarse sand, instead of loamy sand. In such cases, blending may have to be considered.

Trenching: Trenching of poorly permeable soils or a calcitic horizon does not facilitate water movement. The trench is simply a gutter, and the surface of the subgrade must be sloped towards the trench if water movement is to occur. The soccer field at Galatazan Park had a 2 to 3% slope. Therefore, excess water was able to travel above the subgrade until encounters the trench. However, the quantity of irrigation water required to leach salts increases with increasing trench spaces. In addition, irrigation must be performed in a manner which results in percolation losses. Otherwise, salts will accumulate in the topsoil to the level harmful to turf, usually in a matter of a few months or less if irrigation water contains salts in excess of 1000 mg/L.

Excavation: This method is likely to be the last option, because of costs. However, it may be the first option for the development of new facility. In the soils with drainage impairment, the key feature is to slope subgrade so as to guide drainage into a trench (Fig. 25). The appropriate slope of the subgrade is yet to be determined. The existing football field has the crown at a slope of 1 to 2%, mainly to avoid puddling. The soccer field at Galatazan was sloped 2 to 3%, and the exploratory test run at Pavo Real, South, the slope was about 5 inches over 20 feet (or 2%). If a thin layer of coarse sand is placed right on the sloped surface of the subgrade, the slope requirement could possibly be lowered. The thickness of the excavation may range from 6 to 12 inches, although many landscapes are now maintained with topsoil as thin as 4 inches using high frequency irrigation. As indicated earlier, irrigation has to be managed to cause drainage at least once a month during summer.

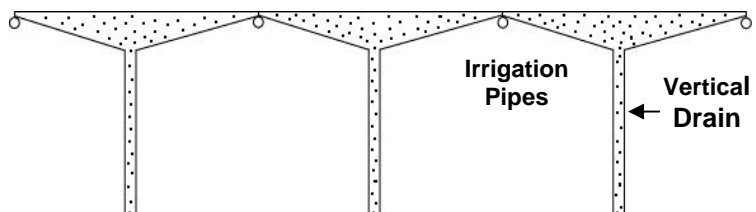


Fig. 25 A conceptual cross-section of ball field developed on deep clay or an impervious calcic horizon.

Tasks Ahead

Inventory of Salt-Affected Fields: The general distribution of salt-affected soils in the El Paso area is known. These are in the Lower Valley, the Upper Valley and the Northwest. However, the detailed distribution of soil types must be known in order to develop a site-specific plan for soil improvements. This task will involve soil survey and testing, using the

existing soil map as a guide. Soil textural classes, the depth to a sand layer, and soil salinity are some of the parameters to be determined.

Improving Irrigation Systems and Management Practices: Not all the salt-affected fields are a consequence of poor soils. Improving irrigation systems and management practices can help improve salt leaching and turf cover, especially in the soils consisting of silt loam, loam, and in some cases, silty clay loam. Water use figures should also be compiled for evaluating irrigation scheduling. The water use data shown in Table 3 indicate some difficulties with irrigation control. Irrigation systems and scheduling should be fixed prior to soil improvement activities.

Selection of Soil Improvement Measures: Selection of soil improvement measures was already discussed, and a summary table is provided in Table 14. Three methods appear to be most promising; soil profile modification, excavation and replacing it with sandy soils, and subsoiling. Costs of these methods need to be established.

Table 14. General guidelines for soil improvement measures.

Soil Types	Slope	Potential Measures
Alluvial Plains		
Loamy sand	flat	
Loamy sand	sloped	consider aerifying
Sandy loam, Silt loam	flat	none or aerification
Sandy loam, Silt loam	sloped	aerification/shallow chisel
Loam, clay loam	flat	shallow chisel, subsoil
Loam, clay loam	stratified	profile modification
Clay, Silty Clay	flat	subsoil or excavation
Upland Soils		
Caliche	sloped	trenching and topsoil
	flat	corrugation and topsoil

Renovation Methods: Fields consisting of deep clay are difficult to maintain mainly because of poor drainage. In the past, these fields were taken off from the use schedule for one or two years under a renovation project. Renovation simply means that grass cover is re-established. Since soil conditions remain essentially the same, the re-established grass cover diminishes in a few years (or shorter in some cases), as long as the high soil salinity is present (Fig. 26). The effective renovation must include salt leaching. However, if the salt level is not very high or salt leaching operation can not be implemented for one reason or another, our experience has shown that the use of shallow chisels,

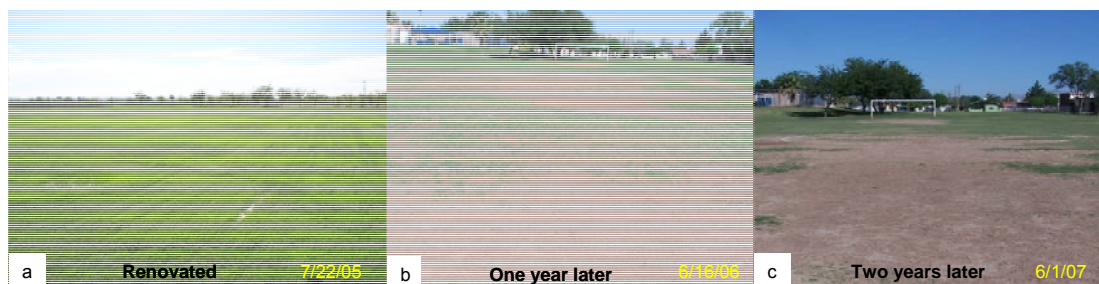


Fig. 26 Degradation of a sports field after renovation: Pavo Real, North.

instead of rotor-tillers or disk speeds up regrowth. The use of light-duty subsoilers with the penetration depth of 17 to 24 inches may prove to be more effective.

The sequence of the conventional renovation work starts with chiseling (or ripping), tilling or disking, crushing of soil clods, leveling, and seeding. If a subsoiler is to be used, it must begin with leveling, patch work in the deteriorated areas, subsoiling and topdressing. In other words, the sequence of work is largely reversed.

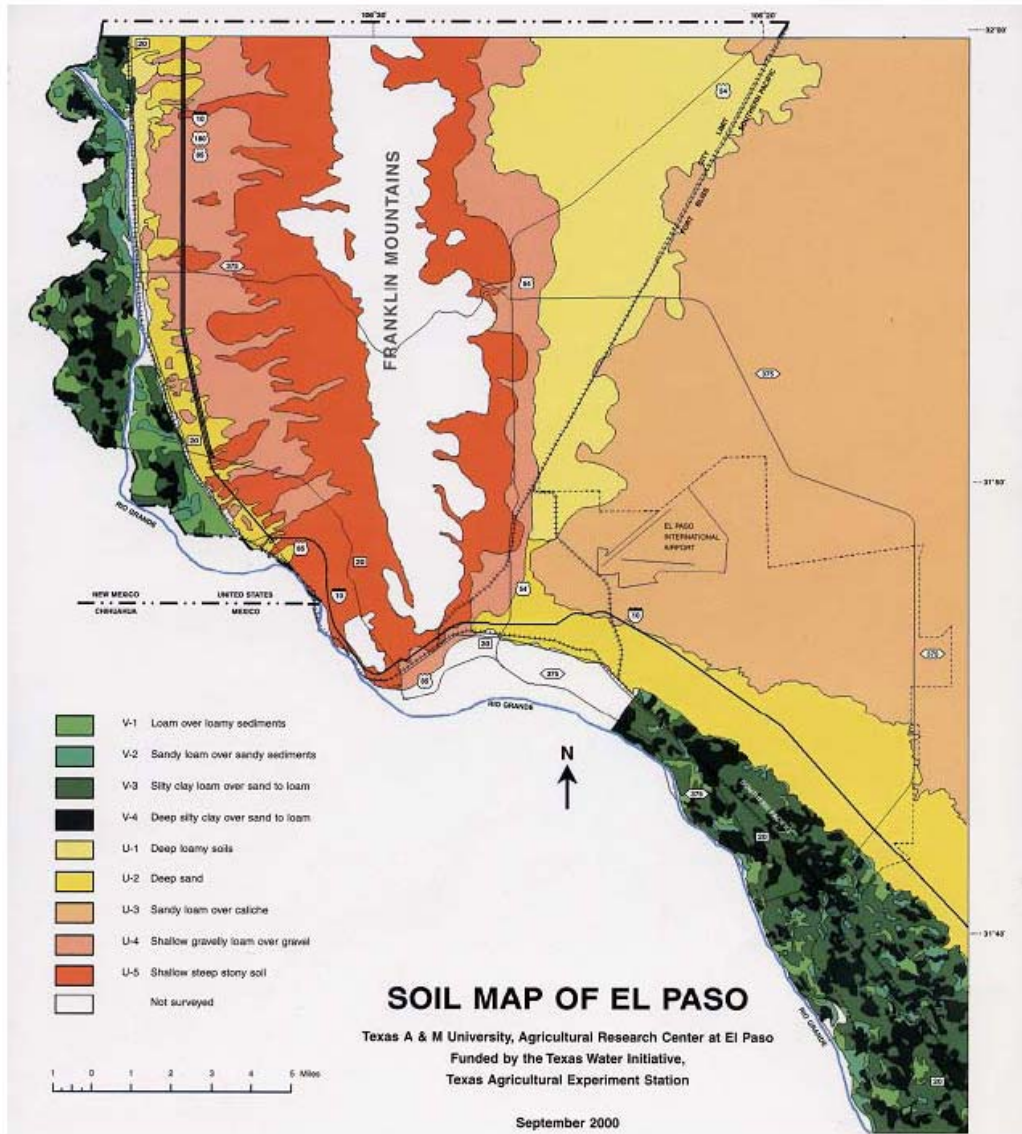
Soil Preparation at New Facility: If the soil is selected and properly prepared at the time of facility construction, there would be little need to improve soils after construction, except for taking care of soil compaction with aerifiers. However, the existing guidelines or specifications for sports fields' construction are based mainly on soil strength and stability, but not on soil salinization potential. With increasing use of water with elevated salinity for irrigation, there is a need to examine the existing guidelines and codes for sports field construction.

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ATTACHMENT I

Soil Map of El Paso, Texas



ATTACHMENT I (Continued)

Description of Soil Mapping Units

Description of soil mapping units for management, and the official designation of applicable soil series or types.

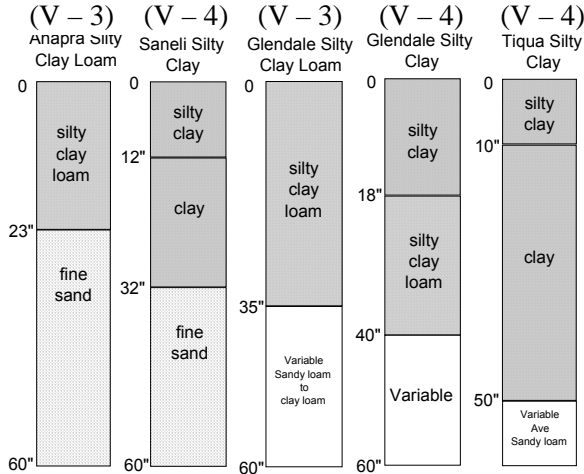
Groups	General Description	Extent	Official Designation ¹ -
Uplands			
U - 1	Deep loamy soils	-	Pajarito (PAA), Turney-Berino (TBB)
U - 2	Deep sand	-	Bluepoint (BPC, BUC)
U - 3	Sandy loam over caliche	-	Hueco (HW), Wink (WKA)
U - 4	Shallow gravelly loam over gravels	-	Augustin (AGB), Canutillo-Del Norte
U - 5	Shallow steep stony soil	-	Del Norte (DCD)
Valley² -			
V - 1	Loam over loamy sediments	8	Gila (GA), Harkey (Ha), Glendale (Gd)
V - 2	Sand loam over sandy sediments	22	Brazito (Br), Gila (Gc), Vinton (Vn)
V - 3	Silty clay loam over sand to loam	46	Anapra (An), Harkey (Hk), Glendale (Ge), Saneli (Sa)
V - 4	Deep silty clay over sand to loam	23	Glendale (Gs), Saneli (Sc), Tigua (Tg)

¹ - These are official designations of applicable soils given in the Soil Survey, El Paso (1971).

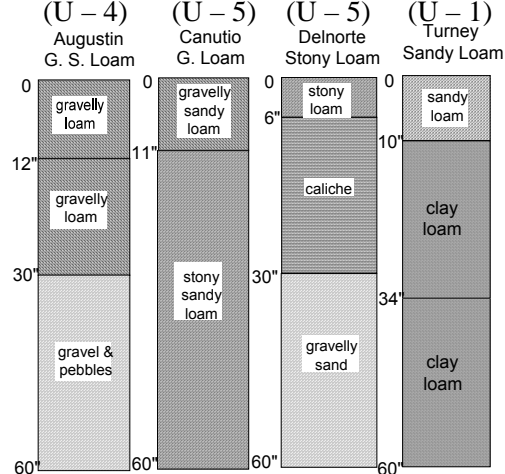
² - In the General Soil map, the soils in the valley are treated as one mapping unit.

Soil Profile which are Prone to Salinization

Entisols



Aridisols



Sites	Mapping Unit	Specific Soil Types
Estrella-Rivera	V - 2	Gila sandy loam
Mary Webb	V - 2	Vinton sandy loam
Lomaland	V - 3	Harkey silty clay loam
Shawver, East	V - 3	Anapra silty clay loam
Shawver, West	V - 3	Saneli silty clay loam
Clint	V - 3	Glendale silty clay loam
Pavo Real, North	V - 3	Glendale silty clay
Pavo Real, South	V - 4	Tigua silty clay
Valley Creek	V - 3	Saneli silty clay
Westside Park	U - 4	Canutillo gravelly loam
Three Hills Park	U - 4	Del Norte gravelly loam

ATTACHMENT II

Irrigation Guidelines for Test Plots

Month	Pan		Turf		EPWU	Average	Irrigation Rate ¹ -	
	Evaporation		Required		Allotment	Rainfall	Bermudagrass	
	in/day	in/mo	in/day	in/mo	in/mo	in/mo	in/mo	Ccf/Ac
1	0.13	4.1	-	-	1.1	0.28	0	
2	0.20	5.8	-	-	1.1	0.35	0	0
3	0.29	9.0	-	-	1.4	0.28	0	0
4	0.40	12.0	0.17	5.1	5.0	0.19	5.1	139
5	0.43	13.3	0.21	6.5	5.5	0.20	6.5	176
6	0.46	13.8	0.23	6.9	7.7	0.58	6.9	187
7	0.44	13.6	0.22	6.5	7.7	1.38	6.5	177
8	0.36	11.2	0.18	5.9	5.5	1.32	5.9	160
9	0.29	8.7	0.15	4.8	5.0	1.05	4.8	130
10	0.23	7.1	0.12	3.7	3.3	0.53	3.7	101
11	0.15	4.5	-	-	1.4	0.24	0	0
12	0.10	<u>3.1</u>	-	-	<u>1.1</u>	<u>0.26</u>	<u>0</u>	0
Annual		106			46	6.7	39.4	
Apr - Oct		80			40	5.3	39.4	

¹-Not corrected for rain or irrigation efficiency.

Scheduling Options

Month	Irrigation Required		Option A		Option B	
	3 Irrig./wk	2 Irrig./wk	Frequency	Depth	Frequency	Depth
	in/application		no/wk	in/appl.	no/wk	in/appl.
April	0.39	0.59	2	0.59	1	1.20
May	0.48	0.73	3	0.48	2	0.73
June	0.54	0.80	3	0.54	2	0.80
July	0.51	0.77	3	0.51	2	0.77
August	0.42	0.63	3	0.42	2	0.63
September	0.35	0.52	2	0.52	1	1.04
October	0.28	0.42	1	0.84	1	0.84

Option A: Sandy soil or loamy sand. Turf during the period of inactive use can be maintained with irrigation using somewhat less quantities of water than indicated.

Option B: Others, especially if reclaimed water is used.

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