# EFFECT OF BRUSH VEGETATION ON DEEP DRAINAGE USING CHLORIDE MASS BALANCE

A Thesis

by

RONALD JOSÉ NAVARRETE GANCHOZO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Soil Science

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Approved by:

Chair of Committee, Charles T. Hallmark
Committee Members, Cristine Morgan
Georgianne Moore
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# ABSTRACT

Effect of Brush Vegetation on Deep Drainage Using Chloride Mass Balance.

(December 2009)

Ronald José Navarrete Ganchozo, B.S., Pan-American School of Agriculture

Chair of Advisory Committee: Dr. Charles T. Hallmark

Groundwater use is of fundamental importance to meet rapidly expanding urban, industrial, and agricultural water requirements, particularly in semiarid zones. To quantify the current rate of groundwater recharge is thus a prerequisite for efficient and sustainable groundwater resource management in these dry areas, where such resources are often the key to economic development. Increased groundwater recharge has been documented where native vegetation or forest/shrub land was converted to grassland or pasture, or where the land was cleared for agricultural purposes. The basic argument for increased recharge is that evapotranspiration, primarily interception and transpiration, is higher in shrublands than grasslands.

Chloride mass balance (CMB) has been used to estimate ancient recharge, but recharge from recent land-use change has also been documented, specifically where vegetation has been altered and deep-rooted species replaced with shallow-rooted grasses. Chloride concentrations are inversely related to recharge rates: low $Cl^-$ concentrations indicate high recharge rates as $Cl^-$ is leached from the system; high $Cl^-$

concentrations indicate low recharge rates since $Cl^-$ accumulates as a result of evapotranspiration.

The objectives were (1) to assess the hypothesis that removal of woody-shrub vegetation and replacement with grasses increases deep drainage, (2) to quantify the amount of deep drainage after land-use change, and (3) to provide science-based data for a better understanding of changing land-use impacts on deep drainage. Eight soils from five locations in the Central Rolling Red Plains near Abilene and Sweetwater were sampled. Each location consisted of a pair of similar soils with contrasting vegetative cover: shrubland and grassland. At each site three to five soil cores were taken as deep as possible and samples were taken by horizon, but horizons were split when their thickness exceeded 0.25 m.

Soil $Cl^-$ profiles under shrubland at three sites showed that virtually no water escapes beyond the root zone. High $Cl^-$ concentrations and inventories reflect soil moisture fluxes that approached 0 mm $yr^{-1}$ with depth. Evapotranspiration may be largely responsible for $Cl^-$ enrichment in those profiles. Surprisingly, soil moisture flux past 200 cm under juniper woodlands was the highest with 2.6 mm $yr^{-1}$. Evapotranspirative $Cl^-$ enrichment in the upper 300 cm was not observed and may suggest a different water uptake mechanism for this plant community.

Soil $Cl^-$ profiles showed increased recharge rates under grassland vegetation ecosystem. Estimated deep drainage past 200 cm of 0.1 to 1.3 mm $yr^{-1}$ was observed. Low $Cl^-$ concentrations and inventories suggest a leaching environment that may be in response to changes in land use/land cover.

# DEDICATION

This thesis and all my achievements are dedicated to my wonderful and beautiful family. Their unconditional support with the passing years translates into important accomplishments in my professional career. They are always supporting my actions and decisions, they are the writers of this history, and I am just an interpreter of all their good wishes.

# ACKNOWLEDGEMENTS

I would like to extend my gratitude to my beautiful family for all their love and support; I still miss each one of you.

I would like to express thanks to Dr. C. T. Hallmark, whose guidance since the beginning of my master’s studies and throughout this research has made possible the completion of my degree. I specially thank him for giving me the opportunity of being his student, for his trust in my capabilities, and his invaluable support since the first time I came to Texas A&M University, and to his wife, Melinda for embracing me like a son. I also extend thanks to my intellectual committee members: Dr. Cristine Morgan, whose teaching skills made the hardest subjects quite easy and Dr. Georgianne Moore for her guidance and trust during the development of this research work.

I extend appreciation to William Shoup, Riley Dayberry, and Jo Parsley of the Abilene NRCS Soil Survey Office. Their invaluable help throughout this research made possible the completion of this work, and to the Texas NRCS for funding this project. I gratefully thank Donna Prochaska and the student workers of the Soil Characterization Laboratory, and to Dr. Jacqui Peterson and Nina Stanley for their enormous contribution in data collection of this research; I am in their debt.

Last but not least, I would like to express my gratitude to my friends abroad for their support when I needed it the most, Nelson Proaño, Ricardo Ochoa, and Mildred Orellana; and to my closest friends at Texas A&M, Ivan Borja, Victor Taleon, and Alba Collart. Thanks all of you for being there unconditionally.

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# 1. INTRODUCTION

Groundwater is Earth's largest freshwater resource. Reduced reliability of surface water supplies in the Western U.S. with projected climate change during the next century may result in increased reliance on groundwater (Scanlon et al., 2005b). Water resources management is critical in Texas because of diminishing water supplies and projected rapid increases in population growth (21 million in 2000 to 46 million in 2060) (Texas Water Development Board, 2007). Groundwater use is of fundamental importance to meet rapidly expanding urban, industrial, and agricultural water requirements, particularly in semiarid zones. Quantifying the current rate of groundwater recharge is thus a prerequisite for efficient and sustainable groundwater resource management in these dry areas where such resources are often the key to economic development (de Vries and Simmers, 2002).

When producing water from an aquifer, the water comes from three possible sources: recharge, storage, or cross-formational flow. Recharge is the amount of water that moves into the aquifer, generally from rainfall, melting snow, or rivers. When it rains, some of the rain runs into streams, some evaporates back into the atmosphere, some is used by plants, and some percolates into the ground, eventually reaching and recharging the aquifer. Conceptually similar to recharging a battery with new power, percolating precipitation recharges an aquifer with new water (Mace et al., 2000).

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This thesis follows the style of the Soil Science Society of America Journal.

Recent droughts have caused researchers to focus attention on recharge issues (Scanlon et al., 2003a), especially the effects of groundwater recharge by removal of mesquite-dominated vegetation in semiarid regions in Texas. Woody vegetation is assumed to control the extent of deep drainage in this region utilizing water from the episodic rainfall events before it can penetrate below the root zone. The root system of these plant communities is dense and deep to effectively extract downward-percolating water while herbaceous plants in the same environment are shallower rooting (Seyfried et al., 2005). Woody-shrub plants have the potential to modify recharge when subsurface water is available (Huxman et al., 2005).

Linkage between woody plant cover and groundwater recharge has been extensively investigated in a range of climates. While such a linkage has been well established for forests in mesic climates, there is less consensus concerning semiarid landscapes (Wilcox, 2002) where evapotranspiration is thought to be the dominant factor limiting groundwater recharge. Semiarid landscapes represent a transitional zone between humid environments in which woody plants have a large effect and arid ones in which the effect is minimal (Huxman et al., 2005). It is for the semiarid environments that the most confusion exists, and therefore the need for knowledge is most critical (Huxman et al., 2005), mainly the influence of vegetation on deep drainage and subsequent groundwater recharge at a local and regional scale. In general, the percent of precipitation that eventually recharges the aquifer is small, generally between one and four percent of the total rainfall. However, the volume of recharge can be large when accumulated over a large outcrop, or recharge zone, and/or if the precipitation is large (Mace et al., 2000).

Deep drainage and groundwater recharge are dependent on many factors: soil type, vegetative cover, landscape setting, precipitation (distribution and total amount), and evapotranspiration. Studies have examined ancient groundwater recharge (Murphy et al., 1996; Phillips, 1994; Scanlon, 2000; Scanlon et al., 2003b; Zhu et al., 2003), groundwater chemical composition (Cook et al., 1989; Zhu et al., 2003), and recharge rates upon changes in land use (Allison and Hughes, 1983; Allison et al., 1990; Petheram et al., 2000; Scanlon et al., 2005b, 2007b, 2009). Some scientific evidence suggests that land use change from woody-shrubs to grassland increases the amount of water percolating beyond the root zone and therefore increases recharge rates in semiarid settings in Texas (Scanlon et al., 2005b, 2007b, 2009), and few studies have evaluated recharge rates upon changes in land-use/land cover at different locations at the same time (Walvoord and Phillips, 2004; Scanlon et al., 2005b; Sandvig and Phillips, 2006). Although the perception that brush control will increase deep drainage (or water yield) is held among landowners, limited research has been conducted in the Rolling Plains area near Abilene to assess the potential increase in deep drainage and groundwater recharge after the removal of woody-shrub vegetation.

The chloride mass balance (CMB) technique has been largely applied in areas of higher aridity than the Texas Rolling Plains area near Abilene, where limited work has been performed. This research intends to evaluate the CMB technique in such areas based on $Cl^-$ concentrations in pore water, $Cl^-$ atmospheric inputs, and precipitation to compare deep drainage in areas dominated by woody-shrub vegetation with those areas where woody-shrub vegetation has been removed and is now dominated by grass. Environmental tracers such as $Cl^-$ are widely used to evaluate flow processes and estimate fluxes of pore water in arid and semiarid regions (Scanlon, 2000). In the CMB method, recharge is determined by applying a mass balance in which the difference between the $Cl^-$ concentration of the soil water and the atmospheric $Cl^-$ input is due to evapotranspirative enrichment.

In this research the $Cl^-$ concentration of soil pore water will be determined and soil $Cl^-$ profiles for brush-cleared and non-cleared sites constructed. The objectives of this study are: (i) to assess the hypothesis that removal of woody-shrub vegetation and replacement with grasses increase deep drainage in a selected semiarid region in Texas; (ii) to estimate the amount of deep drainage and potential groundwater recharge in the Rolling Plains near Abilene upon changes in land use; and (iii) to provide science-based data for a better understanding of changing land use impacts on deep percolation and the fate of groundwater.

# 2. REVIEW OF LITERATURE

Understanding impacts of land use change on water flow and solute transport is critical for managing current and future water resources (Scanlon et al., 2007b). While the impacts of land use change on atmospheric components of the hydrologic cycle are increasingly recognized, impacts of subsurface components are less well recognized, particularly groundwater recharge (Scanlon et al., 2005b).

Groundwater recharge is affected by many complex parameters and processes, which themselves are influenced by many factors. Groundwater recharge is part of the vadose zone soil water budget driven by precipitation, which itself is affected by climatic factors such as wind and temperature, resulting in a very complex and dynamic distribution. Depending on the rainfall intensity, temperature, and land cover, precipitation is subjected to various processes such as evapotranspiration, infiltration, and surface runoff (Jyrkama and Sykes, 2007), which are some of the basic components of the water balance.

## 2.1 Water balance

Many techniques in estimating groundwater recharge are based on the water-budget, which provides a framework of the fundamental relationships between precipitation inputs, soil storage, and deep drainage. A form of the water balance equation can be written as follows:

$$D_{\mathrm{D}} = I - (A_{\mathrm{ET}} + \Delta S)$$

where $D_D$ is deep drainage, $I$ is water input (rain and snowmelt), $A_{ET}$ is the combined loss of water through evaporation and transpiration, and $\Delta S$ is the change in root-zone water storage. All of these terms are expressed as units of length (depth) per time (mm $yr^{-1}$). For deep drainage to occur, $I$ must be greater than $A_{ET} + \Delta S$.

In arid and semiarid regions, the soil water content of the root zone typically returns to approximately the same low value at some point within each year. This observation is consistent with the fact that, in semiarid regions, the potential evapotranspiration greatly exceeds precipitation on an annual basis. Thus, virtually all plant-available soil water is returned to the atmosphere, and for generation of deep drainage, there must be some period during the year in which cumulative net water inputs at least exceed the capacity of the soil to store plant-available water (Seyfried and Wilcox, 2006). Consequently, this indirect or residual approach (water balance) to estimate recharge has a major limitation: the accuracy of the recharge estimate depends on the accuracy with which the other components in the water-budget equation can be measured. This limitation is critical when the magnitude of the recharge rate is small relative to that of other variables, particularly evapotranspiration (Gee and Hillel, 1988; Scanlon et al., 2003a).

Water balance, when applied to arid and semiarid soils relies on subtracting one large quantity (evapotranspiration) from another large quantity (precipitation) to calculate a very small quantity (downward flux). Small errors in the determination or estimation of either evapotranspiration or precipitation will result in relatively large errors in the calculated flux. Conventional water balance calculations in arid and semiarid regions would therefore indicate that there is no net downward flux (Phillips, 1994).

## 2.2 Vegetation and soil water dynamics

In semi-arid environments the large excess of potential evapotranspiration over rainfall has led to the evolution of an ecosystem which uses almost all the incident rainfall (Allison and Hughes, 1983). Furthermore, factors such as increased grazing pressure, reduced fire frequency and increased atmospheric $CO_2$ have contributed to the establishment of this ecosystem over the past 150 years (Seyfried and Wilcox, 2006). This ecosystem is dominated by woody-shrub vegetation, which are species that are more deeply rooted than herbaceous plants, so shrubs and trees generally extract soil water from greater depths than herbaceous vegetation (Wilcox, 2002).

Competitive xeric vegetation is thought to control deep drainage in semiarid regions. Two characteristics are required to exert this control: (1) the roots of those plants must extend to depths of 2–3 m with sufficient density to effectively extract downward-percolating water within those depths, and (2) those plants must be able to generate and maintain relatively low soil water potentials at depths of 2–3 m for very long periods (Seyfried et al., 2005) preventing groundwater recharge over millennial time scales (Scanlon et al., 2005a). Plant roots play an important role in the recharge process not only by enabling plants to draw water from deep in the vadose zone (and even from the saturated zone) thereby reducing the amount of percolating water that reaches the water table, but also by creating preferential flow paths and channels that aid water flow through the soil profile (Le Maitre et al., 1999).

A root study in a water-limited ecosystem conducted by Schenk and Jackson (2002) found that shrubs were more deeply rooted in climates with substantial winter precipitation than in climates with summer rainfall regimes. Winter precipitation tends to infiltrate more deeply than summer rainfall, which is subject to immediate evaporative demand. Regardless of the climate, shrubs were more deeply rooted than herbaceous plants; herbaceous species had deeper rooting depths and larger lateral root spreads in xeric than more mesic environments.

Woody vegetation has been mainly investigated for its influence in modifying stream flow rather than deep drainage. Vegetation influences recharge through the processes of interception and transpiration, and other less commonly characterized, yet potentially significant processes such as stemflow and throughfall (Le Maitre et al., 1999). Evapotranspiration is a process that includes (1) evaporation from the soil surface, (2) transpiration from the plant, and (3) evaporation from plant or litter surfaces (commonly referred to as interception loss). However, evapotranspiration by shrubs can reduce both stream flow and deep drainage. As shrub cover increases, so too does the potential for transpiration and/or interception losses (Wilcox, 2002).

In semi-arid areas, native vegetation intercepts most of the incoming rainfall, resulting in very low rates of groundwater recharge when such vegetation is present (Allison et al., 1990). However, water remaining in the soil after plant demand has been satisfied, or which has bypassed exploring roots, becomes deep drainage (local recharge) and eventually moves to an underlying groundwater system (Allison and Hughes, 1983). Arguably, these processes are very difficult to quantify since they are dependent on a multitude of climatic parameters, such as intensity and duration of rainfall, temperature, and wind speed, as well as the physical characteristics of the individual plants.

Studies in juniper woodlands support the argument that interception rates are considerably higher under juniper canopies than inter-canopy areas; for other shrublands however, interception by shrubs is comparable to that by herbaceous vegetation (Wilcox, 2005). The canopy of an average-size, mature redberry and ashe juniper can intercept 26% and 37% of the annual precipitation, respectively. Redberry and ashe juniper litter can intercept 40% and 43% of the annual rainfall, respectively. Therefore, far less rainfall reaches mineral soil as compared to grasslands, in which interception loss accounts for 11-18% of incident precipitation (Lyons et al., 1998).

The practice of removing woody vegetation to enhance water supply in semiarid rangelands in the United States continues to generate considerable interest, even though past research has yielded apparently contradictory results concerning its efficacy (Seyfried and Wilcox, 2006). When changes in land management and land use reduce the evaporative capacity of vegetation across the landscape, plants draw less water from the soil. The basic argument for the clearing of shrub vegetation is that evapotranspiration is higher in shrublands than in grasslands, which makes less water available for streamflow and groundwater recharge (Seyfried and Wilcox, 2006). Ultimately this change increases the incidence of soil saturation resulting in deep percolation beyond the root zone (Murray-Darling Basin Commission, 2003). The process of percolation is controlled by the hydraulic properties of the soils which are very sensitive to the moisture content and pressure head distributions. A small change in the volumetric water content can often change the hydraulic conductivity by several orders of magnitude. In addition, the soils in the unsaturated zone rarely exhibit homogeneous properties, often consisting of layered sands, silts, and clays, resulting in non-uniform moisture distributions (Jyrkama and Sykes, 2007).

Even in relatively homogeneous materials, the unpredictable occurrence of preferred pathways due to plant roots, cracks and fissures, complicates the hydraulic characterization of soils in the unsaturated zone (Sophocleous, 2004). Large variations in recharge can also occur even across uniform soils due to topography, resulting in depression-focused recharge. Shallow groundwater levels also influence the recharge process by limiting the amount of water entering the ground (Jyrkama and Sykes, 2007).

Groundwater recharge has been documented to occur where native vegetation or forest/shrub land has been converted to grassland or pasture, or where the land has been cleared for agricultural purposes (Scanlon et al., 2005b, 2007b). Tolmie et al. (2004) found low rates of drainage (<1 mm $yr^{-1}$) under native vegetation in a semiarid environment, and an increase in drainage in cropped soils and pasture after clearing of vegetation. Allison and Hughes (1983) showed that in a semiarid region (rainfall 250-300 mm $yr^{-1}$), recharge flux beneath native *Eucalyptus* spp. was <0.1 mm $yr^{-1}$. Recharge was found to increase by up to 2 orders of magnitude following clearing and subsequent cropping. In most of the areas where development of secondary salinization has been studied, the absolute increases in groundwater recharge have been greater than those reported by Allison and Hughes (1983), but the relative increases are often much less. Other scientists have also suggested that a change in land use from shrubs to grassland will increase the amount of deep drainage and therefore increase recharge rates (Walker et al., 1991; Kennettsmith et al., 1994; Petheram et al., 2000; Walker et al., 2002; Scanlon et al., 2005b).

However, other authors have concluded that removing woody vegetation to increase water supply in semiarid rangelands is generally impractical (Hibbert, 1983; Baker, 1984). Most field studies of mesquite rangelands, whether based on the energy budget or the water budget approach, have found that eradication of mesquite does not lead to increased soil moisture and groundwater recharge unless conditions are such that water can move rapidly through the herbaceous rooting zone (Wilcox, 2002). A study conducted by Carlson et al. (1990) showed that deep drainage was consistently small regardless of vegetative cover and precipitation. Results also indicated that mesquite removal, coupled with a subsequent increase in the herbaceous cover, had no benefit in terms of water yield. Slow percolation through the clayey soil, coupled with two restrictive caliche layers, resulted in the soil water being lost via evapotranspiration before it could percolate below the root zone.

These apparently conflicting results are at least partly due to the fact that in semiarid regions, the potential for increasing water supply (streamflow and/or groundwater recharge) is small per unit area and is highly dependent on soil, vegetation, and climatic conditions, which vary widely (Harter, 2005). Nevertheless, groundwater recharge estimation is still critical in evaluating water resources (Scanlon et al., 2003a), and despite the numerous studies, determination of recharge fluxes in semiarid regions remains fraught with uncertainty (de Vries and Simmers, 2002).

## 2.3 Groundwater recharge estimation

To estimate local recharge, some techniques rely on measurements made in the unsaturated zone and, for others, in the saturated zone. One of the major problems in studying the unsaturated zone in semiarid areas is that measurements need to be made beneath the zone where uptake of water by roots is significant. For annual crops and pastures, this is not a great problem as rooting depths usually are <2 m and loss of water from depths greater than this is negligible. However, native vegetation and many trees and shrubs may have living roots to great depth (Allison et al., 1994). Unsaturated-zone techniques for estimating recharge are applied mostly in semiarid and arid regions, where the unsaturated zone is generally thick (Scanlon et al., 2002).

The main techniques that have been used for estimating recharge in Texas include Darcy's law, groundwater modeling, base-flow discharge, and stream loss. Recharge estimates using those techniques may not be reliable because of uncertainties in estimates of regional hydraulic conductivity, and additional information such as groundwater-age data or base-flow discharge data, is required for estimating recharge using groundwater models (Scanlon et al., 2003a). In arid and semiarid regions, those physical methods which rely on measurements of hydrological parameters are problematic for several reasons. First, the fluxes are low and changes in these parameters will be small and difficult to detect. Second, temporal variability is such that measurements must be made for several years to obtain an estimate of mean values. Third, spatial variation brought about by local topography and soil texture changes requires a large number of sampling locations to assess recharge variability (Allison et al., 1994).

A variety of conservative tracers have been used to aid estimation of deep drainage in semiarid environments (Dyck et al., 2003). Natural tracers have both advantages and disadvantages over physical methods. On the positive side, they represent a spatially uniform (at least to a first approximation) input to the soil water-groundwater system. The principal disadvantage is that they may offer only an indirect measure of recharge and mechanisms of infiltration will affect the interpretation of results (Allison et al., 1994). Tracer approaches probably offer the best potential for reliable results in local studies that require 'at-point' information. However, investigations indicate that these approaches are not straightforward, because in some cases preferential flow contributes as much as 90% of the estimated total recharge. Tracer results (e.g. $Cl^-$) must therefore be interpreted with care in areas with multi-modal flow in the vadose zone (de Vries and Simmers, 2002). Such flow under cleared land would certainly contribute to recharge, but this is unlikely to occur as saturated conditions necessary for preferred flow occur rarely in the semiarid environment (Allison et al., 1990).

## 2.4 Chloride mass balance (CMB)

Environmental tracers such as $Cl^-$ are produced naturally in the Earth's atmosphere and are used to estimate recharge rates (Allison and Hughes, 1978; Scanlon, 1991; Phillips, 1994; Scanlon, 2000). In arid and semiarid climates water and solute fluxes below the root zone are small and difficult to quantify; estimates range from <1 to

10 mm $yr^{-1}$ and thus, traditional methods of measuring water flux such as soil water balance and hydraulic gradient techniques are unreliable because the magnitude of error is high (Gee and Hillel, 1988; Dyck et al., 2003).

The CMB technique in the unsaturated zone (Allison and Hughes, 1978) has received considerable attention as a quick, reliable, and economical technique for estimating deep drainage and has been used successfully to evaluate recharge in a range of environments. The CMB approach has been most widely used for estimating low recharge rates (Allison and Hughes, 1978; Allison and Hughes, 1983; Cook et al., 1989; Phillips, 1994; Scanlon, 2000, Scanlon et al., 2006), largely because of the lack of other suitable methods. Global syntheses of the findings from ~140 recharge studies in arid and semiarid regions by Scanlon et al. (2006) show that CMB is the most widely used approach for estimating recharge, in both unsaturated and saturated zones.

In essence, the CMB technique assumes that the long-term average mass flux of $Cl^-$ at the soil surface is equal to the long-term average mass flux of $Cl^-$ below the root zone. The deep drainage rate is estimated as the long-term average annual $Cl^-$ mass flux at the soil surface divided by the average soil water $Cl^-$ concentration below the root zone. Uncertainty in the long-term average $Cl^-$ flux at the soil surface, and the contribution of transport processes such as diffusion and anion exclusion result in uncertainties in deep drainage estimates obtained with CMB (Scanlon, 2000; Dyck et al., 2003). The CMB for a soil profile at steady state can be written as:

$$P(Cl_p) = R(Cl_s) \qquad R = \frac{P(Cl_p)}{Cl_s}$$

where $P$ is the average annual precipitation (mm $yr^{-1}$); $Cl_p$ is the average $Cl^-$ input from all sources, including wet and dry fallout (mg $L^{-1}$); $Cl_s$ is the average $Cl^-$ concentration of pore water below the root zone (mg $L^{-1}$); and $R$ is the average annual recharge rate (mm $yr^{-1}$) (Scanlon, 2000). The mass of $Cl^-$ into the system (precipitation times the $Cl^-$ concentration in $P$) is balanced by the mass out of the system (recharge rate times the $Cl^-$ concentration in drainage water in the unsaturated zone) if surface runoff is assumed to be zero (Scanlon et al., 2003a).

Key assumptions associated with the CMB approach are: (1) one-dimensional, vertically downward, piston water movement, (2) precipitation and dry fallout (Scanlon, 2000) as the only source of $Cl^-$, (3) precipitation and $Cl^-$ inputs are known, and (4) steady, vertical efflux of $Cl^-$ below the root zone (Gee et al., 2005).

It is assumed that the only source of $Cl^-$ is at the soil surface, and that there is no contribution of $Cl^-$ from weathering. In well-drained soils this appears to be a reasonable approximation. Uniform land use must also be assumed for sufficient time to allow enough water to move through the soil to establish a new equilibrium $Cl^-$ profile at least to the depth at which measurements are made (Allison and Hughes, 1978). In areas where post-clearing recharge rates are sufficiently high for steady-state $Cl^-$ fluxes below the root zone to have been re-established, the CMB technique described above can be used to estimate recharge rates following clearing. If steady-state $Cl^-$ fluxes below the root zone have either not been achieved or have not penetrated to a sufficiently large depth for adequate sampling, the use of CMB approach may lead to substantial underestimates of recharge (Allison et al., 1990).

Since $Cl^-$ is a conservative tracer (Davis et al., 1998) and most plant species do not take up significant quantities of $Cl^-$ from soil water (Allison et al., 1994), water flux can be estimated from the degree of $Cl^-$ enrichment in pore water as a result of evapotranspiration relative to the $Cl^-$ concentration in precipitation (Scanlon, 2000), which is transported into the unsaturated zone with infiltrating water. Chloride concentrations increase through the root zone as a result of evapotranspiration because $Cl^-$ is nonvolatile and is not removed by evaporation or by plant transpiration. Below the root zone, $Cl^-$ concentrations should remain constant if recharge rates have not varied over time. Drainage is inversely related to $Cl^-$ concentration in the unsaturated-zone pore water: low $Cl^-$ concentrations indicate high recharge rates because $Cl^-$ is flushed out of the system, whereas high $Cl^-$ concentrations indicate low recharge rates because $Cl^-$ accumulates as a result of evapotranspiration (Reedy et al., 2000).

This inverse relationship results in the CMB approach being much more accurate at low drainage rates because $Cl^-$ concentrations change markedly over small changes in drainage (Scanlon et al., 2003a), thus the precision of the estimate will increase with decreasing recharge rate (Allison et al., 1994). Soil water fluxes as low as 0.05 to 0.1 mm $yr^{-1}$ have been estimated in arid regions in Australia and in the U.S. (Allison and Hughes, 1983; Scanlon, 1991; Cook et al., 1994). The maximum water flux that can be estimated is based on uncertainties in measuring low $Cl^-$ concentrations and potential problems with $Cl^-$ contributions from other sources and is generally considered to be about 300 mm $yr^{-1}$ (Scanlon et al., 2003a).

Most recharge studies have been conducted in natural settings (Scanlon, 1991; Scanlon et al., 2006). Natural ecosystems in semiarid regions are generally characterized by large $Cl^-$ accumulations or “bulges”, which result from little or no recharge (Allison et al., 1990; Phillips, 1994; Scanlon et al., 2005a, 2005b). Bulge-shaped $Cl^-$ profiles at some sites have been attributed to paleoclimatic variations (Scanlon, 1991; Phillips, 1994) or to diffusion to a shallow water table (Cook et al., 1989). The impact of paleoclimatic variations has been documented in the U.S. and Africa. Bulge-shaped $Cl^-$ profiles throughout the Southwestern U.S. are attributed to higher recharge at depth (low $Cl^-$ concentrations generally corresponding to the Pleistocene period 10,000–15,000 years ago) and buildup of $Cl^-$ since that time during the Holocene (Scanlon, 1991; Phillips, 1994). The change in $Cl^-$ concentrations corresponds to a change from humid conditions with mesic vegetation during the Pleistocene to semiarid conditions with xeric vegetation during the Holocene. Current water potential monitoring and modeling analysis indicate that xeric vegetation has been active throughout the Holocene in maintaining dry conditions in the root zone, resulting in discharge through evapotranspiration rather than recharge (Scanlon et al., 2003b). Therefore, there has been no recharge since the Pleistocene in these settings.

Typically, CMB has been used to estimate ancient recharge (Stone, 1992; Phillips, 1994; Murphy et al., 1996; Scanlon et al., 2003b; Zhu et al., 2003) but recharge from recent land-use change has also been documented, specifically where vegetation has been altered and deep-rooted trees were replaced with shallow-rooted grasses

(Allison and Hughes, 1983; Allison et al., 1990; Walker et al., 1991; Scanlon et al., 2005b, 2007b, 2009).

Increased recharge associated with conversion of natural to agricultural ecosystems results in the $Cl^-$ bulge displaced downward in the soil profile (Scanlon et al., 2007b) or flushed away entirely (Stone, 1992). After clearing native vegetation, the downward flux of water increases owing to the shallower rooting depth of the crop and pasture species which replace it. This causes leaching of stored salt, and results in the downward displacement of the original soil water of high $Cl^-$ concentration (Allison et al., 1990). Recharge rates after clearing have been estimated using $Cl^-$ profiles, ranging from <3 mm to >50 mm $yr^{-1}$. The differences are thought to be primarily the result of differences in soil type, while differences in rainfall are thought to be of secondary importance. The increase in vertical water flux following clearing creates a pressure front which moves down the profile in advance of the solute front. The pressure front is formed by the downward displacement of water stored in the profile prior to clearing. Until the pressure front reaches the water table, recharge to groundwater continues at the same rate as before clearing. Rates of groundwater recharge increases only after the pressure front reaches the water table (Allison et al., 1990).

In Australia (Allison and Hughes, 1983) the change in land use from *Eucalyptus* scrub to cropping with wheat caused considerable change in water movement and deep drainage. They found recognizable features. First, an increase in $Cl^-$ concentration with depth to a constant value; under steady-state hydrological conditions where the soil receives $Cl^-$ in rainfall and soil water moves by piston flow, the concentration of $Cl^-$ in soil water should increase to the bottom of the root zone and then remain constant. Second, the maximum $Cl^-$ concentration in soil water is reached deeper in the cropped area compared with that under native vegetation. A displacement of $Cl^-$ to greater depths suggests enhanced percolation since clearing. Chloride concentrations of soil water showed that the mean annual amount of deep drainage increases from less than 0.1 to ~ 3 mm $yr^{-1}$ following clearing of the native vegetation. Changes in recharge resulted from reduced interception, reduced evapotranspiration, shallower rooting depths, and fallow periods.

In another study by Bekele et al. (2003), recharge was documented to be between 11 and 28 mm $yr^{-1}$ for cleared sites. Although, they did find low recharge rates in cleared sites (~5mm $yr^{-1}$), it was too low to represent post-clearing recharge, which made it problematic to assume recharge is generally higher beneath cleared sites. On the bases of their study they concluded that capture of groundwater from the removal of native plants is nearly double that of the native recharge.

A detailed study by Scanlon et al. (2005b) provides strong evidence relating land use/land cover effects on groundwater recharge using CMB and physical measurements. Rangeland ecosystems had similar characteristics: low water potentials and bulge-shaped, high $Cl^-$ concentration profiles, which translate into discharge occurring through evapotranspiration (negligible recharge). These results are consistent with regional analysis throughout the Southwest U.S., which indicate that there has been virtually no recharge in these settings since the late Pleistocene about 10,000 to 15,000 years ago

(Scanlon et al., 2003b). On the other hand, cleared areas (dryland agriculture) showed recharge between 9-32 mm $yr^{-1}$.

In another study, increased recharge beneath rain-fed agriculture is shown by low $Cl^-$ concentrations in unsaturated zone profiles. In areas of coarse-grained soils underlain by shallow water tables (≤10 to 15 m deep), $Cl^-$ is flushed throughout the unsaturated zone, and groundwater levels have risen. However, in areas of finer textured soils and deeper water tables, increased water fluxes related to cultivation have not reached the water table and are shown by downward displacement of salts that previously accumulated under natural ecosystems (Scanlon et al., 2007a).

Groundwater recharge estimates have been shown to be highly variable and a recurring ‘problem’ in recharge estimation includes variability of recharge in time and space (e.g. effects of land-use change on tracer profiles/mass balances). Thus, debate still persists on whether or not clearing of shrublands favors deep drainage. Despite that this problem has not been satisfactorily resolved, considerable progress has been made. Environmental tracers ($Cl^-$, tritium, and C-14) have been used only to a limited extent in Texas (Scanlon et al., 2003a), thus the importance of these types of studies for estimating deep drainage and therefore groundwater recharge at a local scale remains.

As relationships between land use/land cover and recharge become more widely recognized, further impacts of land use/land cover changes on the hydrologic cycle can be evaluated more effectively. Land used/land cover changes may be managed to modify specific components of the water cycle, such as recharge.

# 3. MATERIALS AND METHODS

## 3.1 Site selection and description

Eight sites (soils) from five locations in West Texas were selected. One location (two soils) was in Nolan County and four locations (six soils) in Taylor County (Fig. 1). Sites in Nolan County fall within Major Land Resource Area (MLRA) 78B (Central Rolling Red Plains, Western part) whereas sites in Taylor County fall within MLRA 78C (Central Rolling Red Plains, Eastern part) (NRCS, 2009). Climate information is presented for Sweetwater and Abilene, the county seats for Nolan and Taylor County, respectively (Fig. 1). Mean annual precipitation is 598 and 619 mm and potential evapotranspiration is 1727 and 1631 mm, respectively (NOAA, 2006).

Sites were selected using the following criteria: (1) nearly level landscape for all sites to avoid the loss of water due to run-off and lateral subsurface water flow, (2) stable land use and time-since-clearing of >20 yr to allow changes in the geochemical composition of soil water; (3) soils sufficiently deep to obtain samples to 2 to 3-m depth; (4) soils without evidence of a water table to avoid inclusions of salts due to seasonal water table fluctuations, and (5) sites without known inputs of $Cl^-$ in addition to dry fallout and precipitation. Each location (Fig. 2) consisted of a pair of similar soils with contrasting vegetative cover, one dominated by woody-shrub (S) vegetation and the other where the woody-shrub vegetation had been cleared and grasses (G) are now present. The soil information for each site that follows was taken from the Soil Surveys of Nolan (Lowther et al., 1981) and Taylor (Conner et al., 1976) Counties. Classification of soils follows U.S. Soil Taxonomy (Table 1) (Soil Survey Staff, 2003).

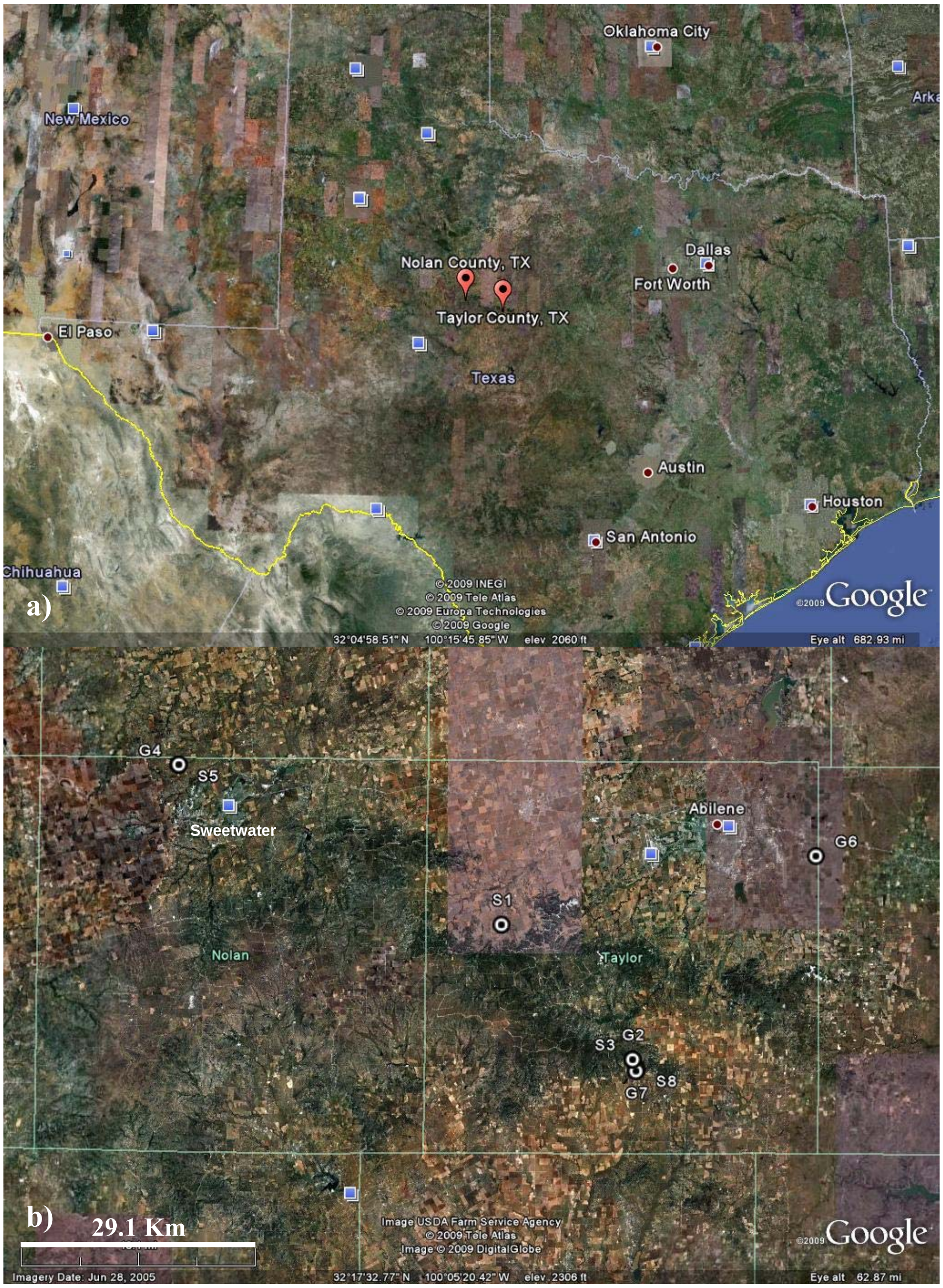

**Fig. 1. Location of (a) Nolan and Taylor Counties, TX and (b) sampling locations (Source: Google Earth).**

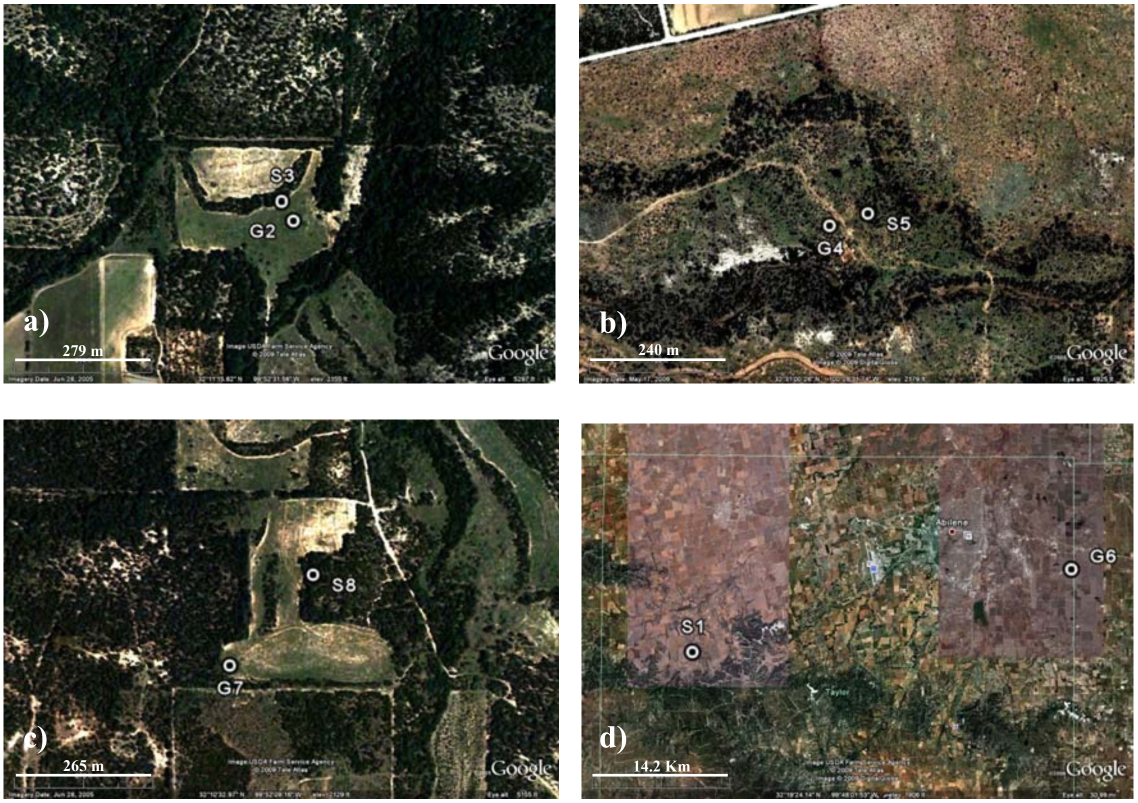

**Fig. 2. Relative site locations of (a) pair 1 (G2,S3), (b) pair 2 (G4,S5), (c) pair 3(G7,S8), and (d) sites S1 and G6 (non-paired) (Source: Google Earth).**

### Site S1

The soil at site S1 was the Sagerton series located in an alluvial plain derived from calcareous loamy alluvium. Sagerton in classified as a fine, mixed, superactive, thermic Typic Argiustolls. Dominant woody-shrub vegetation cover includes honey mesquite (*Prosopis glandulosa*) with other existing vegetation such as dropseed (*Sporobolus*).

### Site G2

The soil at site G2 was the Rotan series located in a footslope landscape position formed in calcareous loamy alluvium of Quaternary age. Rotan is classified as a fine, mixed, superactive, thermic Pachic Paleustolls. Dominant grass vegetation cover includes little bluestem (*Schizachyrium scoparium*) and threeawn (*Aristida*).

### Site S3

The soil at site S3 was the Rotan series located in a footslope landscape position formed in calcareous loamy alluvium of Quaternary age. Rotan is classified as a fine, mixed, superactive, thermic Pachic Paleustolls. Dominant woody-shrub vegetation cover includes juniper (*Juniperus ashei*) with other existing vegetation such as little bluestem (*Schizachyrium scoparium*) and threeawn (*Aristida*).

### Site G4

The soil at site G4 was the Sagerton series located in an alluvial plain derived from calcareous loamy alluvium. Sagerton is classified as a fine, mixed, superactive, thermic Typic Argiustolls. Dominant grass vegetation cover includes dropseed (*Sporobolus*), buffalograss (*Buchloe dactyloides*), and annual broomweed (*Amphiachyris dracunculoides*). Sparse honey mesquite (*Prosopis glandulosa*) trees were also present.

### Site S5

The soil at site S5 was the Sagerton series located in an alluvial plain derived from calcareous loamy alluvium. Sagerton is classified as a fine, mixed, superactive, thermic Typic Argiustolls. Dominant woody-shrub vegetation includes honey mesquite (*Prosopis glandulosa*) with other existing vegetation such as annual broomweed (*Amphiachyris dracunculoides*), dropseed (*Sporobolus*), buffalograss (*Buchloe dactyloides*), and bristlegrass (*Setaria*).

### Site G6

The soil at site G6 was the Rotan series formed in calcareous loamy alluvium of Quaternary age. Rotan is classified as a fine, mixed, superactive, thermic Pachic Paleustolls. Dominant grass vegetation cover includes bluestem (*Andropogon*), kleingrass (*Panicum coloratum*), and white tridens (*Tridens albescens*).

### Site G7

The soil at site G7 was the Hamby series formed in loamy and clayey residuum from Cretaceous sediments. Hamby is classified as a fine, mixed, active, thermic Typic Paleustalfs. Dominant vegetation cover includes annual broomweed (*Amphiachyris dracunculoides*).

### Site S8

The soil at site S8 was the Hamby series formed in loamy and clayey residuum from Cretaceous sediments. Hamby is classified as a fine, mixed, active, thermic Typic Paleustalfs. Dominant woody-shrub vegetation cover includes honey mesquite (*Prosopis glandulosa*), and oak (*Quercus*).

**Table 1. Soil classification and sites selected for the study.**

| Site ID | Pedon No. | Soil Series | Classification |
|---|---|---|---|
| S1 | S08TX441-101 | Sagerton | Fine, mixed, superactive, thermic Typic Argiustolls |
| G2 | S08TX441-102 | Rotan | Fine, mixed, superactive, thermic Pachic Paleustolls |
| S3 | S08TX441-103 | Rotan | Fine, mixed, superactive, thermic Pachic Paleustolls |
| G4 | S09TX353-101 | Sagerton | Fine, mixed, superactive, thermic Typic Argiustolls |
| S5 | S09TX353-102 | Sagerton | Fine, mixed, superactive, thermic Typic Argiustolls |
| G6 | S09TX441-104 | Rotan | Fine, mixed, superactive, thermic Pachic Paleustolls |
| G7 | S09TX441-3041 | Hamby | Fine, mixed, active, thermic Typic Paleustalfs |
| S8 | S09TX441-3042 | Hamby | Fine, mixed, active, thermic Typic Paleustalfs |

Soils were sampled at different times. Sites S1, G2, and S3 were sampled mid November, 2008, while sites G4, S5, and G6 were sampled two months later in January, 2009. Sites G7 and S8 were sampled late May, 2009. In each site three to five soil cores were taken as deep as possible and the diameter of cores ranged from 10 cm to as small as 4 cm. The largest diameter core was used that would penetrate the soil. Samples for bulk samples, clods for bulk density, and portions for *in situ* water content were taken after the soils were described by horizon (Schoeneberger et al., 2002). Samples were taken and composited by horizon (Appendix A), but horizons were split when their thickness exceeded 0.25 m.

## 3.2 Soil analyses

A bulk, composite sample of each horizon from the three to five cores was labeled and dried at 60 ºC in a forced-draft drying chamber. Samples were ground to pass a 2-mm sieve and used to determine particle size distribution, pH, electrical conductivity (EC), total carbon, calcium carbonate equivalent (CCE), extractable bases, cation exchange capacity (CEC), and $Cl^-$ concentration.

Samples for *in situ* water content were obtained immediately after the core was taken to avoid water losses. Two samples for each horizon were placed in separate moisture cans and processed as soon as possible. Weight was recorded before and after the samples were oven-dried at 105 ºC for 24 h. Results reported are the means of duplicates on an oven dried-basis.

Total C was determined by the dry combustion method in a medium-temperature resistance furnace (Nelson and Sommers, 1982). A sample of air-dried and disk-mill ground soil was placed in a ceramic combustion boat along with about 0.25 g of manganese dioxide ($MnO_2$). The sample was heated to 950-1000 °C while $O_2$ was passed through the combustion chamber containing the sample. Carbon dioxide from the oxidizing organic matter and from calcite and dolomite (inorganic) were collected in a bulb by reaction with ascarite and weighed. Organic C was calculated as the difference of the total C and inorganic C as quantified in the determination of $CaCO_3$ equivalent. Means of duplicates were reported on an oven-dried basis (6A2b, Soil Survey Laboratory Staff, 1996).

Calcium carbonate equivalent (CCE) was obtained by the method of Dreimanis (1962) using a Chittick gasometric apparatus. The air-dried and disk-mill ground soil (1.70 g) was mixed with 20 ml of 6N HCl + $FeCl_2$ in the Chittick apparatus and the volume of $CO_2$ generated was corrected for temperature and pressure. The corrected volume of $CO_2$ evolved in 30 s from the reaction was used to calculate the % calcite, while the additional $CO_2$ evolved for up to 15 min gave the dolomite content. Percent calcite and dolomite were used to calculate CCE. Results reported are the means of duplicates corrected to an oven-dried basis.

Extractable bases were determined using a 1 N $NH_4OAc$ (pH 7.0) extracting solution and measured by atomic absorption and flame emission (Holmgren et al., 1977; Peech et al., 1947). A soil sample (2.5 g) was placed in an extraction tube filled with tightly compressed filter pulp at the bottom and connected to an extraction syringe. Once the extraction tube was place on the extractor, it was filled to the 20-ml mark with $NH_4OAc$ and rapidly extracted until the volume of $NH_4OAc$ above the sample pad was 3 to 5 ml. A reservoir tube was placed onto the extraction tube and filled with 40 ml of $NH_4OAc$ solution. The extractor was set for overnight extraction, and the solution obtained was reserved for analyses of extracted cations. Calcium and Mg concentration in the extract was determined by atomic absorption using a $N_2O$-acetylene flame and Na and K by flame emission on an atomic absorption spectrometer (Varian SpectrAA 55) (5B5, Soil Survey Laboratory Staff, 1996). Results reported are the means of duplicates corrected to an oven-dried basis.

Cation exchange capacity (CEC) was determined with 1 N NaOAc (pH 8.2) and replacement by $NH_4OAc$ (Peech et al., 1947; Holmgren et al., 1977). A soil sample (2.5 g) was saturated with 1 N NaOAc to replace all exchangeable cations with Na. Once the extraction tube was placed on the extractor, it was filled to the 20-ml mark with NaOAc and rapidly extracted until the volume of NaOAc above the sample pad was 3 to 5 ml. Reservoir tubes were placed onto the extraction tubes and filled with 40 ml of NaOAc. The NaOAc extract was discarded, and the sample was rinsed twice with ethanol to remove free Na cations. After the ethanol rinsing, an extraction using 1 N $NH_4OAc$ (about 60 ml) was performed, and the extract was saved for analyses. The Na concentration in the extract was determined by flame emission on an atomic absorption spectrometer (Varian SpectrAA 55) (5A2, modified to be used with an automatic extraction machine, Soil Survey Laboratory Staff, 1996). Results reported are the means of duplicates corrected to an oven-dried basis.

Bulk density was determined using the Saran-coated clod method (Brasher et al., 1966; Blake and Hartge, 1986) at 1/3 bar and oven-dry moisture contents. Three clods were obtained from the cores for each horizon, individually wrapped in a hair net, and field-coated with Saran. They were then transported to the laboratory, coated 3 more times and then saturated for 1 to 2 weeks. After saturation, clods were placed in the desorption chamber, and equilibrated at 1/3 bar pressure until no water flowed from the discharge tube (~7 days). After desorption, clod weight in air was recorded. Clods were then coated 3 more times with Saran and weighed in air and water after 30 min from the last coating. Clods were then oven dried at 105 $^{o}$C for 48 h, and after cooling they were coated 3 more times with Saran and weighed in air and water again. Coefficients of linear extensibility (COLE) were calculated using the bulk density values at 1/3 bar and oven-dry. All means are reported as a mean of the three clods.

Particle size distribution was determined according to the pipette method of Kilmer and Alexander (1949). A soil sample (10 g) was dispersed in a 400-ml glass shaker bottle by overnight shaking with 5 ml of sodium hexametaphosphate. A 5-ml aliquot was collected 5 cm into the suspension and transferred to a pre-weighed crucible; this aliquot removed particles <20 µm in diameter which included total clay and fine silts. After an appropriate settling period, another aliquot was removed and transferred to another pre-weighed crucible to measure the amount of total clay (<2 µm). Fine clays (0.2 µm) were determined by centrifugation. The sediments remaining in the shaker bottle after all aliquots were removed were washed through a 300-mesh sieve (<50 µm) to retain all sands. The material on the sieve was transferred into a beaker using distilled water and oven dried at 105 ºC for 24 h. After the sand was dried, it was placed into a nest of sieves to separate sand subfractions, shaken for 5 min, and the material remaining on each sieve was removed and weighed. Results reported are the means of duplicates corrected to an oven-dried basis.

Electrical conductivity (EC) was determined by the saturated paste extract method (Richards, 1954). A soil sample (200 g) was saturated with distilled water and equilibrated overnight. The saturated paste was transferred into a filter funnel (fitted with filter paper Whatman No. 42) connected to a syringe and extracted rapidly until the extract volume in the syringe was 3 to 5 ml. The velocity of extraction was reduced and completed after 2 h; the extract was used to measure electrical conductivity and soluble cations.

Soil reaction (pH) was measured on a 1:1 soil/water extract using a glass electrode (Soil Survey Laboratory Staff, 1996). A soil sample (30 g) was mixed with an equal weight (30 ml) of distilled water and stirred at 15-min intervals for one hour. Then, suspension was stirred again and pH was measured.

### 3.3 Chloride extraction

Chloride was extracted by adding 20 ml of ultra-pure water to a 10-g sample of air dried, ground soil, in a 50-ml high-density polyethylene (HDPE) centrifuge tube and shaken for 4 h. After shaking, soil/water units were centrifuged at 20,000 rpm for 20 min at 4 ºC. A duplicate of soil was extracted every 5th soil sample to test for reproducibility. Supernatant was removed using a steel canula and syringe and filtered through 0.2 µm cellulose filters into HDPE bottles ready for analysis. Chloride concentration in the extracts was determined by ion chromatography (DIONEX ICS 2000). A blank, laboratory standards, and traceable certified standards (National Institute of Standards and Technology) were analyzed every 10th sample. Upon $Cl^-$ determination, soil $Cl^-$ profiles were constructed for each site. The $Cl^-$ mass balance (CMB) for a soil profile at steady-state can be written as: $R=P(Cl_p)/(Cl_s)$

where $R$ is the rate of deep drainage (mm $yr^{-1}$) to a depth of interest.

### 3.4 Chloride deposition

Chloride deposition data were obtained for a 25-year period (1983-2008) from the National Atmospheric Deposition Program (NADP) for the two closest known observation points to Abilene. The closest observation points to Abilene are Sonora (~248 Km) (Edwards County), with an annual average $Cl^-$ deposition in rainfall of 0.221 mg $L^{-1}$ and the L.B.J. National Grasslands station (~254 Km) (Wise County) with an annual average $Cl^-$ deposition in rainfall of 0.223 mg $L^{-1}$ (NAPD, 2009). Due to its location about midway between the two observation points, by linear interpolation the annual average $Cl^-$ deposition rate at Abilene was assumed to be 0.222 mg $L^{-1}$.

### 3.5 Statistical analysis

Soil physical properties such as bulk density and clay content were evaluated for woody-shrub cleared and non-cleared sites to determine any linear dependence with $Cl^-$ concentrations using Pearson correlation coefficients. Volumetric water content, soil $Cl^-$ concentrations, and soil moisture flux were plotted (scatter plot) with depth and inferences on results were obtained by descriptive statistics (mean, standard deviation). Comparison of variables such as soil moisture flux (deep drainage if below 200 cm), depth to maximum $Cl^-$ concentration, maximum $Cl^-$ concentration, cumulative $Cl^-$ inventory, and CMB ages to a depth of interest for paired sites were performed.

# 4. RESULTS AND DISCUSSION

## 4.1 Soil and chloride profiles

In the following section, eight $Cl^-$ profiles are described in detail. Soil moisture fluxes (deep drainage if beyond the root zone) in all sites are compared to a depth below 200 cm for two reasons: (1) rooting depths for grasses is usually <200 cm and loss of water from depths greater than this is negligible, and (2) samples at sites G8 and S7 were taken at a maximum depth of 230 cm. Volumetric water content and estimated soil moisture fluxes are plotted with depth. All referenced depths correspond to the lower boundary of the mentioned soil horizon. Chloride profiles are plotted at different scales and represent $Cl^-$ concentrations in the soil pore water. Total $Cl^-$ mass and CMB ages are calculated at the maximum sampling depth unless stated otherwise. Chloride mass balance ages were calculated by dividing the total $Cl^-$ mass by the $Cl^-$ deposition rate at the soil surface. Chloride deposition rates (g $m^{-2}$ $yr^{-1}$) were calculated by multiplying mean annual precipitation (mm $yr^{-1}$) by $Cl^-$ concentration in precipitation (0.222 mg $L^{-1}$) divided by 1000. Chloride deposition rates were 0.14 and 0.13 g $m^{-2}$ $yr^{-1}$ for Abilene and Sweetwater, respectively. The slight difference corresponds to a lower precipitation rate at Sweetwater than Abilene; 598 and 619 mm $yr^{-1}$, respectively.

Chloride profiles displayed wide variability in their maximum $Cl^-$ concentration, ranging from 102 mg $L^{-1}$ to 16,418 mg $L^{-1}$ (Table 2). If a mean $Cl^-$ deposition rate of 0.14 and 0.13 g $m^{-2}$ $yr^{-1}$ is assumed at the soil surface, estimated soil moisture fluxes below 200 cm ranged from 0.02 to 2.6 mm $yr^{-1}$.

**Table 2. Summary of soil geochemical measurements and moisture fluxes at the study sites.**

| Property | S1 | G2 | S3 | G4 | S5 | G6 | G7 | S8 |
|---|---|---|---|---|---|---|---|---|
| Depth of sampling[a] (cm) | 363 | 375 | 370 | 362 | 350 | 330 | 230 | 218 |
| $Cl^-$, max ($mg\ L^{-1}$) | 8945 | 1336 | 102 | 16418 | 4516 | 192 | 1218 | 3272 |
| $Br^-$, max ($mg\ L^{-1}$) | 26 | 5 | NA | 68 | 20 | NA | NA | 30 |
| Total $Cl^-$ to depth ($g\ m^{-2}$) | 3870 | 316 | 28 | 1961 | 1986 | 48 | 40 | 144 |
| CMB age to depth (yr) | 28165 | 2298 | 207 | 14781 | 14973 | 352 | 291 | 1049 |
| $Cl^-$** ($mg\ L^{-1}$) | 7811 | 963 | 54 | 4803 | 3188 | 106 | 181 | 3272 |
| Moisture flux ($mm\ yr^{-1}$) | 0.02 | 0.1 | 2.6 | 0.03 | 0.04 | 1.3 | 0.8 | 0.04 |
| Mass $Cl^-/Br^-$ ratio | 356 | 154 | NA | 198 | 261 | NA | NA | 95 |
| Correlation coefficient $Cl^-$, $Br^-$ | 0.98 | 0.97 | NA | 0.97 | 0.94 | NA | NA | 0.99 |

[a] Depth of sampling at which total $Cl^-$ and CMB ages are reported

**Depth-weighed $Cl^-$ concentration below 200 cm

NA, not available due to $Br^-$ concentrations in soil-water extracts that were below the analytical detection limits.

Pair 1 included sites G2 and S3 and soils are of the Rotan series (Appendix A). Soil $Cl^-$ concentrations were similar for both sites in the upper 140 cm. Site G2 (Fig. 3) was characterized by soil $Cl^-$ concentrations ranging from 33 mg $L^{-1}$ at 108 cm to 1,336 mg $L^{-1}$ at 300 cm ($Cl^-$ peak). Site G2 has a leached zone to a depth of 175 cm with $Cl^-$ concentrations of <200 mg $L^{-1}$, except for the A horizon which had a $Cl^-$ concentration of 267 mg $L^{-1}$ and corresponded to the lowest soil water content of 0.07 $m^3\ m^{-3}$. Estimated soil moisture flux below 200 cm was 0.1 mm $yr^{-1}$ with decreasing fluxes below that depth in response to higher $Cl^-$ concentrations. Chloride enrichment at 300 cm may represent the displaced solute front resulting from increased water percolation since land clearing. However, steady-state solute fluxes have not been achieved below 200 cm and thus, CMB soil moisture fluxes may not represent true fluxes below the root zone. Water content ranged from 0.07 $m^3\ m^{-3}$ at the surface to 0.21 $m^3\ m^{-3}$ at the bottom of the profile (375 cm) following changes in soil texture (Fig. 3).

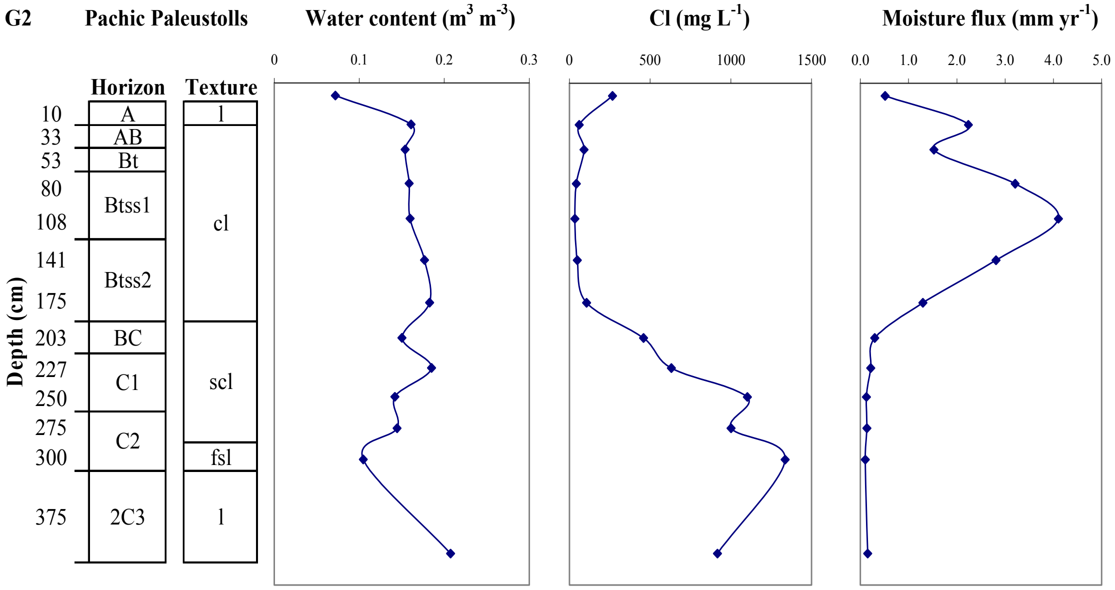

**Fig. 3. Soil profile, texture, volumetric water content, soil water Cl⁻ concentration, and estimated CMB soil moisture fluxes for site G2.**

Salt inclusions from shallow water tables could be considered as a factor increasing soil $Cl^-$ concentrations, however, the opposite has been proposed where the reduction in $Cl^-$ concentrations with depth may be caused by diffusion of salts to a shallow groundwater (Cook et al., 1994). The $Cl^-$ concentrations in the saturated zone are usually lower than that of the unsaturated zone unless sufficient leaching of salts had occurred and caused groundwater salinization. Water table depth for soils of the Rotan series is >200 cm; if grayish colors observed for both sites at depth beyond 300 cm (Appendix A) are indicative of water table fluctuations, then it would influence both sites in the same way. However, fluctuations of shallow water table may not be responsible for the differences in $Cl^-$ concentration with depth as shown below for site S3.

Site S3 (Fig. 4) had lower $Cl^-$ concentrations and distribution than site G2, with the highest concentration of 102 mg $L^{-1}$ at the soil surface. Moisture fluxes were relatively high (1.3-3.6 mm $yr^{-1}$) throughout the entire soil profile. Estimated soil moisture flux below 200 cm was 2.6 mm $yr^{-1}$, an order of magnitude higher than its grassland counterpart. Water content was the lowest at soil surface (0.06 $m^3$ $m^{-3}$) and increased to a maximum value of 0.17 $m^3$ $m^{-3}$ at 158 cm; below that depth there was no consistent trend. Changes in soil texture were responsible for the changes in soil water content as shown in Fig. 4.

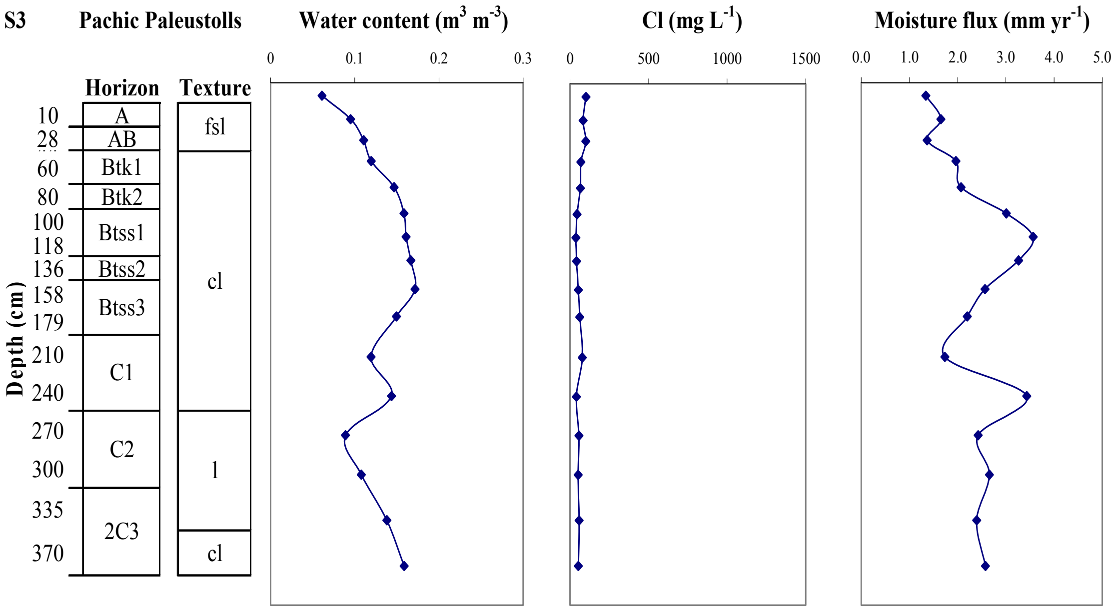

**Fig. 4. Soil profile, texture, volumetric water content, soil water $Cl^-$ concentration, and estimated CMB soil moisture fluxes for site S3.**

Results of this pair do not support the hypothesis that water and solute fluxes are higher under grasslands than shrublands. Sites were located ~70 m apart in the same landscape position where water processes are expected to be the same and the only source of variability would be attributed to changes in land cover. Furthermore, soil morphology in both pedons is almost identical (Appendix A). Significant $Cl^-$ uptake by juniper (land cover) was thought to be responsible for such differences in soil $Cl^-$ concentration. Plant-tissue $Cl^-$ extractions were performed using the hot-water extraction method by Ghosh and Drew (1991) to estimate biomass $Cl^-$ inventory. A total of 14 samples including juniper leaves and branches were tested for $Cl^-$ concentrations. Chloride concentrations on tissue samples ranged from 621 to 2,321 mg $Kg^{-1}$ of dry matter, with a mean value of 1,144 mg $Kg^{-1}$ used for estimation purposes (Appendix C). Juniper trees at the sampling site were about 4 m height with a canopy diameter of about 3 m. Similar height/diameter relations data reported by Owens and Ansley (1997) represent trees between 30 – 40 years old. Trees were uniform in size and assuming a density of 625 trees $ha^{-1}$, 220 kg of above ground biomass (dry weight) for a mature tree (Owens and Ansley, 1997), $Cl^-$ stored in plant tissue was 157 Kg $ha^{-1}$. Cumulative $Cl^-$ mass for site S3 at 370 cm was 288 Kg $ha^{-1}$. The sum of those two values is still considerably lower than that of site G2, with a cumulative $Cl^-$ mass of 3,170 Kg $ha^{-1}$ at 375 cm. Apparently, $Cl^-$ uptake by juniper was not responsible for such differences in soil $Cl^-$ concentrations.

Seasonal water uptake mechanisms and rooting depths of juniper may be responsible for such differences in $Cl^-$ concentrations. McCole and Stern (2007) found that during cool, wet winter months, isotopic composition of juniper (*Juniperus ashei*) xylem water indicated that soil water was the dominant water source. During hot, dry summers coupled with intense evapotranspiration, isotopic composition of juniper xylem water is similar to groundwater, indicating a deeper juniper water source. During the cool season, evapotranspiration is reduced due to low temperatures and reduced plant activity. Net water inputs may exceed water losses and the capacity of the soil to store plant-available water and therefore increase deep drainage. During the hot, dry season, deeper water sources are more important and the resulting evapotranspirative $Cl^-$ enrichment is barely observable (at least at the sampling interval) under juniper vegetation. Juniper has multilevel root systems (Tennesen, 2008); during dry conditions a single taproot (reported at 18 m deep) can provide a third or more of the tree's water, resulting in water uptake mechanisms more efficient than other woody plants.

Similar soil moisture fluxes of ~3 mm $yr^{-1}$ were reported by Walvoord and Phillips (2004) under juniper (*Juniper monosperma* and *Juniperus pinchotti*) woodlands and were also significantly higher compared to grassland sites. They found the highest $Cl^-$ concentrations under creosote bush (*Larrea tridentata*) sites and that it decreased going towards grass then juniper. Relatively low $Cl^-$ concentrations under juniper were also found by Sandvig and Phillips (2006). They concluded that preferential flow was responsible for such lower $Cl^-$ concentrations under juniper (*Juniperus monosperma*) woodlands than in grasslands; their inference was strongly supported by root macropores (root holes containing decaying wood) and extensive rooting (up to 7 m) structures of the juniper tree.

In our site, the low $Cl^-$ concentrations and distribution suggest non-uniform water movement (non-piston flow). Deep juniper roots may be responsible for extracting water at depths beyond the collected woodlands cores. If so, episodic deep percolation events (preferential flow) may be responsible for the low $Cl^-$ concentrations observed, aided by the strong to medium prismatic structure described to a depth of 240 cm which can facilitate non-uniform water movement (Appendix A). However, additional juniper root density studies would need to be conducted to confirm this. If the statement above is true, for site G2 the displaced solute front at 300 cm indicates that there was $Cl^-$ enrichment near the surface by previous vegetation cover other than juniper, because $Cl^-$ enrichment by grasses at those depths is not likely to occur.

Pair 2 were sites G4 and S5, and the soils are of the Sagerton series (Appendix A). Site G4 was multi-peaked with $Cl^-$ concentrations ranging from 151 mg $L^{-1}$ at the top 15 cm to 11,488 mg $L^{-1}$ at 129 cm (first $Cl^-$ peak) and 16,418 mg $L^{-1}$ at 230 cm (second $Cl^-$ peak), which corresponded to the lowest soil moisture contents of 0.07 and 0.03 $m^3$ $m^{-3}$, respectively (Table 2 and Fig. 5). Below the second peak, $Cl^-$ concentrations decreased gradually to 1,609 mg $L^{-1}$ at the bottom of the profile. Soil moisture content showed no systematic relationship with depth but sharply increased from 0.12 to 0.23 $m^3$ $m^{-3}$ at 302 cm due to an increase in clay content.

Soil moisture fluxes were relatively high at the leached zone (top 31 cm) with a sharp decrease to negligible water fluxes (~0.01 mm $yr^{-1}$) to a depth of 230 cm, which suggest that no water has passed below the root zone but rather discharged through evapotranspiration. Below that depth, small increases in water fluxes evidenced past higher recharge rates due to paleoclimatic variations and not due to present climatic conditions. Vadose zone $Cl^-$ concentrations and distribution for this site were not representative of grasslands settings, which indicate that the site was recently cleared and imprints of past land cover remained. This was strongly supported by the fact that $Cl^-$ enrichment by grasses is not likely to occur beyond 150 cm. Besides, strong similarities with site S5 also support this statement.

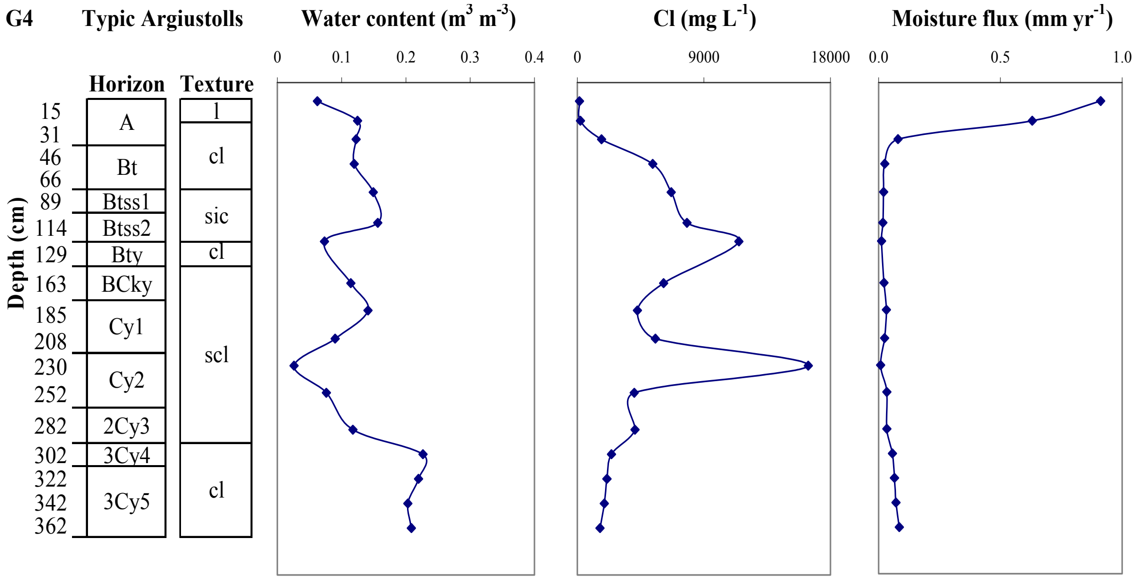

**Fig. 5. Soil profile, texture, volumetric water content, soil water $Cl^-$ concentration, and estimated CMB soil moisture fluxes for site G4.**

Site S5 was similar to site G4. Chloride concentrations for site S5 ranged from 212 mg $L^{-1}$ at 44 cm and sharply increased to 4,516 mg $L^{-1}$ (peak) at 152 cm due to evapotranspirative enrichment (Fig. 6). Below the $Cl^-$ peak, $Cl^-$ concentrations decreased gradually to 2,000 mg $L^{-1}$. Soil moisture fluxes were relatively high at the top 44 cm (leached zone) and were negligible (~0.03 mm $yr^{-1}$) to a depth of 249 cm, suggesting that almost all infiltrating water has been evapotranspired back into the atmosphere. Soil water content gradually increased with depth to a maximum of 0.32 $m^3$ $m^{-3}$ at the bottom of the pedon (Fig. 6). Water contents for both pedons have not been corrected for water in gypsum.

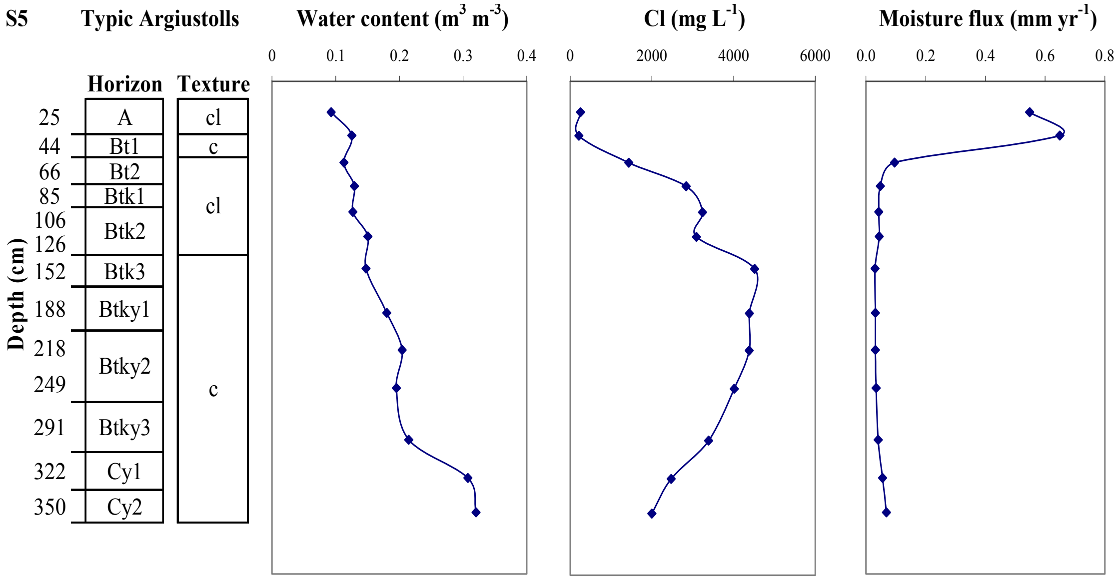

**Fig. 6. Soil profile, texture, volumetric water content, soil water Cl$^-$ concentration, and estimated CMB soil moisture fluxes for site S5.**

Sites G4 and S5 had similar cumulative Cl$^-$ masses of 1,961 and 1,986 g m$^{-2}$ at the depth of sampling, respectively. Similarly, first Cl$^-$ peak for sites G4 and S5 occurred at similar depths intervals of 114 to 129 cm and 126 to 152 cm, respectively. Since soil moisture fluxes for both sites were negligible in the upper 300 cm, first Cl$^-$ peak for site G4 may represent the true solute front. This was also supported by a sharp increase in $SO_4^{-2}$ concentrations (Appendix B) an order of magnitude higher than Cl$^-$ at the same depth intervals for both sites, suggesting that the wetting front from precipitation events reached a maximum depth of 129 and 152 cm for sites G4 and S5, respectively. Sulfate concentrations are generally consistent with an increase in gypsum content with depth and thus, provide more evidence of persistent dry conditions in the unsaturated zone.

Cumulative Cl$^-$ vs. cumulative water plots (Fig. 7) were used to identify ancient recharge rates where changes in the slope (steeper) indicated changes in recharge rates (higher). Piston-type water flow and constant Cl$^-$ flux at the soil surface must be assumed (Allison et al., 1985). Assuming a constant Cl$^-$ deposition rate of 0.13 g m$^2$ yr$^{-1}$, increased recharge rates of ~0.1 mm yr$^{-1}$ occurred around 12,000 to 15,000 years ago when changes in climatic conditions went from a mesic Pleistocene to a xeric Holocene to present and can be observed at depths between 282 and 362 cm for site G4. Since the inclusion of the Holocene until present time, recharge rates of about 0.02 mm yr$^{-1}$ have persisted for about 12,000 years. Higher recharge rates of about 0.1 mm yr$^{-1}$ also occurred around 12,000 to 15,000 years ago and are observed at depths between 291 and 350 cm for site S5. During the last about 12,000 years, recharge rates of about 0.03 mm yr$^{-1}$ have also persisted for this soil. These similarities also indicate that change in land use/land cover for site G4 was recent. However, site G4 may provide little but additional evidence of past climatic conditions where recharge rates were two to three times higher than current estimates (Zhu et al., 2003).

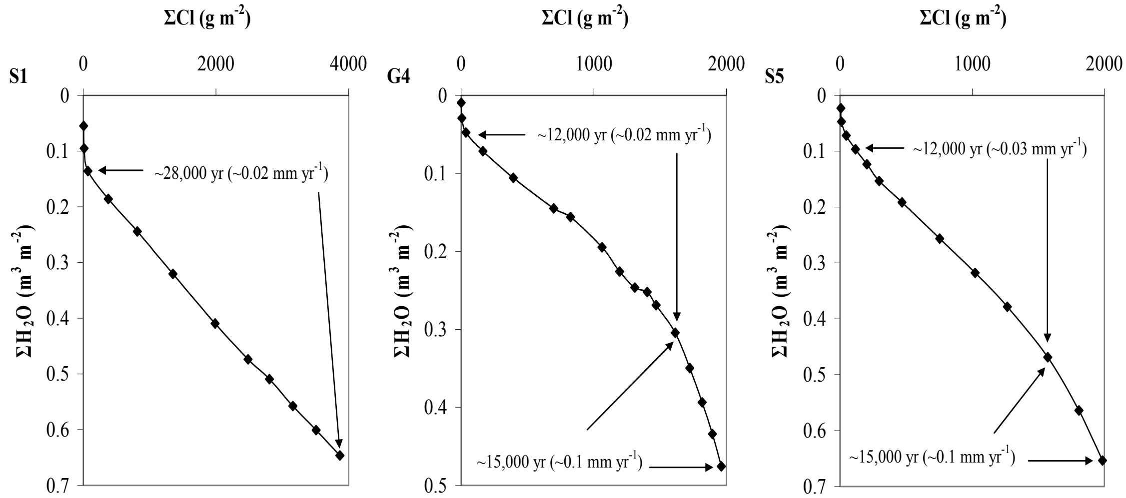

**Fig. 7. Plot of cumulative Cl$^-$ vs. cumulative water for sites S1, G4, and S5.**

The drier environment since the Holocene along with changes in vegetation cover have caused $Cl^-$ to accumulate close to the soil surface and therefore decreasing soil moisture fluxes as compared to the late Pleistocene. This was consistent and strongly supported by the findings of various authors (Scanlon, 1991; Phillips, 1994; Scanlon et al., 2003b), which suggested that downward water movement below the root zone and recharge rates were negligible and rather a net upward water movement has been observed. However, present land cover for site G4 did not represent increases in moisture and solute fluxes in the vadose zone. Imprints of past land use were still present in the soil profile and more time is required to allow for increases in recharge rates.

Pair 3 was sampled to a maximum depth of 230 cm due to coring difficulties in the soil profile by a lithic or paralithic contact. It includes sites G7 and S8; the soil series at both sites is Hamby (Appendix A). Site G7 had $Cl^-$ concentrations ranging from 53 mg $L^{-1}$ at 98 cm to 1,218 mg $L^{-1}$ in the E horizon at 40 cm. This shallow zone (top 40 cm) was characterized by low water contents (0.02-0.09 $m^3$ $m^{-3}$) with corresponding decreases in clay content at that depth interval (loamy fine sand to sand) and, coupled with evapotranspiration, $Cl^-$ enrichment within this shallow root zone was observed (Fig. 8). Beyond this depth (>40 cm) $Cl^-$ concentrations sharply decreased to values of $\leq$200 mg $L^{-1}$. This zone of low $Cl^-$ concentrations corresponded to higher water contents (0.11-0.14 $m^3$ $m^{-3}$) and reflected increases in soil moisture fluxes of 0.7-2.6 mm $yr^{-1}$ at that depth interval. A soil moisture flux of 0.8 mm $yr^{-1}$ below 200 cm was calculated.

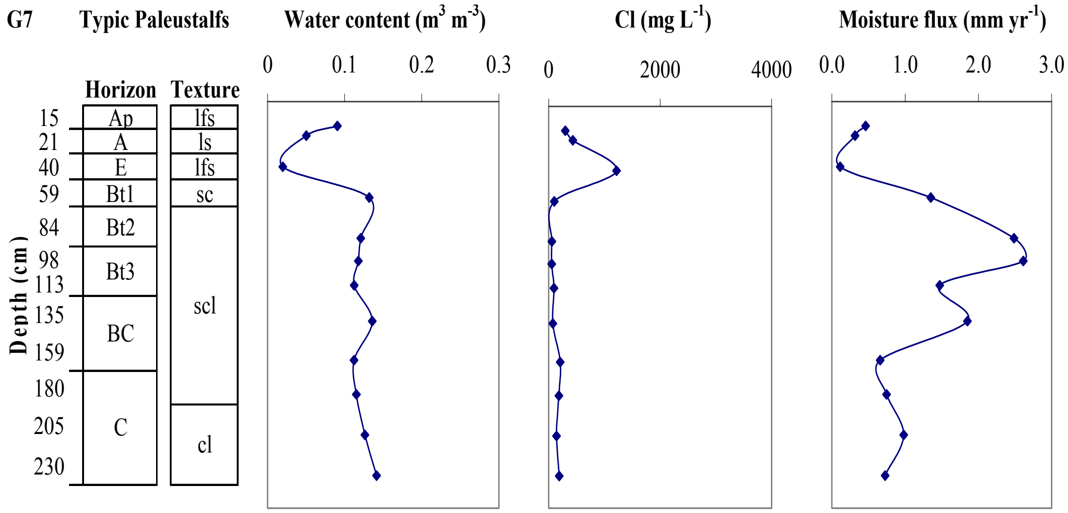

**Fig. 8. Soil profile, texture, volumetric water content, soil water $Cl^-$ concentration, and estimated CMB soil moisture fluxes for site G7.**

Sandy horizons would usually show high soil moisture fluxes. In this case, the combined effects of low water retention of sand particles and high evapotranspiration rates at the soil surface yielded soil moisture fluxes relatively lower than compared to greater depths. Thus, recent dry periods or precipitation events resulted in variations in soil water content, $Cl^-$ concentration, and therefore estimated soil moisture fluxes. At depths greater than 50 cm, $Cl^-$ concentrations may represented longer time periods and are not affected by individual dry periods or precipitation events (Scanlon, 1991). Thus, the $Cl^-$ peak at this site (40 cm) was not likely to represent the true solute front but instead, it is related to soil physical properties and recent changes in soil water content.

Clearly, $Cl^-$ concentrations expressed as mg $L^{-1}$ are highly dependent on water contents, which may be misleading if water contents with depth are also highly variable due to changes in soil texture. Other ways of expressing soil $Cl^-$ concentrations must be sought in order to make reliable comparisons such as mg $Kg^{-1}$ of soil or mg $L^{-1}$ of soil pore volume.

Site S8 had $Cl^-$ concentrations ranging from 74 mg $L^{-1}$ at 58 cm to 3,272 mg $L^{-1}$ ($Cl^-$ peak) at 218 cm. Moisture contents of 0.12 and 0.08 $m^3$ $m^{-3}$ in the A and E horizon (12 and 28 cm, respectively) corresponded to changes in clay content and were slightly higher than those of site G8. Moisture content sharply increased to 0.21 $m^3$ $m^{-3}$ at 43 cm resulting from a clay content increase in the Btss1 horizon and gradually decreased with depth to a value of 0.06 $m^3$ $m^{-3}$. Chloride concentrations were the lowest (<200 mg $L^{-1}$) in the pedon to a depth of 113 cm so soil moisture fluxes were the greatest (~1-1.8 mm $yr^{-1}$) through that depth interval. Chloride concentrations increased beyond that depth as a result of evapotranspiration with corresponding soil moisture fluxes that approached 0 mm $yr^{-1}$ at the bottom of the pedon (Fig. 9).

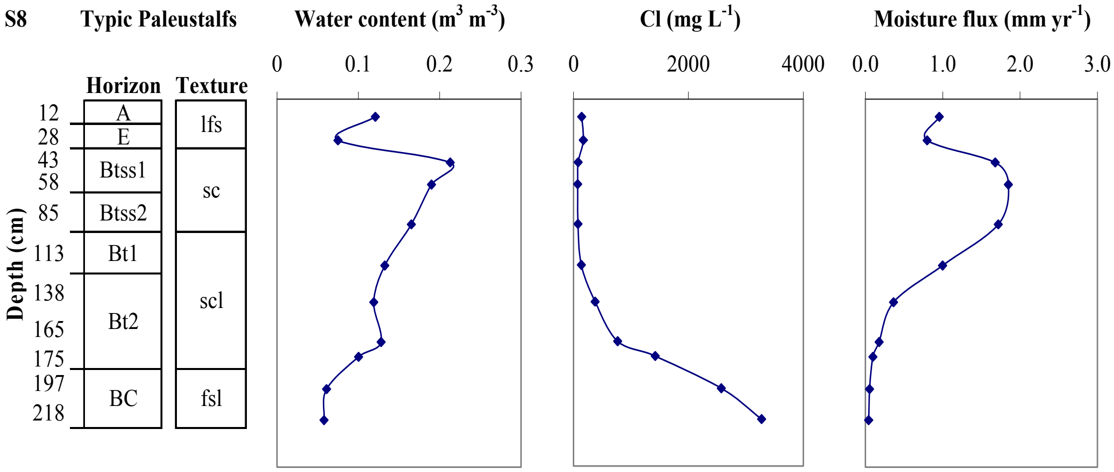

**Fig. 9. Soil profile, texture, volumetric water content, soil water $Cl^-$ concentration, and estimated CMB soil moisture fluxes for site S8.**

The increasing $Cl^-$ concentrations with depth may be indicative of a $Cl^-$ bulge, however, it was hard to assess since this pedon was sampled to a shallower depth than the others due to a lithic or paralithic contact (sandstone). This restrictive layer may in part be responsible for the high $Cl^-$ concentrations at the bottom of the pedon as water and plant roots may concentrate at those depths due to a physical impediment. The same lithic contact was found at site G7; however, $Cl^-$ concentrations were remarkably lower than that of site S8 which suggests that plant roots may be playing an important role in the geochemical composition of soil water at those depths.

Differences in soil moisture distribution, $Cl^-$ concentrations, and soil moisture fluxes were observed between sites G7 and S8. Soil moisture fluxes below 200 cm were 0.8 and 0.04 mm $yr^{-1}$ for sites G7 and S8, respectively; an order of magnitude increase in deep drainage possibly as a result of enhanced percolation since land clearing. However, steady-state water fluxes below ~200 cm for site G7 could not be assess because of the shallow sampling depth of the soil. Total $Cl^-$ mass to the depth of sampling (230 and 218 cm) was 40 and 144 g $m^{-2}$ for sites G7 and S8, respectively (Table 2). In spite of the shallower sampling depth for shrubland site S8, it had at least 100 g $m^{-2}$ more $Cl^-$ as compared to grassland sites at a similar depth, which represented about an additional 700 yr of $Cl^-$ accumulation.

Sites G6 and S1 were individual sites without a near-by “pair”, but valuable information was obtained. Site G6 (Fig. 10) was characterized by low $Cl^-$ concentrations of <200 mg $L^{-1}$ throughout the entire soil profile, ranging from 32 mg $L^{-1}$ at 187 cm to 192 mg $L^{-1}$ at 330 cm (bottom). Due to considerably low $Cl^-$ concentrations, estimated soil moisture fluxes were high (1.8-4.3 mm yr$^{-1}$) within 13-279 cm with an estimated deep drainage rate of 1.3 mm yr$^{-1}$ below 200 cm. Leaching of salts have occurred to a significant extent since clearing (>80 years ago), and increases in soil moisture fluxes below the root zone were observed. Solute front displacement was observed at the bottom of the pedon in response to increased water percolation since land clearing. Soil water contents were relatively higher than the other grassland sites (0.11-0.26 m$^3$ m$^{-3}$) because of the high clay content and showed no systematic relationship with depth.

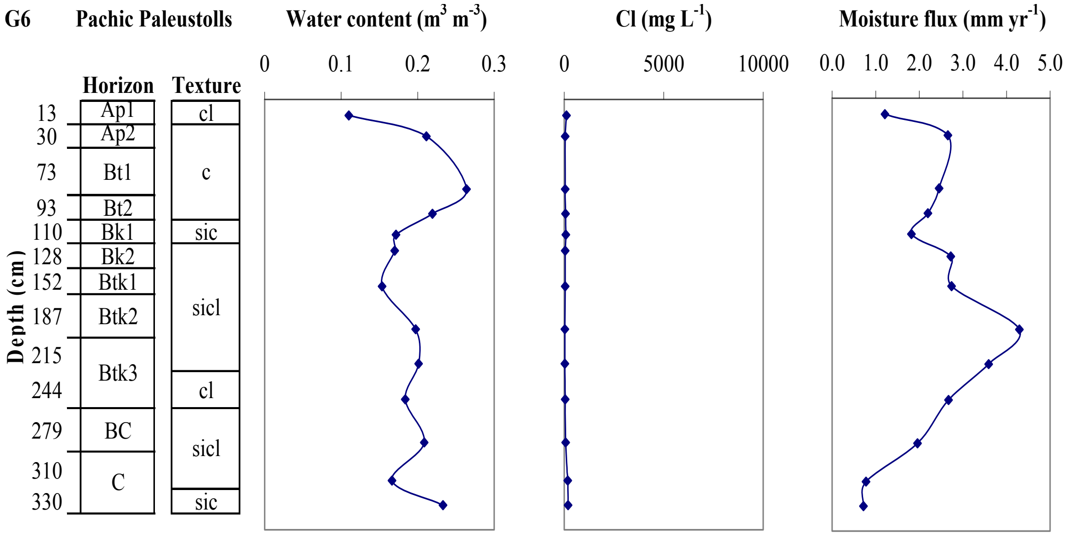

**Fig. 10. Soil profile, texture, volumetric water content, soil water Cl$^-$ concentration, and estimated CMB soil moisture fluxes for site G6.**

Site S1 had a leached zone of ~60 cm with Cl$^-$ concentrations <200 mg L$^{-1}$ and soil moisture fluxes of about 1 mm yr$^{-1}$ through that depth interval (Fig. 11). Beyond 60 cm, Cl$^-$ concentrations sharply increased so soil moisture fluxes were negligible (~0.02 mm yr$^{-1}$) and approached 0 mm yr$^{-1}$ beyond a depth of 300 cm, which suggest that almost all infiltrating water from precipitation has been evapotranspired. The Cl$^-$ peak occurred at 291 cm (8,945 mg $L^{-1}$); high and relatively constant $Cl^-$ concentrations (6,000-8,000 mg $L^{-1}$) above and below the peak may correspond to soil $Cl^-$ enrichment within the root zone. Soil water contents were relatively higher than the other shrubland sites (0.14-0.22 $m^3$ $m^{-3}$) throughout the soil profile due to the high clay content and showed an increasing trend to a depth of 235 cm.

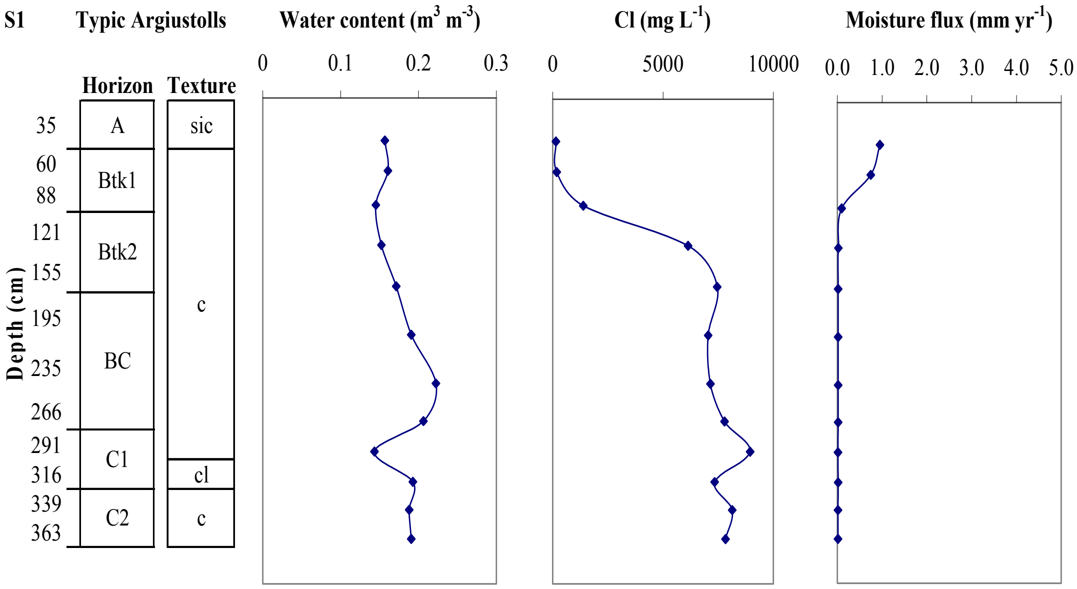

**Fig. 11. Soil profile, texture, volumetric water content, soil water $Cl^-$ concentration, and estimated CMB soil moisture fluxes for site S1.**

Although the amount of $Cl^-$ accumulated in the S1 soil to a depth of 363 cm would require about 28,000 yr (Table 2), a gradual decreasing trend in $Cl^-$ concentration was not observed in this soil pedon through the 363 cm sampling depth, which suggests that $Cl^-$ accumulation persisted even during more mesic climatic conditions. The same observation was made by (Murphy et al., 1996; Sandvig and Phillips, 2006) and $Cl^-$ accumulation periods as long as 90,000 yr have been reported (Scanlon et al., 2003b).

Their results were attributed to variability in soil physical properties, rooting depths, subtle differences in topography, and uncertainties in $Cl^-$ deposition rates. A recent publication (Scanlon et al., 2009) also showed $Cl^-$ accumulation periods of ~29,000 yr; however, a clear understanding regarding the process governing such long accumulation periods has not been formulated. Further evaluation was limited due to the shallower sampling depth of this soil profile as compared to the referenced studies, where sampling depths usually reached 10-25 m.

Even though sites G6 and S1 were from soil series Rotan and Sagerton, respectively, they shared common soil physical properties (Appendix A). Clay contents ranged from 32 to 46%, which helps explain the relatively higher moisture contents in both pedons, and had slopes of ≤1%. Both sites are deep, well drained, moderately slowly permeable soils that formed in calcareous loamy alluvium. It is reasonable to conclude that the substantial differences in $Cl^-$ concentration and soil moisture fluxes at the sampling interval may be attributed to enhanced water percolation due to differences in land use/land cover.

Variability within shrubland sites was considerable (Fig. 12), which is not uncommon for $Cl^-$ distribution studies around the globe due to the inherent variability of soil properties and plant root distribution. Significant variability may be also in response of the distance between sites, up to 65 Km apart in some cases. Soil physical and hydraulic properties are suggested as responsible for such large variations in $Cl^-$ concentration and the correspondingly large differences in recharge rates. Therefore, determination and development of statistical and soil and hydrological techniques for estimating recharge across a sizable area remain an important problem in recharge evaluations.

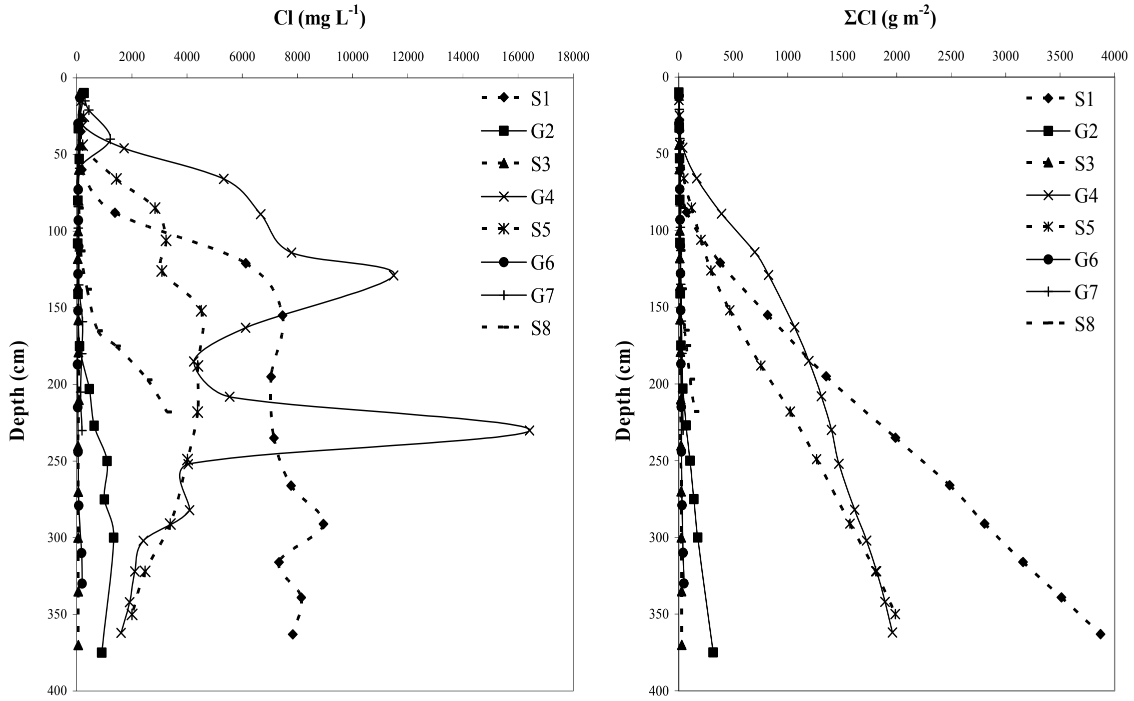

**Fig. 12. Soil water Cl$^-$ concentration and cumulative Cl$^-$ mass with depth for all sites.**

The differences in Cl$^-$ concentrations, distribution, and cumulative amount for both ecosystems are better observed graphically. Despite the variability, considerably lower Cl$^-$ concentrations for grasslands (G2, G6, and G7) as compared to shrublands (S1, S5, and S8) and the greater depth of a Cl$^-$ peak for grassland sites were observed. Both characteristics suggest that enhanced percolation since land clearing may be responsible for the downward solute front displacement and reductions in soil Cl$^-$ concentrations. However, results cannot be extrapolated to nearby areas since CMB estimations are site dependent and give only “point” estimates of potential recharge; in that regard, Cl$^-$ data provide information on spatial variability in downward water movement as each profile represents a point estimate of moisture flux. It would require extensive field sampling to provide areal estimates of recharge.

Upon changes in land use/land cover, rises in groundwater levels are likely to occur as shown by studies conducted in Australia (Allison et al., 1990) and in the U.S. High Plains (Scanlon et al., 2005b). However, in order to state statistically significant differences in recharge rates between grasslands and shrublands, more sampling sites would be required due to the highly variable results obtained.

The new soil moisture flux (deep drainage if beyond the root zone) will only become groundwater recharge when it reaches the water table and thus, estimations of deep drainage are estimates of "potential recharge". Layers of low permeability below the sampling depths may cause lateral flow or considerably reduce the recharge rate. The lag time (decades to centuries) between increased water fluxes below the root zone following clearing of woody-shrub vegetation and water-table rises varies depending on the water flux, the average water content in the unsaturated zone, and the depth of the water table, which can be long because in semiarid regions the water table is generally deep (>20 m) (Allison et al., 1990; Scanlon et al., 2005b).

High clay content in Bt horizons is regarded to influence $Cl^-$ concentrations and therefore reduces soil moisture fluxes (Newman et al., 1997). In this study, clay contents ranged from 7 to 50% as shown in Table 3, with clay contents in the Bt horizons ranging from 23 to 48 % (Appendix D). Significant negative correlation coefficients between clay content and $Cl^-$ concentrations of -0.78 ($P$=0.001), -0.66 ($P$=0.005), and -0.71

(*P*=0.01) were observed at the 95% confidence level for sites G2, S3, and G7, respectively. Low $Cl^-$ inventories were common for these sites. For all other sites, correlation coefficients were rather weak (Table 3) and not significant. Furthermore, relatively high (>2,000 mg $L^{-1}$) and low (<200 mg $L^{-1}$) soil $Cl^-$ concentrations were observed in soils with >35% clay in Bt horizons, and sharp increases in $Cl^-$ concentration did not match increases in clay content. Even though clay content influenced soil water contents, the same systematic relationship between $Cl^-$ concentration and % clay was not observed and is shown in all soil profiles (Figs. 3-6, 8-11). Thus, increases in clay content can be disregarded as a factor strongly affecting $Cl^-$ concentration and thus, soil moisture fluxes. Soil bulk density had no effect on soil $Cl^-$ concentrations (Appendix D); its usefulness was limited to conversion of gravimetric water content to a volume basis.

**Table 3. Summary of hydraulic and soil physical properties of soil core samples.**

| Property | S1 | G2 | S3 | G4 | S5 | G6 | G7 | S8 |
|---|---|---|---|---|---|---|---|---|
| Water content, mean ($m^3$ $m^{-3}$) | 0.18 | 0.17 | 0.13 | 0.13 | 0.19 | 0.20 | 0.11 | 0.12 |
| Water content, SD ($m^3$ $m^{-3}$) | 0.03 | 0.04 | 0.03 | 0.06 | 0.07 | 0.04 | 0.04 | 0.05 |
| Water content, min ($m^3$ $m^{-3}$) | 0.14 | 0.07 | 0.06 | 0.03 | 0.09 | 0.11 | 0.02 | 0.06 |
| Water content, max ($m^3$ $m^{-3}$) | 0.22 | 0.21 | 0.17 | 0.23 | 0.32 | 0.26 | 0.14 | 0.21 |
| Bulk density, mean (g $cm^{-3}$) | 1.51 | 1.59 | 1.51 | 1.42 | 1.40 | 1.43 | 1.59 | 1.53 |
| Bulk density, SD (g $cm^{-3}$) | 0.05 | 0.14 | 0.11 | 0.03 | 0.07 | 0.18 | 0.10 | 0.06 |
| Bulk density, min (g $cm^{-3}$) | 1.42 | 1.23 | 1.29 | 1.35 | 1.23 | 1.16 | 1.43 | 1.41 |
| Bulk density, max (g $cm^{-3}$) | 1.58 | 1.69 | 1.66 | 1.46 | 1.47 | 1.67 | 1.74 | 1.59 |
| Clay content, min (%) | 36 | 17 | 16 | 21 | 27 | 32 | 7 | 8 |
| Clay content, max (%) | 46 | 36 | 37 | 44 | 50 | 46 | 36 | 43 |
| Correlation coefficient $Cl^-$, clay% | -0.30 | -0.78* | -0.66* | 0.01 | 0.43 | 0.18 | -0.71* | -0.40 |

SD=standard deviation

*Significant at the 95% confidence level.

## 4.2 Validity of CMB assumptions

The one-dimensional, vertically downward water movement assumption is considered valid because soil $Cl^-$ profiles are from topographically flat areas having slopes of ≤2%. The direction of moisture flux is downward; if the moisture flux were in fact upward, the highest $Cl^-$ concentrations would have occurred at the soil surface. Maximum $Cl^-$ concentrations observed at depths from 150 to 291 cm in shrublands indicated that the net moisture flux is downward at this depth interval of the unsaturated zone. However, some studies have attributed “net upward” water movement to sites where high $Cl^-$ concentrations and upward water potential gradients within the root zone indicate that water is discharged through evapotranspiration, such as in shrublands (Scanlon et al., 2003b; 2005b; Seyfried et al., 2005). For grasslands, the downward solute front displacement and increased moisture fluxes are good indicatives of net downward water movement.

The piston flow assumption is more difficult to assess. Near the soil surface where desiccation cracks develop, non-piston flow may be important, especially in soils with high clay content and smectitic mineralogy. However, flow along preferential pathways appears to be more prevalent in wetter areas (800-1,200 mm $yr^{-1}$) (Scanlon, 1991). Allison et al. (1990) suggested that near saturated conditions necessary for preferential flow occur rarely in a semiarid environment; however, other observations indicate that preferential flow does not require saturated conditions (Dr. Cristine Morgan, personal communication). For sites G2, G6, G7 and S8, the relatively uniform $Cl^-$ concentrations observed above the solute front indicated piston flow water movement. Site S3 was the exception, where preferential flow along macropores and root channels may be responsible for the low $Cl^-$ concentrations and distribution. Sites S1, G4, and S5 showed a more uniform $Cl^-$ distribution as compared to site S3, where $Cl^-$ concentrations increased at the root zone, then decreased or remained constant below it as expected. However, pulse-type tracers such as bomb $^3H$ and $^{36}Cl$ would need to be used to evaluate whether water was moving preferentially (Scanlon, 2000).

The study area consisted of well drained, deep (Rotan series) to very deep (Sagerton and Hamby series) soils where weathering has occurred to a significant extent and any residual $Cl^-$ released by weathering would have been removed. The $Cl^-/Br^-$ mass ratios (Table 2) of 95 to 356 for sites S1, G2, G4, S5, and S1 are similar to those in precipitation (50-150) and sea water (290), and are generally consistent with an atmospheric deposition source (Davis et al., 1998). Furthermore, high $Cl^-/Br^-$ correlation coefficients of 0.98, 0.97, 0.97, 0.94, and 0.99 for sites S1, G2, G4, S5, and S8 (Table 2) respectively, suggest atmospheric deposition as the sole source of $Cl^-$ (Davis et al., 1998). Therefore, any in situ $Cl^-$ source can be considered as negligible.

A constant $Cl^-$ concentration below the root zone is required for the CMB method to be valid. Despite the observed solute front displacement under grassland sites, a steady-state efflux of $Cl^-$ below the root zone has not been achieved for sites G2, G6, and G7 at least at the sampling depth of this study. Estimated moisture fluxes below the root zone were 0.1, 1.3, and 0.8 mm $yr^{-1}$, respectively, whereas estimated fluxes as high as 4.1, 4.3, and 2.6 mm $yr^{-1}$ were observed for the same sites at shallower depths, suggesting that more time is needed in order to achieve a new equilibrium and a steady-state efflux of $Cl^-$ below the root zone. In that regard, an estimate of recharge rate before a steady-state is re-established may lead to substantial underestimation of the recharge rates for these sites. The steady-state assumption for shrubland sites was difficult to evaluate because of the shallow sampling depths; it is for the grasslands that a new equilibrium must be achieved after clearing of woody-shrub vegetation. However, the long time period represented by $Cl^-$ profiles under shrublands settings (15,000-28,000 years) spanned paleoclimatic variations and may invalidate the steady-state subsurface flow assumption. The change in environmental conditions was evaluated by plotting cumulative $Cl^-$ concentration against cumulative water content (Fig. 7). Although it was evident for sites S5 and G4 (recently cleared), site S1 did not show evidence of paleoclimatic variations.

If vadose zone fluxes were controlled solely by climate, then vadose zone moisture fluxes should change gradually along with changes in aridity. That is not the case as these results were very similar to the findings by Sandvig and Phillips (2006) and Scanlon (1991), studies conducted in areas of higher aridity. However, the vadose zone properties ($Cl^-$ concentration and moisture fluxes) markedly change with changes in vegetation cover. Profiles within each ecosystem were characterized by similar $Cl^-$ concentrations and inventories, whereas between ecosystems, there were abrupt changes under the same climatic conditions.

Special attention should be paid to CMB ages for the different soil profiles (Table 2). Chloride mass balance ages were calculated by dividing the $Cl^-$ inventory to a depth of interest by the $Cl^-$ deposition rate. If one considers sites G6 and S1, there was a substantial difference in $Cl^-$ inventory affecting CMB ages for these sites located about 40 Km apart. Chloride mass balance ages were 352 yr (48 g $Cl^-$ $m^2$) and 25,556 yr (3,511 g $Cl^-$ $m^2$) at 330 and 339 cm for comparison purposes, respectively. If one assumes a constant and uniform $Cl^-$ deposition rate of 0.14 g $m^2$ $yr^{-1}$ over the study area, then the difference in $Cl^-$ inventory (3,463 g $m^2$) between sites G6 and S1 has been flushed out of the system and indicates that episodic flushing events may have occurred at least a few hundreds (sites G6, G7) to couple of thousands (G2) years ago.

If that is true, then recent changes in land use may not be entirely responsible for increased recharge rates, but rather from relatively recent flushing events (at least to the depth investigated) or from preferential flow that removed small amounts of $Cl^-$ on a regular basis. Further, run-on can be a significant source of $Cl^-$, raising the $Cl^-$ input by twice to as much as an order of magnitude more than the assumed $Cl^-$ deposition. Uncertainties in $Cl^-$ deposition rates are by far the largest source of error in $Cl^-$ tracer studies (Scanlon, 2000). Additional study to include soil matric potentials and stable isotopes would be needed in order to elucidate the influence of preferential flow and $Cl^-$ deposition from other sources.

# 5. SUMMARY AND CONCLUSIONS

Chloride profiles from grasslands and shrublands displayed wide variability in their maximum $Cl^-$ concentrations and distribution suggesting differences in soil moisture fluxes between ecosystems.

Common features for three out of four shrubland sites included: (1) sharp increases in $Cl^-$ concentration with depth and high $Cl^-$ concentration gradients ranging from 33 to 143 mg $L^{-1}$ $cm^{-1}$ as a result of evapotranspirative $Cl^-$ enrichment within the root zone, (2) maximum $Cl^-$ concentrations ranging from 3,272 to 8,945 mg $L^{-1}$ at varying depths, but usually at depths shallower than in grasslands, and (3) $Cl^-$ concentrations of >2,000 mg $L^{-1}$ below 200 cm, suggesting negligible soil moisture fluxes and water discharge due to high evapotranspiration rates.

Common features for three out of four grassland sites included: (1) lower $Cl^-$ concentrations (<1,400 mg $L^{-1}$) and $Cl^-$ concentration gradients (<1 to 41 mg $L^{-1}$ $cm^{-1}$) than shrublands, suggesting a leaching environment possibly due to changes in land use/land cover, (2) maximum $Cl^-$ concentrations ranged from 192 to 1,336 mg $L^{-1}$ at depths >300 cm, and (3) downward displacement of solute fronts in the profile (>300 cm) possibly due to enhanced water percolation and soil moisture fluxes with depth of up to 4.6 mm $yr^{-1}$.

Although soil types and amount of slope were selected to be similar for this study, substantial differences in $Cl^-$ concentrations and inventories were observed. Data of $Cl^-$ profiles showed potential increases in soil moisture fluxes in the grassland setting compared to shrubland. Lower $Cl^-$ concentrations under grasslands suggest increases in moisture fluxes and therefore “potential recharge”. For shrublands S5 and S1, data suggest that virtually no water has escaped below the root zone in the last 15,000 – 28,000 yr as indicated by $Cl^-$ inventories and CMB ages. Results were consistent with other findings in more arid settings, and suggested that vadose zone characteristics were not solely controlled by climate, but vegetation was also important in determining hydrological components of the water cycle such as recharge.

Estimated moisture fluxes below the root zone under grassland settings ranged from 0.1 to 1.3 mm $yr^{-1}$ and were largely in response to low $Cl^-$ concentrations. However, the steady-state $Cl^-$ efflux condition below the root zone has not been achieved and therefore may result in underestimation of deep drainage rates. Under shrublands, soil moisture fluxes below the root zone could not be estimated because roots may extend beyond our sampling depths. However, $Cl^-$ profiles suggested that xeric vegetation can maintain dry conditions (represented by $Cl^-$ concentrations) in the subsurface for millennial timescales and that almost all infiltrating water has been evapotranspired back into the atmosphere under these settings.

An interesting finding in vadose zone characteristics in this study was that juniper woodlands appeared capable of allowing deep water percolation (2.6 mm $yr^{-1}$) as suggested by the S3 site. Thus, assuming the functions of the root zone a priori may limit the analysis by not addressing the mechanisms responsible for root-water uptake and raise questions concerning the complexity of ecohydrological processes under this plant community. Chloride mass balance ages represented by various soil profiles suggested the possibility of recent flushing events as indicated by the low $Cl^-$ inventory in some sites.

These results underscore the ability of vegetation to regulate subsurface flow and indicate that changes in vegetation are likely to impact groundwater recharge. Although there is much to learn about temporal and spatial distribution of soil moisture in the root zone, vegetation and climate influence on soil moisture fluxes, and water uptake mechanisms, results indicate that the nature of the vegetation community is critical in controlling deep drainage and therefore, groundwater recharge.

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# APPENDIX A

## PEDON DESCRIPTIONS

**Soil description at site S1**
**Soil Series:** Sagerton
**Soil Classification:** Fine, mixed, superactive, thermic Typic Argiustolls
**Location:** Taylor County, TX. Lat 32°20’22.506” north; Long 100°2’52.944” west
**Slope:** 1%
**Parent material:** Calcareous loamy alluvium
**Dominant vegetation:** Shrub cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 11/12/2008

**A** --- 0 to 35 centimeters; brown (7.5YR 4/3) dry, clay; dark brown (7.5YR 3/3) moist; null percent sand; null percent silt; 42 percent clay; moderate medium and coarse subangular blocky structure; very firm, hard, very sticky, very plastic; common fine roots throughout; strongly effervescent; clear smooth boundary.

**Btk1** --- 35 to 88 centimeters; brown (7.5YR 4/4) dry, clay; dark brown (7.5YR 3/4) moist; null percent sand; null percent silt; 45 percent clay; strong fine and medium subangular blocky structure; very firm, hard, very sticky, very plastic; common fine roots in cracks; 5 percent (few) patchy faint clay films on all faces of peds; 5 percent (common) medium masses of carbonate; 5 percent non-flat sub rounded indurated 2 to 15 millimeters limestone fragments; violently effervescent; Horizon to be split at 60 cm.; clear smooth boundary.

**Btk2** --- 88 to 155 centimeters; brown (7.5YR 4/4) dry, clay; dark brown (7.5YR3/4) moist; null percent sand; null percent silt; 45 percent clay; moderate medium and coarse subangular blocky structure; very firm, hard, very sticky, very plastic; common very fine roots in cracks; 5 percent (few) patchy faint clay films on all faces of peds; 8 percent (common) medium masses of carbonate; strongly effervescent; Horizon to be split at 121 cm.; clear smooth boundary.

**BC** --- 155 to 266 centimeters; brown (7.5YR 4/2) dry, clay; dark brown (7.5YR 3/2) moist; null percent sand; null percent silt; 43 percent clay; moderate medium and coarse subangular blocky structure; very firm, hard, very sticky, very plastic; common very fine roots in cracks; 5 percent (common) medium masses of carbonate; strongly effervescent; Horizon to be split at 195 and 235; clear smooth boundary.

**C1** --- 266 to 316 centimeters; light brown (7.5YR 6/3) dry, clay; brown (7.5YR 5/3) moist; null percent sand; null percent silt; 41 percent clay; moderate medium and coarse subangular blocky structure; very firm, hard, very sticky, very plastic; violently effervescent; Horizon to be split at 291 cm.; abrupt smooth boundary.

**C2** --- 316 to 363 centimeters; 60 percent brown (7.5YR 4/4) dry and 40 percent pink (7.5YR 7/3) dry, clay loam; 60 percent dark brown (7.5YR 3/4) moist and 40 percent light brown (7.5YR 6/3) moist; null percent sand; null percent silt; 32 percent clay; 40 percent medium distinct irregular pink (7.5YR 7/3) and 40 percent medium distinct irregular light brown (7.5YR 6/3) mottles; moderate medium and coarse subangular blocky structure; very firm, hard, very sticky, very plastic; violently effervescent; Horizon to be split at 339 cm.

**Remarks:**

**Soil description at site G2**
**Soil Series:** Rotan
**Soil Classification:** Fine, mixed, superactive, thermic Pachic Paleustolls
**Location:** Taylor County, TX. Lat 32°11’19.32” north; Long 99°52’29.634” west
**Slope:** 2%
**Parent material:** Calcareous loamy alluvium of Quaternary age
**Dominant vegetation:** Grass/herbaceous cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 11/13/2008

**A** --- 0 to 10 centimeters; brown (7.5YR 4/3) dry, clay loam; dark brown (7.5YR 3/2) moist; null percent sand; null percent silt; 32 percent clay; moderate medium subangular blocky structure; friable, very sticky, very plastic; common medium roots throughout, common fine roots throughout and common very fine roots throughout; common medium tubular moderate continuity and common fine tubular moderate continuity pores; non-effervescent; clear smooth boundary.

**AB** --- 10 to 33 centimeters; dark brown (7.5YR 3/2) dry, clay loam; dark brown (7.5YR 3/3) moist; null percent sand; null percent silt; 35 percent clay; strong medium subangular blocky structure; firm, very sticky, very plastic; common medium roots throughout, common very fine roots throughout and common fine roots throughout; common medium tubular moderate continuity and common fine tubular moderate continuity pores; non-effervescent; clear smooth boundary.

**Bt** --- 33 to 53 centimeters; dark brown (7.5YR 3/3) dry, clay loam; dark brown (7.5YR 3/2) moist; null percent sand; null percent silt; 36 percent clay; strong fine prismatic parting to strong fine and medium angular blocky structure; firm, very sticky, very plastic; common very fine roots in cracks and common fine roots in cracks; very slightly effervescent; clear smooth boundary.

**Btss1** --- 53 to 108 centimeters; brown (7.5YR 4/3) dry, clay loam; brown (7.5YR 4/2) moist; null percent sand; null percent silt; 37 percent clay; strong fine prismatic parting to strong fine and medium wedge structure; very firm, very sticky, very plastic; common very fine roots in cracks; common fine tubular moderate continuity pores; 3 percent non-flat subangular indurated 2 to 75 millimeters limestone fragments; very slightly effervescent; Horizon split at 80 cm.; clear smooth boundary.

**Btss2** --- 108 to 175 centimeters; dark gray (7.5YR 4/1) dry, clay loam; brown (7.5YR 4/2) moist; null percent sand; null percent silt; 37 percent clay; strong fine prismatic parting to strong fine wedge structure; very firm, very sticky, very plastic; common very fine roots in cracks; 2 percent non-flat subangular indurated 2 to 75 millimeters limestone fragments; very slightly effervescent; Horizon split at 141 cm.; gradual smooth boundary.

**BC** --- 175 to 203 centimeters; 60 percent dark gray (7.5YR 4/1) dry and 40 percent yellow (2.5Y 7/8) dry, clay loam; 60 percent brown (7.5YR 4/2) moist and 40 percent olive yellow (2.5Y 6/8) moist; null percent sand; null percent silt; 35 percent clay; 40 percent coarse prominent irregular yellow (2.5Y 7/8) and 40 percent coarse prominent irregular olive yellow (2.5Y 6/8) mottles; strong fine prismatic parting to strong fine and medium angular blocky structure; firm, very sticky, very plastic; 3 percent non-flat subangular indurated 2 to 75 millimeters limestone fragments; non-effervescent; clear smooth boundary.

**C1** --- 203 to 250 centimeters; 40 percent reddish yellow (7.5YR 6/8) dry, 30 percent pale yellow (2.5Y 7/3) dry and 30 percent brown (7.5YR 5/3) dry, sandy clay; 40 percent strong brown (7.5YR 5/8) moist, 30 percent light yellowish brown (2.5Y 6/3) moist and 30 percent brown (7.5YR 4/3) moist; null percent sand; null percent silt; 38 percent clay; 30 percent coarse prominent irregular brown (7.5YR 5/3), 30 percent coarse prominent irregular brown (7.5YR 4/3), 30 percent coarse prominent irregular pale yellow (2.5Y 7/3) and 30 percent coarse prominent irregular light yellowish brown (2.5Y 6/3) mottles; strong fine prismatic parting to strong fine and medium angular blocky structure; firm, moderately sticky, moderately plastic; non-effervescent; Horizon split at 227 cm.; abrupt wavy boundary.

**C2** --- 250 to 300 centimeters; 50 percent pale yellow (2.5Y 8/3) dry and 50 percent brownish yellow (10YR 6/8) dry, sandy clay loam; 50 percent pale yellow (2.5Y 8/2) moist and 50 percent yellowish brown (10YR 5/8) moist; null percent sand; null percent silt; 35 percent clay; 50 percent medium distinct irregular pale yellow (2.5Y 8/2) and 50 percent medium distinct irregular pale yellow (2.5Y 8/3) mottles; moderate fine prismatic parting to moderate fine and medium angular blocky structure; firm, moderately sticky, moderately plastic; non-effervescent; Horizon split at 275 cm.

**2C3** --- 300 to 375 centimeters; 80 percent light greenish gray (10Y 8/1) dry and 20 percent yellow (10YR 7/8) dry, clay; 80 percent light greenish gray (10Y 8/1) moist and 20 percent brownish yellow (10YR 6/8) moist; null percent sand; null percent silt; 68 percent clay; 20 percent coarse distinct (10YR 7/) and 20 percent coarse distinct (10YR 6/) mottles; very firm, very sticky, very plastic; very slightly effervescent; angular rock structure.

**Remarks:**

**Soil description at site S3**
**Soil Series:** Rotan
**Soil Classification:** Fine, mixed, superactive, thermic Pachic Paleustolls
**Location:** Taylor County, TX. Lat 32°11'20.556" north; Long 99°52'30.534" west
**Slope:** 2%
**Parent material:** Calcareous loamy alluvium of Quaternary age
**Dominant vegetation:** Tree cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 11/13/2008

**A** --- 0 to 10 centimeters; brown (7.5YR 4/3) dry, clay loam; dark brown (7.5YR 3/2) moist; null percent sand; null percent silt; 30 percent clay; moderate medium subangular blocky structure; friable, slightly hard, very sticky, very plastic; common very fine roots throughout, common fine roots throughout and common medium roots throughout; common medium tubular moderate continuity and common fine tubular moderate continuity pores; non-effervescent; clear smooth boundary.

**AB** --- 10 to 28 centimeters; dark brown (7.5YR 3/2) dry, clay loam; dark brown (7.5YR 3/3) moist; null percent sand; null percent silt; 33 percent clay; strong medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; common very coarse roots throughout, common fine roots throughout, common very fine roots throughout and common medium roots throughout; common medium tubular moderate continuity and common fine tubular moderate continuity pores; non-effervescent; clear smooth boundary.

**Btk1** --- 28 to 60 centimeters; dark brown (7.5YR 3/3) dry, clay loam; dark brown (7.5YR 3/2) moist; null percent sand; null percent silt; 36 percent clay; strong fine prismatic parting to strong fine and medium angular blocky structure; firm, moderately hard, very sticky, very plastic; common medium roots throughout and common very fine roots throughout; 5 percent (few) patchy faint clay films on all faces of peds; 2 percent (common) fine faint threadlike non-cemented masses of carbonate with diffuse boundaries in matrix; very slightly effervescent; split at 44; clear smooth boundary.

**Btk2** --- 60 to 80 centimeters; brown (7.5YR 4/3) dry, clay loam; brown (7.5YR 4/2) moist; null percent sand; null percent silt; 37 percent clay; strong fine prismatic parting to strong fine and medium angular blocky structure; very firm, hard, very sticky, very plastic; common medium roots throughout and common very fine roots in cracks; common fine tubular moderate continuity pores; 5 percent (few) patchy faint clay films on all faces of peds; 2 percent (common) fine faint threadlike non-cemented masses of carbonate with diffuse boundaries in matrix; 3 percent non-flat subangular indurated 2 to 75 millimeters limestone fragments; very slightly effervescent; clear smooth boundary.

**Btss1** --- 80 to 118 centimeters; dark gray (7.5YR 4/1) dry, clay; brown (7.5YR 4/2) moist; null percent sand; null percent silt; 44 percent clay; strong fine prismatic parting to strong fine prismatic structure; very firm, hard, very sticky, very plastic; common fine roots in cracks and common very fine roots in cracks; 10 percent (few) continuous distinct slickensides (pedogenic) on vertical faces of peds and 5 percent (few) patchy faint clay films on all faces of peds; 2 percent non-flat subangular indurated 2 to 75 millimeters limestone fragments; very slightly effervescent; Split at 100; gradual smooth boundary.

**Btss2** --- 118 to 136 centimeters; dark gray (7.5YR 4/1) dry, clay; brown (7.5YR 4/2) moist; null percent sand; null percent silt; 35 percent clay; strong fine prismatic parting to strong fine and medium prismatic structure; firm, moderately hard, very sticky, very plastic; common very fine roots in cracks; 5 percent (few) continuous distinct slickensides (pedogenic) on vertical faces of peds and 5 percent (few) patchy faint clay films on all faces of peds; 3 percent non-flat subangular indurated 2 to 75 millimeters limestone fragments; non-effervescent;; clear smooth boundary.

**Btss3** --- 136 to 179 centimeters; 40 percent yellow (2.5Y 7/8) dry and 30 percent brown (7.5YR 5/3) dry, clay; 40 percent olive yellow (2.5Y 6/8) moist and 30 percent brown (7.5YR 4/3) moist; null percent sand; null percent silt; 38 percent clay; 30 percent coarse prominent irregular brown (7.5YR 5/3) and 30 percent coarse prominent irregular brown (7.5YR 4/3) mottles; strong fine prismatic parting to strong fine and medium wedge structure; firm, moderately hard, very sticky, very plastic; common fine roots throughout and common medium roots throughout; 5 percent (few) continuous distinct slickensides (pedogenic) on vertical faces of peds and 5 percent (few) patchy faint clay films on all faces of peds; non-effervescent; Split at 158; abrupt wavy boundary.

**C1** --- 179 to 240 centimeters; 40 percent reddish yellow (7.5YR 6/8) dry, 30 percent brown (7.5YR 5/3) dry and 30 percent very pale brown (10YR 7/3) dry, clay; 40 percent strong brown (7.5YR 5/8) moist, 30 percent brown (7.5YR 5/3) moist and 30 percent pale brown (10YR 6/3) moist; null percent sand; null percent silt; 42 percent clay; 30 percent coarse distinct irregular dark brown (7.5YR 3/3), 30 percent coarse distinct irregular brown (7.5YR 5/3), 30 percent coarse distinct irregular very pale brown (10YR 7/3) and 30 percent coarse distinct irregular pale brown (10YR 6/3) mottles; moderate fine prismatic parting to moderate fine prismatic structure; firm, moderately hard, very sticky, very plastic; common fine roots in cracks and common very fine roots in cracks; non-effervescent; Split at 210; clear wavy boundary.

**C2** --- 240 to 300 centimeters; 80 percent very pale brown (10YR 8/1) dry and 20 percent yellow (10YR 7/8) dry, sandy clay loam; 80 percent very pale brown (10YR 8/1) moist and 20 percent brownish yellow (10YR 6/8) moist; null percent sand; null percent silt; 38 percent clay; 20 percent coarse distinct irregular yellow (10YR 7/8) and 20 percent coarse distinct irregular brownish yellow (10YR 6/8) mottles; massive; very firm, hard, moderately sticky, moderately plastic; common fine roots in cracks and common very fine roots in cracks; very slightly effervescent; Split at 270; clear wavy boundary.

**2C3** --- 300 to 370 centimeters; 80 percent white (7.5YR 8/1) dry and 20 percent reddish yellow (7.5YR 7/8) dry, clay; 80 percent light gray (7.5YR 7/1) moist and 20 percent reddish yellow (7.5YR 6/8) moist; null percent sand; null percent silt; 68 percent clay; 20 percent coarse distinct irregular reddish yellow (7.5YR 7/8) and 20 percent coarse distinct irregular reddish yellow (7.5YR 6/8) mottles; massive; very firm, hard, very sticky, very plastic; common very fine roots in cracks; very slightly effervescent; Split at 335.

**Remarks:**

**Soil description at site G4**
**Soil Series:** Sagerton
**Soil Classification:** Fine, mixed, superactive, thermic Typic Argiustolls
**Location:** Nolan County, TX. Lat 32°31'3.054" north; Long 100°28'34.032" west
**Slope:** 1%
**Parent material:** Calcareous loamy alluvium
**Dominant vegetation:** Grass/herbaceous cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 1/12/2009

**A** --- 0 to 31 centimeters; brown (7.5YR 4/3) dry, clay loam; dark brown (7.5YR 3/2) moist; null percent sand; null percent silt; 32 percent clay; moderate medium subangular blocky structure; firm, moderately hard, moderately sticky, moderately plastic; common medium roots throughout and common very fine roots throughout; non-effervescent; Split at 15 cm.; clear smooth boundary.

**Bt** --- 31 to 66 centimeters; brown (7.5YR 4/3) dry, clay loam; brown (7.5YR 4/3) moist; null percent sand; null percent silt; 38 percent clay; strong medium subangular blocky structure; firm, very hard, moderately sticky, moderately plastic; many very fine roots throughout; common very fine vesicular low continuity pores; 18 percent (few) continuous prominent clay films on all faces of peds; slightly effervescent; Split at 46 cm.; gradual smooth boundary.

**Btss1** --- 66 to 89 centimeters; yellowish red (5YR 4/6) dry, clay; yellowish red (5YR 4/6) moist; null percent sand; null percent silt; 44 percent clay; strong medium prismatic parting to strong medium wedge structure; friable, very hard, very sticky, very plastic; moderately few very fine roots throughout; 12 percent (few) continuous distinct slickensides (pedogenic) on vertical faces of peds and 20 percent (few) continuous prominent clay films on all faces of peds; slightly effervescent; Split at 78 cm.; clear smooth boundary.

**Btss2** --- 89 to 114 centimeters; yellowish red (5YR 4/6) dry, clay; yellowish red (5YR 4/6) moist; null percent sand; null percent silt; 42 percent clay; strong medium prismatic parting to strong medium wedge structure; friable, very hard, very sticky, very plastic; moderately few very fine roots throughout; common very fine vesicular high continuity pores; 20 percent (few) continuous distinct slickensides (pedogenic) on vertical faces of peds and 20 percent (few) continuous prominent clay films on all faces of peds; 1 percent (few) medium distinct irregular non-cemented masses of carbonate with clear boundaries in matrix; slightly effervescent; Split at 101 cm.; gradual smooth boundary.

**Bty** --- 114 to 129 centimeters; yellowish red (5YR 4/6) dry, clay loam; yellowish red (5YR 4/6) moist; null percent sand; null percent silt; 39 percent clay; moderate medium prismatic structure; friable, hard, moderately sticky, moderately plastic; moderately few very fine roots throughout; common very fine vesicular low continuity pores; 15 percent (few) discontinuous distinct clay films on all faces of peds; 3 percent (common) fine distinct irregular non-cemented gypsum crystals with clear boundaries in matrix; slightly effervescent; clear smooth boundary.

**BCky** --- 129 to 163 centimeters; yellowish red (5YR 5/6) dry, sandy clay loam; yellowish red (5YR 5/6) moist; null percent sand; null percent silt; 23 percent clay; massive parting to moderate medium subangular blocky; friable, moderately hard, slightly sticky, slightly plastic; moderately few very fine roots throughout; common very fine vesicular high continuity pores; 1 percent (few) fine distinct irregular non-cemented masses of carbonate with clear boundaries in matrix and 1 percent (few) fine distinct irregular non-cemented gypsum crystals with clear boundaries in matrix; strongly effervescent; Split at 146 cm.; clear smooth boundary.

**Cy1** --- 163 to 208 centimeters; yellowish red (5YR 5/8) dry, sandy clay loam; yellowish red (5YR 5/6) moist; null percent sand; null percent silt; 24 percent clay; massive; moderately few very fine roots throughout; very slightly effervescent; Split at 185 cm; gradual smooth boundary.

**Cy2** --- 208 to 252 centimeters; yellowish red (5YR 5/6) dry, sandy clay loam; yellowish red (5YR 4/6) moist; null percent sand; null percent silt; 26 percent clay; massive; moderately few very fine roots throughout; very slightly effervescent; Split at 230 cm; abrupt smooth boundary.

**2Cy3** --- 252 to 268 centimeters; yellowish red (5YR 5/6) dry, sandy clay loam; yellowish red (5YR 4/6) moist; null percent sand; null percent silt; 21 percent clay; massive; slightly effervescent; clear smooth boundary.

**3Cy4** --- 268 to 302 centimeters; 80 percent dark reddish brown (5YR 3/4) dry and 20 percent pinkish white (5YR 8/2) dry, clay loam; 80 percent dark reddish brown (5YR 3/3) moist; slightly effervescent; abrupt smooth boundary.

**3Cy5** --- 302 to 362 centimeters; 80 percent dark reddish brown (5YR 3/4) dry and 20 percent pinkish white (5YR 8/2) dry, clay loam; 80 percent dark reddish brown (5YR 3/3) moist and 20 percent dark reddish brown (5YR 3/4) moist; slightly effervescent.

**Remarks:**

**Soil description at site S5**
**Soil Series:** Sagerton
**Soil Classification:** Fine, mixed, superactive, thermic Typic Argiustolls
**Location:** Nolan County, TX. Lat 32°31'3.75" north; Long 100°28'31.488" west
**Slope:** 1%
**Parent material:** Calcareous loamy alluvium
**Dominant vegetation:** Shrub cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 1/12/2009

**A** --- 0 to 25 centimeters; brown (7.5YR 4/3) dry, clay loam; dark brown (7.5YR 3/3) moist; null percent sand; null percent silt; 32 percent clay; strong medium subangular blocky structure; very firm, hard, moderately sticky, moderately plastic; common very fine roots throughout and common fine roots throughout; common fine pores; non-effervescent; clear smooth boundary.

**Bt1** --- 25 to 44 centimeters; brown (7.5YR 4/3) dry, clay; dark brown (7.5YR 3/3) moist; null percent sand; null percent silt; 41 percent clay; strong fine and medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; many very fine roots throughout; common coarse vesicular low continuity pores; 15 percent (few) continuous prominent clay films on all faces of peds; slightly effervescent; gradual smooth boundary.

**Bt2** --- 44 to 66 centimeters; reddish brown (5YR 5/4) dry, clay loam; dark reddish brown (5YR 3/4) moist; null percent sand; null percent silt; 36 percent clay; strong medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; common fine roots throughout and many very fine roots throughout; common coarse pores; 18 percent (few) continuous prominent clay films on all faces of peds; strongly effervescent; gradual smooth boundary.

**Btk1** --- 66 to 85 centimeters; reddish brown (5YR 4/4) dry, clay loam; reddish brown (5YR 4/3) moist; null percent sand; null percent silt; 39 percent clay; strong medium subangular blocky structure; very firm, hard, very sticky, very plastic; common very fine roots throughout; common coarse vesicular high continuity pores; 18 percent (few) continuous prominent clay films on all faces of peds; 3 percent (common) medium distinct irregular non-cemented masses of carbonate with clear boundaries in matrix; violently effervescent; Split at 101 cm.; clear smooth boundary.

**Btk2** --- 85 to 126 centimeters; dark reddish brown (5YR 3/3) dry, clay loam; dark reddish brown (5YR 3/2) moist; null percent sand; null percent silt; 38 percent clay; strong medium prismatic parting to strong medium subangular blocky structure; very firm, hard, very sticky, very plastic; common fine roots throughout and common very fine roots throughout; many fine and common coarse vesicular low continuity pores; 18

percent (few) discontinuous distinct clay films on all faces of peds; 4 percent (common) medium distinct irregular non-cemented masses of carbonate with clear boundaries in matrix; 5 percent non-flat subrounded indurated 2 to 35 millimeters limestone fragments; strongly effervescent; clear smooth boundary.

**Btk3** --- 126 to 152 centimeters; reddish brown (5YR 4/4) dry, clay; dark reddish brown (5YR 3/4) moist; null percent sand; null percent silt; 41 percent clay; strong medium prismatic parting to strong medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; common fine roots throughout and common very fine roots throughout; many fine and common coarse vesicular high continuity pores; 15 percent (few) discontinuous distinct clay films on all faces of peds; 5 percent (common) fine distinct irregular non-cemented masses of carbonate with clear boundaries in matrix and; 2 percent non-flat subrounded indurated 2 to 35 millimeters limestone fragments; strongly effervescent; Split at 146 cm.; clear smooth boundary.

**Btky1** --- 152 to 188 centimeters; 90 percent reddish brown (5YR 4/3) dry and 10 percent pinkish white (5YR 8/2) dry, clay; 90 percent dark reddish brown (5YR 3/3) moist and 10 percent pinkish white (5YR 8/2) moist; null percent sand; null percent silt; 42 percent clay; strong medium prismatic parting to strong medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; common fine roots throughout and common very fine roots throughout; many fine and common coarse pores; 15 percent (few) discontinuous distinct clay films on all faces of peds; 5 percent (common) fine distinct irregular non-cemented gypsum crystals with clear boundaries on faces of peds and 4 percent (common) fine distinct irregular non-cemented masses of carbonate with clear boundaries in matrix; 2 percent non-flat subrounded indurated 2 to 35 millimeters limestone fragments; strongly effervescent; Split at 185 cm.; clear smooth boundary.

**Btky2** --- 188 to 249 centimeters; 80 percent reddish brown (5YR 4/3) dry and 20 percent pinkish white (5YR 8/2) dry, clay; 80 percent dark reddish brown (5YR 3/3) moist and 20 percent pinkish white (5YR 8/2) moist; null percent sand; null percent silt; 48 percent clay; strong medium prismatic parting to strong medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; common very fine roots throughout; common fine pores; 18 percent (few) discontinuous distinct clay films on all faces of peds; 8 percent (common) fine distinct irregular non-cemented gypsum crystals with clear boundaries on faces of peds and 4 percent (common) fine distinct irregular non-cemented masses of carbonate with clear boundaries in matrix; 2 percent non-flat subrounded indurated 2 to 35 millimeters limestone fragments; slightly effervescent; Split at 230 cm.; clear smooth boundary.

**Btky3** --- 249 to 291 centimeters; 80 percent reddish brown (5YR 5/4) dry and 20 percent pinkish white (5YR 8/2) dry, clay; 80 percent reddish brown (5YR 4/3) moist and 20 percent pinkish white (5YR 8/2) moist; null percent sand; null percent silt; 51 percent clay; strong medium prismatic parting to strong medium subangular blocky structure; firm, moderately hard, very sticky, very plastic; common very fine roots throughout; common coarse and common fine pores; 18 percent (few) discontinuous distinct clay films on all faces of peds; 4 percent (common) fine distinct irregular non-cemented gypsum crystals with clear boundaries in matrix and 4 percent (common) fine distinct irregular non-cemented masses of carbonate with clear boundaries in matrix; 2 percent non-flat subrounded indurated 2 to 35 millimeters limestone fragments; strongly effervescent; clear smooth boundary.

**Cy1** --- 291 to 322 centimeters; 70 percent reddish brown (5YR 5/4) dry and 30 percent pinkish white (5YR 8/2) dry, clay; 70 percent reddish brown (5YR 5/4) moist and 30 percent pinkish white (5YR 8/2) moist; massive; 20 percent (many) fine prominent irregular non-cemented gypsum crystals with diffuse boundaries in matrix; violently effervescent; abrupt smooth boundary.

**Cy2** --- 322 to 350 centimeters; 50 percent white (5YR 8/1) dry and 50 percent reddish brown (5YR 5/4) dry, clay; 50 percent white (5YR 8/1) moist and 50 percent reddish brown (5YR 5/4) moist; massive; 50 percent (many) fine prominent irregular non-cemented gypsum crystals with diffuse boundaries in matrix; violently effervescent.

**Remarks:**

**Soil description at site G6**
**Soil Series:** Rotan
**Soil Classification:** Fine, mixed, superactive, thermic Pachic Paleustolls
**Location:** Taylor County, TX. Lat 32°24’59.706” north; Long 99°37’54.216” west
**Slope:** 1%
**Parent material:** Calcareous loamy alluvium of Quaternary age
**Dominant vegetation:** Grass/herbaceous cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 1/13/2009

**Ap1** --- 0 to 13 centimeters; very dark grayish brown (10YR 3/2) dry, clay; very dark brown (10YR 2/2) moist; null percent sand; null percent silt; 48 percent clay; strong medium subangular blocky structure; firm, moderately hard; common fine roots throughout and common very fine roots throughout; common very fine vesicular moderate continuity pores; 3 percent limestone fragments; very slightly effervescent; gradual smooth boundary.

**Ap2** --- 13 to 30 centimeters; very dark grayish brown (10YR 3/2) dry, clay; very dark brown (10YR 2/2) moist; null percent sand; null percent silt; 41 percent clay; moderate medium subangular blocky structure; firm, moderately hard; common fine roots throughout and common very fine roots throughout; common very fine vesicular moderate continuity pores; 2 percent limestone fragments and 2 percent quartzite fragments; slightly effervescent; clear smooth boundary.

**Bt1** --- 30 to 73 centimeters; brown (7.5YR 4/3) dry, clay; brown (7.5YR 4/3) moist; null percent sand; null percent silt; 42 percent clay; moderate medium prismatic parting to moderate medium subangular blocky structure; friable, moderately hard; common fine roots throughout and common very fine roots throughout; 15 percent (few) discontinuous distinct clay films on vertical faces of peds; 3 percent limestone fragments; non-effervescent; clear smooth boundary.

**Bt2** --- 73 to 93 centimeters; brown (7.5YR 4/3) dry, clay; brown (7.5YR 4/3) moist; null percent sand; null percent silt; 45 percent clay; strong medium prismatic parting to strong medium angular blocky structure; firm, hard; common very fine roots throughout; common very fine vesicular moderate continuity pores; 15 percent (few) discontinuous distinct clay films on vertical faces of peds; 3 percent quartzite fragments; very slightly effervescent; abrupt smooth boundary.

**Bk1** --- 93 to 110 centimeters; brown (7.5YR 5/3) dry, clay; brown (7.5YR 4/3) moist; null percent sand; null percent silt; 45 percent clay; weak coarse subangular blocky structure; very friable, slightly hard; common fine roots throughout and common very fine roots throughout; common very fine vesicular moderate continuity pores; 10 percent (common) medium distinct irregular non-cemented masses of carbonate with clear boundaries throughout; 1 percent quartzite fragments; strongly effervescent; Split at; abrupt smooth boundary.

**Bk2** --- 110 to 128 centimeters; reddish yellow (7.5YR 7/6) dry, clay loam; reddish yellow (7.5YR 7/8) moist; null percent sand; null percent silt; 38 percent clay; weak medium subangular blocky structure; very friable, slightly hard; common fine roots throughout; common very fine vesicular moderate continuity pores; 15 percent (common) fine distinct non-cemented finely disseminated carbonates with sharp boundaries throughout and 10 percent (common) medium distinct irregular non-cemented masses of carbonate with sharp boundaries throughout; 4 percent limestone fragments; strongly effervescent; abrupt smooth boundary.

**Btk1** --- 128 to 152 centimeters; 70 percent reddish yellow (5YR 6/8) dry and 30 percent reddish brown (5YR 4/3) dry, clay loam; 70 percent reddish yellow (5YR 6/6) moist and 30 percent dark reddish brown (5YR 3/3) moist; null percent sand; null percent silt; 38 percent clay; weak coarse subangular blocky structure; very friable, slightly hard; common very fine roots throughout; 13 percent (few) discontinuous distinct clay films on vertical faces of peds; 16 percent (common) medium distinct irregular non-cemented masses of carbonate with sharp boundaries throughout; 5 percent limestone fragments; strongly effervescent; clear smooth boundary.

**Btk2** --- 152 to 187 centimeters; reddish yellow (5YR 6/8) dry, clay loam; reddish yellow (5YR 6/6) moist; null percent sand; null percent silt; 36 percent clay; moderate medium prismatic parting to moderate medium subangular blocky structure; very friable, slightly hard; common very fine roots throughout; common very fine vesicular moderate continuity pores; 10 percent (few) discontinuous distinct clay films on vertical faces of peds; 16 percent (common) medium distinct irregular non-cemented masses of carbonate with sharp boundaries throughout; 2 percent limestone fragments; strongly effervescent; clear smooth boundary.

**Btk3** --- 187 to 244 centimeters; yellowish red (5YR 5/8) dry, clay; yellowish red (5YR 5/6) moist; null percent sand; null percent silt; 48 percent clay; weak medium subangular blocky structure; friable, hard; common very fine vesicular moderate continuity pores; 10 percent (few) discontinuous distinct clay films on vertical faces of peds; 7 percent (common) fine distinct irregular non-cemented masses of carbonate with clear boundaries throughout; 3 percent quartzite fragments and 3 percent limestone fragments; strongly effervescent; gradual smooth boundary.

**BC** --- 244 to 279 centimeters; yellowish red (5YR 5/8) dry, clay; yellowish red (5YR 5/6) moist; null percent sand; null percent silt; 50 percent clay; weak medium angular blocky structure; friable, hard; common very fine vesicular moderate continuity pores; 3 percent quartzite fragments and 3 percent limestone fragments; slightly effervescent; fine angular rock structure; abrupt smooth boundary.

**C** --- 279 to 330 centimeters; 50 percent reddish yellow (7.5YR 7/6) dry, 45 percent reddish yellow (5YR 7/6) dry and 5 percent greenish gray (5GY 6/1) dry, clay; 50 percent reddish yellow (7.5YR 6/6) moist, 45 percent reddish yellow (5YR 6/6) moist and 5 percent greenish gray (5GY 6/1) moist; null percent sand; null percent silt; 50 percent clay; massive; firm, very hard; 5 percent limestone fragments; strongly effervescent; fine angular rock structure.

**Remarks:**

**Soil description at site G7**
**Soil Series:** Hamby
**Soil Classification:** Fine, mixed, active, thermic Typic Paleustalfs
**Location:** Taylor County, TX. Lat 32°10'32.7" north; Long 99°52'14.2" west
**Slope:** 2%
**Parent material:** Loamy and clayey residuum from cretaceous sediments
**Dominant vegetation:** Grass/herbaceous cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 5/26/2009

**Ap** --- 0 to 15 centimeters; dark brown (7.5YR 3/2) dry, loamy fine sand; dark brown (7.5YR 3/3) moist; 83 percent sand; null percent silt; 11 percent clay; weak fine granular structure; friable, slightly hard; common very fine roots and common fine roots; common fine pores; non-effervescent by HCl, 1 normal; clear smooth boundary.

**A** --- 15 to 24 centimeters; brown (7.5YR 4/3) dry, loamy fine sand; brown (7.5YR 4/3) moist; 84 percent sand; null percent silt; 13 percent clay; weak medium granular structure; friable, slightly hard; common very fine roots and common fine roots; common very fine pores; non-effervescent by HCl, 1 normal; abrupt smooth boundary.

**E** --- 21 to 40 centimeters; light brown (7.5YR 6/3) dry, sand; brown (7.5YR 5/3) moist; 89 percent sand; null percent silt; 9 percent clay; moderate medium subangular blocky structure; loose, slightly hard; common very fine roots and common fine roots; common very fine and common fine pores; non-effervescent by HCl, 1 normal; abrupt smooth boundary.

**Bt1** --- 40 to 59 centimeters; strong brown (7.5YR 4/6) dry, clay; strong brown (7.5YR 4/6) moist; 14 percent sand; null percent silt; 47 percent clay red (10R 4/8) and 10 percent red (10R 4/8) mottles; strong medium prismatic structure; very firm, hard; common very fine roots; 25 percent (common) clay films on all faces of peds; 10 percent (common) medium distinct irregular non-cemented masses of oxidized iron clear in matrix; non-effervescent by HCl, 1 normal; clear smooth boundary.

**Bt2** --- 59 to 84 centimeters; brown (7.5YR 5/3) dry, sandy clay; brown (7.5YR 4/3) moist; 46 percent sand; null percent silt; 43 percent clay red (10R 4/6) and 5 percent red (10R 4/6) mottles; strong medium prismatic structure; very firm, hard; common very fine roots; 10 percent (few) clay films on all faces of peds; 5 percent (common) medium distinct irregular non-cemented masses of oxidized iron clear in matrix; non-effervescent by HCl, 1 normal; clear smooth boundary.

**Bt3** --- 84 to 113 centimeters; dark gray (7.5YR 4/1) dry, sandy clay; very dark gray (7.5YR 3/1) moist; 47 percent sand; null percent silt; 48 percent clay red (10R 4/6) and 5 percent red (10R 5/6) mottles; strong medium prismatic structure; very firm, hard;

common very fine roots; 10 percent (few) clay films on all faces of peds; 5 percent (common) medium distinct irregular non-cemented masses of oxidized iron clear in matrix; non-effervescent by HCl, 1 normal; clear smooth boundary.

**BC** --- 113 to 159 centimeters; gray (10YR 6/1) dry, sandy clay; gray (10YR 5/1) moist; 56 percent sand; null percent silt; 48 percent clay red (10R 4/6) and 5 percent red (10R 5/6) mottles; strong medium prismatic structure; very firm, hard; common very fine roots; 5 percent (common) medium distinct irregular non-cemented masses of oxidized iron clear in matrix; non-effervescent by HCl, 1 normal; abrupt smooth boundary.

**C** --- 159 to 230 centimeters; gray (10YR 6/1) dry, clay; gray (10YR 5/1) moist; 30 percent sand; null percent silt; 38 percent clay; strong fine prismatic structure; very firm, hard; slightly effervescent by HCl, 1 normal.

**Remarks:**

**Soil description at site S8**
**Soil Series:** Hamby
**Soil Classification:** Fine, mixed, active, thermic Typic Paleustalfs
**Location:** Taylor County, TX. Lat 32°10’38.3” north; Long 99°52’8.1” west
**Slope:** 2%
**Parent material:** Loamy and clayey residuum from cretaceous sediments
**Dominant vegetation:** Shrub cover
**Described and sampled by:** William Shoup, Riley Dayberry, Jo Parsley, C.T. Hallmark, and Ronald Navarrete
**Description date:** 5/26/2009

**A** --- 0 to 12 centimeters; brown (7.5YR 5/3) dry, fine sandy loam; brown (7.5YR 4/3) moist; 72 percent sand; null percent silt; 5 percent clay; weak fine subangular blocky structure; very friable, soft; common fine roots; common very fine pores; non-effervescent by HCl, 1 normal; abrupt smooth boundary.

**E** --- 12 to 28 centimeters; light brown (7.5YR 6/4) dry, loamy sand; brown (7.5YR 5/4) moist; 77 percent sand; null percent silt; 3 percent clay; weak medium subangular blocky structure; very firm, hard; common very fine roots; common very fine pores; non-effervescent by HCl, 1 normal; abrupt smooth boundary.

**Btss1** --- 28 to 58 centimeters; reddish brown (2.5YR 4/4) dry, clay; reddish brown (2.5YR 4/4) moist; 20 percent sand; null percent silt; 48 percent clay; moderate prismatic and strong coarse prismatic structure; very firm, hard; common fine roots and common medium roots; common very fine pores; 30 percent (common) continuous prominent slickensides (pedogenic) on all faces of peds and 60 percent (many) continuous prominent clay films on all faces of peds; non-effervescent by HCl, 1 normal; clear smooth boundary.

**Btss2** --- 58 to 85 centimeters; 80 percent reddish brown (2.5YR 4/4) dry and 20 percent red (2.5YR 5/6) dry, clay; 80 percent reddish brown (2.5YR 4/4) moist and 20 percent red (2.5YR 4/6) moist; 34 percent sand; null percent silt; 49 percent clay; moderate prismatic and strong coarse prismatic structure; firm, moderately hard; common medium roots and common coarse roots; common very fine pores; 15 percent (few) continuous prominent slickensides (pedogenic) on all faces of peds and 70 percent (many) continuous distinct clay films on all faces of peds; non-effervescent by HCl, 1 normal; clear smooth boundary.

**Bt1** --- 85 to 113 centimeters; 70 percent reddish brown (2.5YR 4/4) dry and 30 percent red (2.5YR 5/6) dry, clay; 70 percent reddish brown (2.5YR 4/4) moist and 30 percent red (2.5YR 4/6) moist; 38 percent sand; null percent silt; 41 percent clay; moderate prismatic and strong coarse prismatic structure; firm, moderately hard; common fine roots and common coarse roots; common very fine pores; 60 percent (many) clay films on all faces of peds; non-effervescent by HCl, 1 normal; clear smooth boundary.

**Bt2** --- 113 to 175 centimeters; 50 percent reddish yellow (5YR 6/6) dry and 50 percent yellowish red (5YR 4/6) dry, sandy clay; 50 percent reddish yellow (5YR 6/6) moist and 50 percent yellowish red (5YR 4/6) moist; 53 percent sand; null percent silt; 36 percent clay; moderate medium subangular blocky and moderate medium prismatic structure; firm, moderately hard; common medium roots and common fine roots; common fine pores; 45 percent (common) clay films on all faces of peds; non-effervescent by HCl, 1 normal; abrupt smooth boundary.

**BC** --- 175 to 218 centimeters; reddish yellow (7.5YR 7/6) dry, sandy clay; reddish yellow (7.5YR 6/6) moist; 86 percent sand; null percent silt; 5 percent clay; weak fine subangular blocky structure; firm, moderately hard; common very fine roots; common fine pores; non-effervescent by HCl, 1 normal.

**Remarks:**

# APPENDIX B

## SOIL CHLORIDE, BROMIDE, AND SULFATE EXTRACTION DATA

### Site S1, S08TX441-101

| | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm | | mg/L | | g | ml | g/g | $g/cm^3$ |
| 7348 | 35 | 7.7072 | 0.0000 | 2.5312 | 10.23 | 20.02 | 0.10 | 1.50 |
| 7349 | 60 | 9.9271 | 0.0000 | 4.1904 | 10.42 | 20.01 | 0.10 | 1.55 |
| 7350 | 88 | 65.1574 | 0.2036 | 11.2381 | 10.04 | 20.06 | 0.09 | 1.55 |
| 7351 | 121 | 305.7319 | 0.8693 | 72.6369 | 10.30 | 20.05 | 0.10 | 1.57 |
| 7352 | 155 | 418.1859 | 1.1151 | 217.7607 | 10.00 | 20.00 | 0.11 | 1.53 |
| 7353 | 195 | 469.5054 | 1.2365 | 411.2101 | 10.15 | 20.04 | 0.13 | 1.45 |
| 7354 | 235 | 575.6445 | 1.6863 | 556.2434 | 10.30 | 20.02 | 0.16 | 1.42 |
| 7355 | 266 | 555.5749 | 1.6844 | 1540.5086 | 10.17 | 20.10 | 0.14 | 1.46 |
| 7356 | 291 | 417.4116 | 1.2008 | 858.2264 | 10.10 | 20.03 | 0.09 | 1.55 |
| 7357 | 316 | 478.5022 | 1.2490 | 257.0115 | 10.33 | 20.07 | 0.13 | 1.52 |
| 7358 | 339 | 516.6602 | 1.3725 | 513.8628 | 10.06 | 20.00 | 0.13 | 1.49 |
| 7359 | 363 | 484.9345 | 1.3500 | 408.2536 | 10.26 | 20.00 | 0.12 | 1.58 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

### Site G2, S08TX441-102

| | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | (cm) | | mg/L | | g | ml | g/g | $g/cm^3$ |
| 7360 | 10 | 8.0567 | 2.6605 | 3.9423 | 10.33 | 20.01 | 0.06 | 1.23 |
| 7361 | 33 | 3.7288 | 0.0692 | 2.8032 | 10.34 | 20.13 | 0.12 | 1.36 |
| 7362 | 53 | 4.8017 | 0.0996 | 2.0935 | 10.16 | 20.00 | 0.10 | 1.47 |
| 7363 | 80 | 2.2814 | 0.0983 | 2.6594 | 10.31 | 20.06 | 0.10 | 1.53 |
| 7364 | 108 | 1.7472 | 0.0855 | 6.2739 | 10.16 | 20.06 | 0.10 | 1.55 |
| 7365 | 141 | 2.6694 | 0.0000 | 9.7612 | 10.05 | 20.07 | 0.11 | 1.62 |
| 7366 | 175 | 6.3852 | 0.0000 | 37.5782 | 10.49 | 20.03 | 0.11 | 1.59 |
| 7367 | 203 | 22.8334 | 0.0000 | 64.0896 | 10.15 | 20.04 | 0.10 | 1.53 |
| 7368 | 227 | 37.5469 | 0.1541 | 142.6862 | 10.18 | 20.08 | 0.12 | 1.58 |
| 7369 | 250 | 47.0478 | 0.1720 | 166.8451 | 10.03 | 20.10 | 0.09 | 1.66 |
| 7370 | 275 | 44.2626 | 0.1693 | 174.6474 | 10.28 | 20.12 | 0.09 | 1.67 |
| 7371 | 300 | 43.4197 | 0.1750 | 90.7075 | 10.48 | 20.01 | 0.06 | 1.69 |
| 7372 | 375 | 55.8929 | 0.2570 | 190.5787 | 10.09 | 20.15 | 0.12 | 1.69 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

**Site S3, S08TX441-103**

| | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm | | mg/L | | g | ml | g/g | g/cm$^3$ |
| 7373 | 10 | 2.3456 | 0.0000 | 2.0482 | 10.18 | 20.21 | 0.05 | 1.34 |
| 7374 | 28 | 3.0627 | 0.0000 | 1.7594 | 10.01 | 20.01 | 0.07 | 1.29 |
| 7375 | 44 | 4.1446 | 0.1024 | 2.0295 | 10.22 | 20.01 | 0.08 | 1.37 |
| 7376 | 60 | 3.0160 | 0.1095 | 2.1815 | 10.10 | 20.01 | 0.09 | 1.40 |
| 7377 | 80 | 3.3735 | 0.1031 | 1.6695 | 10.00 | 20.06 | 0.10 | 1.44 |
| 7378 | 100 | 2.4777 | 0.0974 | 5.3050 | 10.01 | 20.01 | 0.11 | 1.46 |
| 7379 | 118 | 2.2699 | 0.0000 | 10.8416 | 10.19 | 20.03 | 0.12 | 1.39 |
| 7380 | 136 | 2.4191 | 0.0000 | 11.0743 | 10.22 | 20.03 | 0.11 | 1.48 |
| 7381 | 158 | 3.0875 | 0.0000 | 9.5234 | 10.17 | 20.01 | 0.11 | 1.51 |
| 7382 | 179 | 3.2192 | 0.0000 | 22.7812 | 10.30 | 20.07 | 0.10 | 1.49 |
| 7383 | 210 | 3.1773 | 0.0000 | 26.0895 | 10.07 | 20.23 | 0.08 | 1.48 |
| 7384 | 240 | 1.9418 | 0.0000 | 20.1107 | 10.11 | 20.09 | 0.10 | 1.49 |
| 7385 | 270 | 1.6569 | 0.0000 | 12.5069 | 10.30 | 20.20 | 0.06 | 1.55 |
| 7386 | 300 | 1.6612 | 0.0000 | 8.2453 | 10.01 | 20.72 | 0.07 | 1.62 |
| 7387 | 335 | 2.3010 | 0.0000 | 7.0194 | 10.04 | 20.82 | 0.08 | 1.66 |
| 7388 | 370 | 2.5754 | 0.0000 | 11.4811 | 10.14 | 20.06 | 0.10 | 1.66 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

**Site G4, S09TX353-101**

| | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm | | mg/L | | g | ml | g/g | g/cm$^3$ |
| 7462 | 15 | 3.4135 | 0.0000 | 12.0956 | 10.12 | 20.03 | 0.04 | 1.39 |
| 7463 | 31 | 10.0091 | 0.0000 | 15.7492 | 10.03 | 20.03 | 0.09 | 1.36 |
| 7464 | 46 | 74.0908 | 0.3295 | 17.5689 | 10.13 | 20.06 | 0.09 | 1.43 |
| 7465 | 66 | 221.1108 | 1.2396 | 21.7130 | 10.27 | 20.70 | 0.08 | 1.43 |
| 7466 | 89 | 347.0957 | 2.1714 | 50.2565 | 10.24 | 20.10 | 0.10 | 1.46 |
| 7467 | 114 | 432.3317 | 2.4974 | | 10.30 | 20.01 | 0.11 | 1.45 |
| 7468 | 129 | 299.2446 | 1.3967 | 1247.0166 | 10.16 | 20.01 | 0.05 | 1.43 |
| 7469 | 163 | 257.3561 | 1.1968 | 2725.9270 | 10.15 | 20.02 | 0.08 | 1.38 |
| 7470 | 185 | 226.6511 | 1.0167 | 2565.7634 | 10.24 | 20.00 | 0.10 | 1.35 |
| 7471 | 208 | 177.2327 | 0.8054 | 2409.0032 | 10.08 | 20.08 | 0.06 | 1.41 |
| 7472 | 230 | 152.5550 | 0.6288 | 2313.3360 | 10.29 | 20.00 | 0.02 | 1.43 |
| 7473 | 252 | 106.7487 | 0.6341 | 2323.1353 | 10.03 | 20.09 | 0.05 | 1.44 |
| 7474 | 282 | 168.2198 | 0.7483 | 2909.3853 | 10.00 | 20.13 | 0.08 | 1.42 |
| 7475 | 302 | 202.3524 | 0.9383 | 3260.6923 | 10.32 | 20.07 | 0.16 | 1.39 |
| 7476 | 322 | 163.9498 | 0.9454 | 3199.3126 | 10.17 | 20.06 | 0.15 | 1.43 |
| 7477 | 342 | 138.8982 | 0.8175 | 3285.5622 | 10.08 | 20.05 | 0.14 | 1.41 |
| 7478 | 362 | 118.1418 | 0.6785 | 3129.1038 | 10.29 | 20.03 | 0.14 | 1.46 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

## Site S5, S09TX353-102

| | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm | | mg/L | | g | ml | g/g | g/cm$^3$ |
| 7479 | 25 | 8.8467 | 0.0000 | 247.8202 | 10.14 | 20.04 | 0.07 | 1.33 |
| 7480 | 44 | 9.9683 | 0.0000 | 270.6419 | 10.16 | 20.18 | 0.09 | 1.34 |
| 7481 | 66 | 57.0687 | 0.1799 | 1005.3943 | 10.10 | 20.03 | 0.08 | 1.43 |
| 7482 | 85 | 126.3954 | 0.5274 | 930.4931 | 10.20 | 20.17 | 0.09 | 1.47 |
| 7483 | 106 | 144.7820 | 0.6502 | 2612.9600 | 10.34 | 20.00 | 0.09 | 1.47 |
| 7484 | 126 | 161.9698 | 0.7256 | 3264.3200 | 10.19 | 20.03 | 0.10 | 1.46 |
| 7485 | 152 | 232.3805 | 1.0066 | 4367.8308 | 10.23 | 20.09 | 0.10 | 1.46 |
| 7486 | 188 | 271.6276 | 1.1798 | 2634.4948 | 10.06 | 20.77 | 0.13 | 1.41 |
| 7487 | 218 | 315.1993 | 1.1359 | 3237.1448 | 10.09 | 20.03 | 0.14 | 1.43 |
| 7488 | 249 | 281.1001 | 0.9503 | 3208.7213 | 10.27 | 20.04 | 0.14 | 1.43 |
| 7489 | 291 | 271.0070 | 0.8823 | 3203.4765 | 10.34 | 20.27 | 0.16 | 1.37 |
| 7490 | 322 | 285.9862 | 1.0834 | 3140.3482 | 10.32 | 20.05 | 0.22 | 1.37 |
| 7491 | 350 | 258.5329 | 0.9669 | 2934.4459 | 10.26 | 20.67 | 0.26 | 1.23 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

## Site G6, S09TX441-104

| | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm | | mg/L | | g | ml | g/g | g/cm$^3$ |
| 7492 | 13 | 5.4791 | 0.0000 | 52.7672 | 10.29 | 20.23 | 0.09 | 1.16 |
| 7493 | 30 | 4.5617 | 0.0000 | 26.4917 | 10.20 | 20.01 | 0.17 | 1.22 |
| 7494 | 73 | 5.6659 | 0.0000 | 11.0245 | 10.38 | 20.20 | 0.20 | 1.34 |
| 7495 | 93 | 5.0117 | 0.0000 | 11.4054 | 10.26 | 20.36 | 0.16 | 1.38 |
| 7496 | 110 | 5.1345 | 0.0000 | 10.6918 | 10.17 | 20.72 | 0.14 | 1.24 |
| 7497 | 128 | 3.6073 | 0.0000 | 7.3438 | 10.22 | 20.41 | 0.14 | 1.19 |
| 7498 | 152 | 3.2925 | 0.0000 | 8.3951 | 10.28 | 20.01 | 0.13 | 1.20 |
| 7499 | 187 | 2.1278 | 0.0000 | 13.5253 | 10.28 | 20.21 | 0.13 | 1.51 |
| 7500 | 215 | 2.6017 | 0.0000 | 17.3349 | 10.36 | 20.58 | 0.14 | 1.49 |
| 7501 | 244 | 3.1981 | 0.0000 | 14.9167 | 10.35 | 20.16 | 0.12 | 1.52 |
| 7502 | 279 | 4.6811 | 0.0000 | 16.9053 | 10.29 | 20.09 | 0.13 | 1.60 |
| 7503 | 310 | 9.3183 | 0.0000 | 24.8732 | 10.33 | 20.07 | 0.10 | 1.62 |
| 7504 | 330 | 13.4749 | 0.0000 | 27.1755 | 10.08 | 20.01 | 0.14 | 1.67 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

**Site G7, S09TX441-3041**

|  | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm |  | mg/L |  | g | ml | g/g | $g/cm^3$ |
| 7603 | 15 | 9.0257 | 0.0000 | 5.6097 | 10.00 | 20.01 | 0.06 | 1.50 |
| 7604 | 21 | 7.3301 | 0.0000 | 4.3036 | 10.00 | 20.21 | 0.03 | 1.48 |
| 7605 | 40 | 7.6919 | 0.0000 | 2.9952 | 10.00 | 20.04 | 0.01 | 1.57 |
| 7606 | 59 | 4.4703 | 0.0000 | 3.9518 | 10.00 | 20.02 | 0.09 | 1.50 |
| 7607 | 84 | 2.3358 | 0.0000 | 3.4824 | 10.01 | 20.02 | 0.08 | 1.43 |
| 7608 | 98 | 1.9278 | 0.0000 | 4.7824 | 10.00 | 20.20 | 0.07 | 1.59 |
| 7609 | 113 | 3.1367 | 0.0000 | 8.8007 | 10.01 | 20.32 | 0.07 | 1.65 |
| 7610 | 135 | 2.9076 | 0.0000 | 8.0488 | 10.01 | 20.35 | 0.08 | 1.71 |
| 7611 | 159 | 6.6925 | 0.0000 | 6.6227 | 10.00 | 20.07 | 0.06 | 1.74 |
| 7612 | 180 | 6.3335 | 0.0000 | 10.3241 | 10.01 | 20.03 | 0.07 | 1.67 |
| 7613 | 205 | 5.5586 | 0.0000 | 22.8528 | 10.00 | 20.54 | 0.08 | 1.55 |
| 7614 | 230 | 8.5663 | 0.0000 | 23.9264 | 10.00 | 20.05 | 0.09 | 1.56 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

**Site S8, S09TX441-3042**

|  | Depth | $Cl^-$ | $Br^-$ | $SO_4^{-2}$ | Soil weight | Water | WC* | BD** |
|---|---|---|---|---|---|---|---|---|
| Sample ID | cm |  | mg/L |  | g | ml | g/g | $g/cm^3$ |
| 7615 | 12 | 5.8229 | 0.0000 | 2.7596 | 10.01 | 20.07 | 0.08 | 1.49 |
| 7616 | 28 | 4.3084 | 0.0000 | 2.0189 | 10.01 | 20.13 | 0.05 | 1.49 |
| 7617 | 43 | 5.9844 | 0.0000 | 3.8050 | 10.00 | 20.11 | 0.15 | 1.45 |
| 7618 | 58 | 4.9662 | 0.0000 | 4.6239 | 10.00 | 20.19 | 0.13 | 1.41 |
| 7619 | 85 | 4.4312 | 0.0000 | 6.4225 | 10.01 | 20.03 | 0.11 | 1.49 |
| 7620 | 113 | 5.8461 | 0.0000 | 10.5425 | 10.00 | 20.01 | 0.09 | 1.56 |
| 7621 | 138 | 14.0254 | 0.1638 | 17.3937 | 10.01 | 20.11 | 0.07 | 1.59 |
| 7622 | 165 | 30.8352 | 0.3148 | 22.2812 | 10.01 | 20.11 | 0.08 | 1.59 |
| 7623 | 175 | 45.4931 | 0.5095 | 25.6967 | 10.01 | 20.02 | 0.06 | 1.57 |
| 7624 | 197 | 50.7467 | 0.5436 | 19.7177 | 10.01 | 20.01 | 0.04 | 1.55 |
| 7625 | 218 | 59.6593 | 0.5560 | 15.0311 | 10.02 | 20.04 | 0.04 | 1.59 |

* Water content: g of water per g of oven dried soil.

** Bulk density at 1/3 bar.

# APPENDIX C

## PLANT TISSUE CHLORIDE EXTRACTION DATA

| **Sample ID** | **$Cl^-$** | | **Water** | **Sample wt** | **$Cl^-$** |
|---|---|---|---|---|---|
| | **mg/L** | **mg/ml** | **ml** | **mg** | **mg/Kg** |
| Tree A, #1 | 11.847 | 0.0118 | 10 | 150 | 790 |
| Tree A, #2 | 34.811 | 0.0348 | 10 | 150 | 2321 |
| Tree A, #3 | 30.994 | 0.0310 | 10 | 150 | 2066 |
| Tree A, #4 | 22.433 | 0.0224 | 10 | 150 | 1496 |
| Tree A, Branch | 9.749 | 0.0097 | 10 | 150 | 650 |
| Tree B, #1 | 13.424 | 0.0134 | 10 | 150 | 895 |
| Tree B, #1rep | 14.058 | 0.0141 | 10 | 150 | 937 |
| Tree B, #2 | 12.667 | 0.0127 | 10 | 150 | 844 |
| Tree B, #3 | 15.830 | 0.0158 | 10 | 150 | 1055 |
| Tree B, #4 | 14.839 | 0.0148 | 10 | 150 | 989 |
| Tree B, Branch | 9.319 | 0.0093 | 10 | 150 | 621 |
| Tree C, #1 | 15.861 | 0.0159 | 10 | 150 | 1057 |
| Tree C, #1rep | 13.290 | 0.0133 | 10 | 150 | 886 |
| Tree C, Branch | 21.140 | 0.0211 | 10 | 150 | 1409 |

# APPENDIX D

# SOIL CHARACTERIZATION DATA

## Site S1, S08TX441-101

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

| | | | |
|---|---|---|---|
| SOIL SERIES: | Sagerton | PEDON NUMBER: S08TX441-101 | 10/20/09 |
| SOIL FAMILY: | Typic Argiustolls; fine, mixed, superactive, thermic | | |
| LOCATION: | Taylor County | | |

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH (cm) | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS | ORGN C |
| | | | % | | | | | | | | | | | % | % |
| 7348 | 0-35 | A | 0.4 | 0.3 | 1.4 | 6.9 | 4.9 | 13.9 | 30.6 | 41.1 | 15.4 | 45.0 | SiC | 2 | 1.36 |
| 7349 | 35-60 | Btk1 | 0.8 | 0.6 | 1.7 | 8.2 | 4.8 | 16.1 | 29.7 | 38.2 | 19.0 | 45.7 | C | 4 | 0.66 |
| 7350 | 60-88 | Btk1 | 0.9 | 0.9 | 2.3 | 10.7 | 5.6 | 20.4 | 26.7 | 35.3 | 20.0 | 44.3 | C | 2 | 0.50 |
| 7351 | 88-121 | Btk2 | 0.8 | 0.4 | 1.8 | 11.8 | 7.3 | 22.1 | 25.2 | 34.4 | 20.0 | 43.5 | C | 1 | 0.32 |
| 7352 | 121-155 | Btk2 | 0.5 | 0.6 | 2.3 | 13.6 | 7.8 | 24.8 | 23.0 | 32.3 | 19.4 | 42.9 | C | 1 | 0.44 |
| 7353 | 155-195 | BC | 0.3 | 0.4 | 1.8 | 10.8 | 7.7 | 21.0 | 24.0 | 34.8 | 19.1 | 44.2 | C | | 0.39 |
| 7354 | 195-235 | BC | 0.2 | 0.4 | 1.3 | 7.2 | 6.6 | 15.7 | 24.4 | 35.2 | 29.3 | 49.1 | C | 1 | 0.46 |
| 7355 | 235-266 | BC | 0.1 | 0.3 | 1.4 | 7.8 | 7.3 | 16.9 | 22.3 | 35.9 | 30.1 | 47.2 | C | | 0.28 |
| 7356 | 266-291 | C1 | 0.1 | 0.4 | 3.4 | 16.0 | 10.6 | 30.5 | 20.1 | 34.8 | 20.3 | 34.7 | CL | 1 | 0.30 |
| 7357 | 291-316 | C1 | 0.6 | 0.8 | 5.1 | 17.0 | 9.4 | 32.9 | 20.4 | 30.7 | 19.7 | 36.4 | CL | 4 | 0.13 |
| 7358 | 316-339 | C2 | 0.9 | 1.0 | 3.0 | 8.2 | 4.9 | 18.0 | 26.2 | 36.2 | 19.1 | 45.8 | C | 8 | 0.17 |
| 7359 | 339-363 | C2 | 0.6 | 1.0 | 3.1 | 8.5 | 4.9 | 18.1 | 27.3 | 36.3 | 20.0 | 45.6 | C | 4 | 0.25 |

| | | NH4OAc EXTR BASES | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | pH (H2O) | CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
| | 1:1 | Meq/100g | | | | | | | | % | | | % | | | |
| 7348 | 8.0 | 47.4 | 5.9 | 0.1 | 1.4 | 54.8 | | 25.8 | | 100 | 0 | 0 | 6.4 | 1.9 | 8.4 | |
| 7349 | 8.2 | 47.3 | 7.8 | 0.2 | 0.7 | 56.0 | | 23.4 | | 100 | 1 | 1 | 9.6 | 2.5 | 12.2 | |
| 7350 | 8.2 | 46.7 | 11.5 | 0.8 | 0.6 | 59.6 | | 23.2 | | 100 | 3 | 2 | 10.6 | 2.5 | 13.2 | |
| 7351 | 8.0 | 46.6 | 13.4 | 2.8 | 0.6 | 63.4 | | 23.3 | | 100 | 8 | 6 | 11.6 | 2.3 | 14.0 | |
| 7352 | 8.0 | 48.1 | 15.9 | 3.8 | 0.6 | 68.4 | | 24.6 | | 100 | 9 | 7 | 10.4 | 1.4 | 12.0 | |
| 7353 | 7.9 | 47.4 | 15.6 | 4.5 | 0.6 | 68.1 | | 28.0 | | 100 | 9 | 7 | 8.7 | 1.7 | 10.4 | |
| 7354 | 7.8 | 47.9 | 17.8 | 5.2 | 0.7 | 71.6 | | 30.3 | | 100 | 10 | 7 | 6.4 | 1.0 | 7.6 | |
| 7355 | 7.7 | 59.7 | 15.8 | 5.2 | 0.7 | 81.4 | | 29.1 | | 100 | 9 | 7 | 8.0 | 1.5 | 9.6 | 0.4 |
| 7356 | 7.7 | 60.0 | 9.8 | 3.5 | 0.5 | 73.8 | | 17.4 | | 100 | 11 | 6 | 17.2 | 1.0 | 18.3 | 0.2 |
| 7357 | 7.8 | 41.9 | 9.4 | 3.8 | 0.5 | 55.6 | | 16.4 | | 100 | 13 | 8 | 12.9 | 2.0 | 15.1 | |
| 7358 | 7.8 | 46.7 | 9.7 | 4.0 | 0.5 | 60.9 | | 16.7 | | 100 | 12 | 7 | 23.6 | 4.1 | 28.0 | |
| 7359 | 7.8 | 48.3 | 10.0 | 3.8 | 0.5 | 62.6 | | 17.0 | | 100 | 12 | 8 | 21.1 | 4.2 | 25.6 | |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND | H2O CONT | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | dS/m | % | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7348 | 0.5 | 51 | 2.9 | 0.9 | 0.5 | 0.3 | | | | 1.50 | 1.73 | 0.049 | 24.5 | |
| 7349 | 0.5 | 48 | 2.4 | 1.6 | 0.8 | 0.1 | | | | 1.55 | 1.81 | 0.053 | 22.9 | |
| 7350 | 1.2 | 48 | 2.7 | 3.7 | 4.2 | 0.1 | | | | 1.55 | 1.82 | 0.055 | 22.4 | |
| 7351 | 4.3 | 52 | 7.5 | 14.0 | 19.6 | 0.1 | | | | 1.57 | 1.89 | 0.064 | 23.6 | |
| 7352 | 5.8 | 58 | 10.5 | 19.7 | 27.4 | 0.2 | | | | 1.53 | 1.87 | 0.069 | 25.2 | |
| 7353 | 6.9 | 61 | 15.0 | 25.5 | 32.6 | 0.2 | | | | 1.45 | 1.85 | 0.085 | 29.0 | |
| 7354 | 7.7 | 65 | 18.0 | 28.0 | 35.2 | 0.2 | | | | 1.42 | 1.83 | 0.088 | 30.2 | |
| 7355 | 9.0 | 63 | 29.9 | 37.0 | 38.7 | 0.2 | | | | 1.46 | 1.84 | 0.080 | 27.9 | |
| 7356 | 7.8 | 51 | 26.9 | 28.0 | 32.6 | 0.2 | | | | 1.55 | 1.82 | 0.055 | 24.2 | |
| 7357 | 7.3 | 48 | 17.0 | 21.4 | 34.8 | 0.2 | | | | 1.52 | 1.88 | 0.073 | 26.0 | |
| 7358 | 8.4 | 53 | 26.9 | 26.3 | 37.4 | 0.1 | | | | 1.49 | 1.73 | 0.051 | 24.7 | |
| 7359 | 7.6 | 50 | 21.0 | 21.4 | 35.7 | 0.1 | | | | 1.58 | 1.80 | 0.044 | 23.6 | |

# Site G2, S08TX441-102

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

SOIL SERIES: Rotan PEDON NUMBER: S08TX441-102 10/20/09
SOIL FAMILY: Pachic Paleustolls; fine, mixed, superactive, thermic
LOCATION: Taylor County

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH (cm) | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS % | ORGN C % |
| | | | % | | | | | | | | | | | | |
| 7360 | 0-10 | A | 0.1 | 0.4 | 3.4 | 27.8 | 18.2 | 49.9 | 13.2 | 31.3 | 10.3 | 18.8 | L | | 1.92 |
| 7361 | 10-33 | AB | 0.1 | 0.2 | 2.7 | 24.5 | 14.7 | 42.2 | 13.7 | 28.6 | 19.2 | 29.2 | CL | | 1.13 |
| 7362 | 33-53 | Bt | 0.1 | 0.2 | 2.7 | 24.0 | 12.8 | 39.8 | 14.2 | 26.2 | 23.7 | 34.0 | CL | | 0.69 |
| 7363 | 53-80 | Btss1 | 0.2 | 0.3 | 2.5 | 23.2 | 11.1 | 37.3 | 16.0 | 26.9 | 22.1 | 35.8 | CL | 5 | 0.58 |
| 7364 | 80-108 | Btss1 | 0.3 | 0.4 | 2.9 | 23.0 | 10.7 | 37.3 | 16.3 | 26.5 | 22.4 | 36.2 | CL | 2 | 0.41 |
| 7365 | 108-141 | Btss2 | 0.6 | 0.7 | 3.4 | 25.3 | 10.5 | 40.5 | 15.2 | 25.1 | 22.9 | 34.4 | CL | 3 | 0.30 |
| 7366 | 141-175 | Btss2 | 0.8 | 0.5 | 3.3 | 28.5 | 11.2 | 44.3 | 12.5 | 22.5 | 24.1 | 33.2 | CL | 4 | 0.21 |
| 7367 | 175-203 | BC | 0.5 | 0.6 | 3.8 | 32.0 | 10.9 | 47.8 | 10.3 | 20.5 | 23.3 | 31.7 | SCL | 8 | 0.11 |
| 7368 | 203-227 | C1 | 1.0 | 0.7 | 4.2 | 38.2 | 10.6 | 54.7 | 7.2 | 15.9 | 22.2 | 29.4 | SCL | 10 | 0.08 |
| 7369 | 227-250 | C1 | 1.2 | 1.4 | 4.8 | 44.0 | 9.8 | 61.2 | 5.8 | 13.3 | 19.5 | 25.5 | SCL | 7 | 0.11 |
| 7370 | 250-275 | C2 | 0.3 | 0.4 | 3.9 | 53.6 | 8.9 | 67.1 | 5.5 | 12.1 | 16.0 | 20.8 | SCL | 1 | 0.07 |
| 7371 | 275-300 | C2 | 0.2 | 0.2 | 4.4 | 51.3 | 10.0 | 66.1 | 7.1 | 17.3 | 11.8 | 16.6 | FSL | 1 | 0.07 |
| 7372 | 300-375 | 2C3 | 0.8 | 0.9 | 3.8 | 25.3 | 10.9 | 41.7 | 20.7 | 35.2 | 12.3 | 23.1 | L | 1 | 0.20 |

| LAB NO | pH (H2O) 1:1 | CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NH4OAc EXTR BASES | | | | | | | | | | | | | | |
| | | Meq/100g | | | | | | | | % | | | % | | | |
| 7360 | 7.2 | 14.6 | 1.8 | 0.1 | 1.0 | 17.5 | | 16.8 | | 100 | 1 | | | | | |
| 7361 | 7.0 | 16.0 | 2.1 | 0.1 | 0.9 | 19.1 | | 26.0 | | 73 | 0 | | | | | |
| 7362 | 7.3 | 17.9 | 2.7 | 0.2 | 0.7 | 21.5 | | 27.2 | | 79 | 1 | | | | | |
| 7363 | 7.9 | 46.8 | 3.9 | 0.2 | 0.6 | 51.5 | | 28.2 | | 100 | 1 | | 2.4 | 0.8 | 3.3 | |
| 7364 | 8.1 | 47.4 | 5.9 | 0.5 | 0.6 | 54.4 | | 26.8 | | 100 | 2 | 2 | 3.4 | 0.7 | 4.2 | |
| 7365 | 8.2 | 46.7 | 5.7 | 0.7 | 0.6 | 53.7 | | 27.1 | | 100 | 2 | 3 | 2.8 | 0.5 | 3.3 | |
| 7366 | 8.2 | 25.4 | 6.0 | 1.1 | 0.5 | 33.0 | | 25.9 | | 100 | 3 | 4 | 1.0 | 0.4 | 1.4 | |
| 7367 | 8.0 | 22.8 | 5.8 | 1.3 | 0.5 | 30.4 | | 24.4 | | 100 | 4 | 5 | 1.0 | 0.3 | 1.3 | |
| 7368 | 7.9 | 24.6 | 5.8 | 1.6 | 0.4 | 32.4 | | 18.8 | | 100 | 6 | 5 | 1.2 | 0.4 | 1.6 | |
| 7369 | 7.9 | 39.2 | 3.9 | 1.5 | 0.4 | 45.0 | | 16.7 | | 100 | 6 | 5 | 4.0 | 0.8 | 4.9 | |
| 7370 | 7.9 | 21.0 | 3.4 | 1.2 | 0.3 | 25.9 | | 12.7 | | 100 | 6 | 5 | 1.5 | 0.1 | 1.6 | |
| 7371 | 8.1 | 8.1 | 2.5 | 1.0 | 0.2 | 11.8 | | 9.7 | | 100 | 10 | | | | | |
| 7372 | 8.1 | 47.1 | 3.4 | 1.4 | 0.3 | 52.2 | | 12.9 | | 100 | 6 | 5 | 16.4 | 0.5 | 16.9 | |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND dS/m | H2O CONT % | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE cm/cm | 0.33 BAR | 15 BAR |
| | | | Meq/l | | | | | | | g/cc | | | WT% | |
| 7360 | | | | | | | | | | 1.23 | 1.33 | 0.026 | 31.5 | |
| 7361 | | | | | | | | | | 1.36 | 1.57 | 0.049 | 29.7 | |
| 7362 | | | | | | | | | | 1.47 | 1.70 | 0.050 | 26.3 | |
| 7363 | | | | | | | | | | 1.53 | 1.75 | 0.046 | 23.7 | |
| 7364 | 0.4 | 51 | 1.5 | 0.6 | 1.8 | 0.1 | | | | 1.55 | 1.83 | 0.057 | 23.6 | |
| 7365 | 0.4 | 50 | 1.2 | 0.6 | 2.6 | 0.1 | | | | 1.62 | 1.86 | 0.047 | 21.8 | |
| 7366 | 0.6 | 52 | 1.2 | 0.6 | 3.8 | 0.1 | | | | 1.59 | 1.82 | 0.046 | 22.8 | |
| 7367 | 1.0 | 52 | 2.1 | 1.1 | 5.9 | 0.1 | | | | 1.53 | 1.77 | 0.050 | 25.0 | |
| 7368 | 1.6 | 52 | 4.6 | 2.0 | 9.6 | 0.1 | | | | 1.58 | 1.82 | 0.048 | 23.6 | |
| 7369 | 2.0 | 49 | 6.5 | 2.6 | 10.9 | 0.1 | | | | 1.66 | 1.83 | 0.033 | 20.5 | |
| 7370 | 2.0 | 41 | 8.0 | 3.3 | 11.7 | 0.1 | | | | 1.67 | 1.82 | 0.029 | 19.0 | |
| 7371 | | | | | | | | | | 1.69 | 1.80 | 0.021 | 17.7 | |
| 7372 | 2.4 | 47 | 8.0 | 3.4 | 13.0 | 0.1 | | | | | | | | |

## Site S3, S08TX441-103

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

SOIL SERIES: Rotan PEDON NUMBER: S08TX441-103 10/20/09
SOIL FAMILY: Pachic Paleustolls; fine, mixed, superactive, thermic
LOCATION: Taylor County

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS | ORGN C |
| | (cm) | | % | | | | | | | | | | | % | % |
| 7373 | 0-10 | A | 0.4 | 0.8 | 3.9 | 29.3 | 21.3 | 55.7 | 10.9 | 28.7 | 6.9 | 15.6 | FSL | 1 | 1.61 |
| 7374 | 10-28 | AB | 0.9 | 1.3 | 3.6 | 26.9 | 19.4 | 52.1 | 11.0 | 28.5 | 9.4 | 19.4 | FSL | 7 | 1.24 |
| 7375 | 28-44 | Btk1 | 1.0 | 1.1 | 3.2 | 20.5 | 16.8 | 42.6 | 13.8 | 32.1 | 11.8 | 25.3 | L | 3 | 0.98 |
| 7376 | 44-60 | Btk1 | 0.6 | 1.1 | 3.0 | 18.5 | 15.5 | 38.7 | 15.1 | 32.5 | 13.4 | 28.8 | CL | 3 | 0.83 |
| 7377 | 60-80 | Btk2 | 0.5 | 0.7 | 2.8 | 18.2 | 13.7 | 35.9 | 15.7 | 30.4 | 16.1 | 33.7 | CL | 2 | 0.59 |
| 7378 | 80-100 | Btss1 | 0.4 | 0.6 | 2.6 | 17.2 | 12.6 | 33.4 | 17.0 | 30.3 | 18.3 | 36.3 | CL | 2 | 0.52 |
| 7379 | 100-118 | Btss1 | 0.5 | 0.7 | 2.8 | 17.3 | 12.2 | 33.5 | 16.9 | 29.9 | 19.3 | 36.6 | CL | 3 | 0.34 |
| 7380 | 118-136 | Btss2 | 0.8 | 0.9 | 2.8 | 17.4 | 12.4 | 34.3 | 16.6 | 30.4 | 18.8 | 35.3 | CL | 3 | 0.32 |
| 7381 | 136-158 | Btss3 | 0.8 | 0.8 | 2.7 | 17.9 | 12.5 | 34.7 | 15.4 | 29.0 | 20.2 | 36.3 | CL | 5 | 0.26 |
| 7382 | 158-179 | Btss3 | 1.6 | 1.1 | 3.0 | 18.1 | 13.0 | 36.8 | 15.0 | 27.9 | 20.6 | 35.3 | CL | 5 | 0.27 |
| 7383 | 179-210 | C1 | 1.4 | 0.9 | 2.7 | 15.9 | 11.8 | 32.7 | 24.2 | 37.4 | 17.4 | 29.9 | CL | 4 | 0.20 |
| 7384 | 210-240 | C1 | 0.5 | 0.6 | 3.1 | 19.3 | 12.9 | 36.4 | 19.5 | 34.4 | 18.2 | 29.2 | CL | 2 | 0.16 |
| 7385 | 240-270 | C2 | 0.4 | 0.6 | 4.9 | 25.0 | 14.9 | 45.8 | 17.0 | 29.7 | 15.2 | 24.5 | L | 1 | 0.08 |
| 7386 | 270-300 | C2 | 0.2 | 0.7 | 8.4 | 21.8 | 13.7 | 44.8 | 18.0 | 33.9 | 13.3 | 21.3 | L | 1 | 0.15 |
| 7387 | 300-335 | 2C3 | 0.2 | 0.3 | 1.4 | 9.8 | 16.0 | 27.7 | 24.0 | 45.6 | 16.2 | 26.7 | L | 3 | 0.10 |
| 7388 | 335-370 | 2C3 | 0.1 | 0.2 | 0.4 | 5.7 | 16.0 | 22.4 | 22.2 | 46.6 | 16.6 | 31.0 | CL | | 0.05 |

| LAB NO | pH (H2O) | NH4OAc EXTR BASES CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1:1 | Meq/100g | | | | | | | | % | | | % | | | |
| 7373 | 7.9 | 35.9 | 0.7 | 0.0 | 0.5 | 37.1 | | 16.0 | | 100 | | 0 | 2.6 | 0.5 | 3.1 | |
| 7374 | 8.0 | 46.5 | 0.6 | 0.1 | 0.4 | 47.6 | | 16.4 | | 100 | 1 | | 7.4 | 0.4 | 7.9 | |
| 7375 | 8.1 | 46.4 | 0.8 | 0.1 | 0.4 | 47.7 | | 17.6 | | 100 | 1 | | 14.1 | 0.3 | 14.4 | |
| 7376 | 8.1 | 47.1 | 1.1 | 0.1 | 0.4 | 48.7 | | 18.8 | | 100 | 1 | | 13.9 | 0.5 | 14.4 | |
| 7377 | 8.1 | 46.8 | 1.7 | 0.1 | 0.5 | 49.1 | | 26.9 | | 100 | 0 | | 8.6 | 0.4 | 9.0 | |
| 7378 | 8.0 | 46.9 | 2.6 | 0.1 | 0.6 | 50.2 | | 29.7 | | 100 | 0 | 0 | 5.9 | 0.6 | 6.6 | |
| 7379 | 8.0 | 46.9 | 3.1 | 0.2 | 0.6 | 50.8 | | 30.5 | | 100 | 1 | 1 | 5.0 | 1.0 | 6.1 | |
| 7380 | 8.0 | 46.2 | 3.4 | 0.2 | 0.6 | 50.4 | | 30.2 | | 100 | 1 | 1 | 4.7 | 0.8 | 5.6 | |
| 7381 | 8.1 | 48.2 | 3.8 | 0.3 | 0.5 | 52.8 | | 28.8 | | 100 | 1 | 1 | 4.8 | 0.7 | 5.6 | |
| 7382 | 8.0 | 47.1 | 3.6 | 0.3 | 0.5 | 51.5 | | 29.6 | | 100 | 1 | 1 | 4.4 | 0.5 | 4.9 | |
| 7383 | 8.1 | 46.4 | 2.8 | 0.3 | 0.5 | 50.0 | | 19.1 | | 100 | 1 | 1 | 16.7 | 0.8 | 17.6 | |
| 7384 | 8.1 | 48.0 | 2.6 | 0.3 | 0.4 | 51.3 | | 17.8 | | 100 | 1 | 1 | 8.3 | 0.4 | 8.7 | |
| 7385 | 8.3 | 47.4 | 2.1 | 0.2 | 0.3 | 50.0 | | 15.1 | | 100 | 1 | | 6.8 | 0.6 | 7.5 | |
| 7386 | 8.4 | 47.6 | 1.5 | 0.2 | 0.3 | 49.6 | | 12.0 | | 100 | 2 | | 4.3 | 0.2 | 4.5 | |
| 7387 | 8.2 | 47.9 | 1.7 | 0.2 | 0.3 | 50.1 | | 13.4 | | 100 | 2 | | 6.6 | 0.6 | 7.4 | |
| 7388 | 8.0 | | 1.7 | 0.1 | 0.4 | | | 15.2 | | | 1 | | 2.9 | 0.5 | 3.4 | |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND | H2O CONT | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | dS/m | % | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7373 | 0.8 | 0 | 7.5 | 0.4 | 0.2 | 0.2 | 45 | | | 1.34 | 1.41 | 0.017 | 27.2 | |
| 7374 | | | | | | | | | | 1.29 | 1.38 | 0.023 | 30.5 | |
| 7375 | | | | | | | | | | 1.37 | 1.47 | 0.024 | 29.4 | |
| 7376 | | | | | | | | | | 1.40 | 1.54 | 0.032 | 23.3 | |
| 7377 | | | | | | | | | | 1.44 | 1.62 | 0.040 | 24.2 | |
| 7378 | 0.3 | 0 | 2.3 | 0.3 | 0.4 | 0.1 | 53 | | | 1.46 | 1.70 | 0.052 | 25.9 | |
| 7379 | 0.3 | 1 | 2.0 | 0.3 | 0.5 | 0.1 | 55 | | | 1.39 | 1.70 | 0.069 | 28.7 | |
| 7380 | 0.3 | 1 | 1.9 | 0.3 | 0.6 | 0.1 | 55 | | | 1.48 | 1.78 | 0.063 | 26.0 | |
| 7381 | 0.3 | 1 | 1.9 | 0.3 | 0.7 | 0.1 | 56 | | | 1.51 | 1.75 | 0.050 | 24.7 | |
| 7382 | 0.4 | 1 | 2.1 | 0.4 | 1.1 | 0.1 | 54 | | | 1.49 | 1.74 | 0.053 | 25.4 | |
| 7383 | 0.4 | 1 | 2.4 | 0.5 | 1.1 | 0.1 | 50 | | | 1.48 | 1.72 | 0.051 | 25.0 | |
| 7384 | 0.4 | 1 | 2.0 | 0.4 | 1.0 | 0.1 | 52 | | | 1.49 | 1.80 | 0.065 | 25.4 | |
| 7385 | | | | | | | | | | 1.55 | 1.74 | 0.039 | 20.7 | |
| 7386 | | | | | | | | | | 1.62 | 1.90 | 0.055 | 21.8 | |
| 7387 | | | | | | | | | | 1.66 | 2.02 | 0.068 | 22.0 | |
| 7388 | | | | | | | | | | 1.66 | 2.06 | 0.075 | 22.5 | |

# Site G4, S09TX353-101

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

| | | | |
|---|---|---|---|
| SOIL SERIES: | Sagerton | PEDON NUMBER: S09TX353-101 | 10/22/09 |
| SOIL FAMILY: | Typic Argiustolls; fine, mixed, superactive, thermic | | |
| LOCATION: | Nolan County | | |

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH (cm) | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS % | ORGN C % |
| | | | % | | | | | | | | | | | | |
| 7462 | 0-15 | A | 0.0 | 0.3 | 1.6 | 7.7 | 23.0 | 32.6 | 20.1 | 42.7 | 11.0 | 24.7 | L | | 1.29 |
| 7463 | 15-31 | A | 0.0 | 0.1 | 0.7 | 5.3 | 18.1 | 24.2 | 22.0 | 42.7 | 17.6 | 33.1 | CL | | 1.07 |
| 7464 | 31-46 | Bt | 0.0 | 0.1 | 0.3 | 3.9 | 16.3 | 20.6 | 24.2 | 44.7 | 13.8 | 34.7 | CL | | 0.80 |
| 7465 | 46-66 | Bt | 0.1 | 0.0 | 0.4 | 3.8 | 15.9 | 20.2 | 25.3 | 45.5 | 13.9 | 34.3 | CL | | 0.64 |
| 7466 | 66-89 | Btss1 | 0.0 | 0.1 | 0.4 | 3.7 | 14.8 | 19.0 | 26.3 | 40.5 | 15.1 | 40.5 | SiC | | 0.50 |
| 7467 | 89-114 | Btss2 | 0.0 | 0.0 | 0.3 | 2.8 | 10.8 | 13.9 | 31.7 | 42.3 | 15.6 | 43.8 | SiC | | 0.38 |
| 7468 | 114-129 | Bty | | | | | | | | | | | | | 0.28 |
| 7469 | 129-163 | BCky | | | | | | | | | | | | | 0.18 |
| 7470 | 163-185 | Cy1 | | | | | | | | | | | | | 0.14 |
| 7471 | 185-208 | Cy1 | | | | | | | | | | | | | 0.20 |
| 7472 | 208-230 | Cy2 | | | | | | | | | | | | | 0.15 |
| 7473 | 230-252 | Cy2 | | | | | | | | | | | | | 0.16 |
| 7474 | 252-282 | 2Cy3 | 0.1 | 0.1 | 2.4 | 15.2 | 22.3 | 10.1 | 14.8 | 33.4 | 15.1 | 26.5 | L | | 0.17 |
| 7475 | 282-302 | 3Cy4 | 0.0 | 0.2 | 0.9 | 5.8 | 17.6 | 24.5 | 21.5 | 40.2 | 19.2 | 35.3 | CL | | 0.19 |
| 7476 | 302-322 | 3Cy5 | 0.1 | 0.2 | 1.7 | 8.6 | 17.6 | 28.2 | 20.3 | 38.0 | 17.6 | 33.8 | CL | | 0.20 |
| 7477 | 322-342 | 3Cy5 | 0.1 | 0.2 | 1.4 | 9.5 | 18.8 | 30.0 | 19.7 | 35.1 | 18.3 | 34.9 | CL | | 0.22 |
| 7478 | 342-362 | 3Cy5 | | | | | | | | | | | | | 0.20 |

| LAB NO | pH (H2O) 1:1 | NH4OAc EXTR BASES CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Meq/100g | | | | | | | | % | | | % | | | |
| 7462 | 7.6 | | | | | | | 25.9 | | | | | | | | |
| 7463 | 7.8 | | | | | | | 30.8 | | | | | | | | |
| 7464 | 8.0 | | | | | | | 28.6 | | | | | 5.3 | 0.5 | 5.8 | |
| 7465 | 7.9 | | | | | | | 25.8 | | | | | 7.0 | 0.5 | 7.5 | |
| 7466 | 8.0 | | | | | | | 28.6 | | | | | 10.7 | 0.6 | 11.4 | |
| 7467 | 8.0 | | | | | | | 28.4 | | | | | 11.5 | 2.3 | 14.0 | |
| 7468 | 8.0 | | | | | | | 16.1 | | | | | 9.4 | 1.5 | 11.1 | 0.1 |
| 7469 | 8.2 | | | | | | | 14.0 | | | | | 6.7 | 1.6 | 8.4 | 1.0 |
| 7470 | 8.3 | | | | | | | 11.5 | | | | | 4.9 | 1.3 | 6.3 | 5.1 |
| 7471 | 8.2 | | | | | | | 9.3 | | | | | 3.5 | 0.6 | 4.2 | 6.2 |
| 7472 | 8.1 | | | | | | | 9.3 | | | | | 3.3 | 0.5 | 3.9 | 6.0 |
| 7473 | 8.0 | | | | | | | 8.7 | | | | | 2.7 | 0.5 | 3.2 | 6.4 |
| 7474 | 8.2 | | | | | | | 14.4 | | | | | 3.5 | 0.7 | 4.3 | 10.4 |
| 7475 | 8.1 | | | | | | | 18.3 | | | | | 4.6 | 0.4 | 5.1 | 12.5 |
| 7476 | 8.1 | | | | | | | 18.2 | | | | | 3.7 | 0.6 | 4.4 | 11.4 |
| 7477 | 8.1 | | | | | | | 18.6 | | | | | 3.8 | 0.7 | 4.6 | 10.1 |
| 7478 | 8.0 | | | | | | | 18.1 | | | | | 4.6 | 1.0 | 5.8 | 10.4 |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND dS/m | H2O CONT % | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | | | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7462 | | | | | | | | | | 1.39 | 1.54 | 0.035 | 28.3 | |
| 7463 | 0.6 | 55 | 3.3 | 1.5 | 0.4 | 0.4 | | | | 1.36 | 1.66 | 0.069 | 29.5 | |
| 7464 | 1.3 | 55 | 6.5 | 4.1 | 1.0 | 0.4 | | | | 1.43 | 1.68 | 0.055 | 27.5 | |
| 7465 | 3.0 | 55 | 10.5 | 12.3 | 3.2 | 0.5 | | | | 1.43 | 1.67 | 0.053 | 27.0 | |
| 7466 | 4.4 | 58 | 11.0 | 21.4 | 7.4 | 0.5 | | | | 1.46 | 1.81 | 0.074 | 27.1 | |
| 7467 | 6.0 | 60 | 11.0 | 33.7 | 17.8 | 0.7 | | | | 1.45 | 1.84 | 0.083 | 28.8 | |
| 7468 | 8.7 | 49 | 22.0 | 65.8 | 28.3 | 0.6 | | | | 1.43 | 1.65 | 0.049 | 25.4 | |
| 7469 | 9.6 | 49 | 21.5 | 74.0 | 41.3 | 0.6 | | | | 1.38 | 1.62 | 0.055 | 28.1 | |
| 7470 | 9.3 | 42 | 21.0 | 65.8 | 43.0 | 0.6 | | | | 1.35 | 1.50 | 0.036 | 26.8 | |
| 7471 | 8.7 | 36 | 20.5 | 57.6 | 41.3 | 0.6 | | | | 1.41 | 1.50 | 0.021 | 21.3 | |
| 7472 | 7.9 | 36 | 20.0 | 49.3 | 37.8 | 0.5 | | | | 1.43 | 1.56 | 0.029 | 25.6 | |
| 7473 | 7.4 | 33 | 19.5 | 41.1 | 34.8 | 0.4 | | | | 1.44 | 1.54 | 0.023 | 23.0 | |
| 7474 | 9.2 | 49 | 20.0 | 57.6 | 47.8 | 0.3 | | | | 1.42 | 1.60 | 0.041 | 26.2 | |
| 7475 | 9.3 | 62 | 20.0 | 57.6 | 50.0 | 0.3 | | | | 1.39 | 1.67 | 0.063 | 30.5 | |
| 7476 | 9.3 | 91 | 20.0 | 57.6 | 50.0 | 0.3 | | | | 1.43 | 1.73 | 0.066 | 29.6 | |
| 7477 | 8.9 | 61 | 20.0 | 57.6 | 48.3 | 0.3 | | | | 1.41 | 1.77 | 0.079 | 30.2 | |
| 7478 | 8.6 | 59 | 19.5 | 57.6 | 45.7 | 0.3 | | | | 1.46 | 1.76 | 0.064 | 27.5 | |

# Site S5, S09TX353-102

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

SOIL SERIES: Sagerton PEDON NUMBER: S09TX353-102 10/22/09
SOIL FAMILY: Typic Argiustolls; fine, mixed, superactive, thermic
LOCATION: Nolan County

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH (cm) | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS % | ORGN C % |
| 7479 | 0-25 | A | 0.1 | 0.3 | 1.2 | 7.1 | 22.3 | 31.0 | 20.1 | 41.9 | 11.6 | 27.1 | CL | | 1.75 |
| 7480 | 25-44 | Bt1 | 0.2 | 0.3 | 1.0 | 5.4 | 19.4 | 26.3 | 22.1 | 40.1 | 13.5 | 33.6 | CL | | 0.89 |
| 7481 | 44-66 | Bt2 | 0.6 | 0.4 | 1.0 | 6.8 | 19.8 | 28.6 | 22.3 | 38.5 | 13.8 | 32.9 | CL | 2 | 0.58 |
| 7482 | 66-85 | Btk1 | 0.1 | 0.2 | 0.7 | 8.9 | 22.2 | 32.1 | 21.0 | 36.1 | 14.3 | 31.8 | CL | | 0.58 |
| 7483 | 85-106 | Btk2 | 0.8 | 0.6 | 1.5 | 7.9 | 19.7 | 30.5 | 20.8 | 34.8 | 14.0 | 34.7 | CL | 3 | 0.52 |
| 7484 | 106-126 | Btk2 | 0.4 | 0.5 | 1.5 | 9.1 | 20.8 | 32.3 | 20.0 | 33.2 | 15.6 | 34.5 | CL | 1 | 0.43 |
| 7485 | 126-152 | Btk3 | 0.1 | 0.6 | 3.1 | 9.8 | 18.8 | 32.4 | 20.0 | 32.3 | 16.2 | 35.3 | CL | | 0.45 |
| 7486 | 152-188 | Btky1 | | | | | | | | | | | | 1 | 0.46 |
| 7487 | 188-218 | Btky2 | | | | | | | | | | | | | 0.42 |
| 7488 | 218-249 | Btky2 | | | | | | | | | | | | 2 | 0.36 |
| 7489 | 249-291 | Btky3 | | | | | | | | | | | | | 0.38 |
| 7490 | 291-322 | Cy1 | | | | | | | | | | | | 1 | 0.37 |
| 7491 | 322-350 | Cy2 | | | | | | | | | | | | | 0.32 |

| LAB NO | pH (H2O) 1:1 | NH4OAc EXTR BASES CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Meq/100g | | | | | | | | % | | | % | | | |
| 7479 | 7.3 | | | | | | | 27.2 | | | | | | | | |
| 7480 | 8.1 | | | | | | | 26.6 | | | | | 6.7 | 0.7 | 7.5 | |
| 7481 | 8.0 | | | | | | | 23.7 | | | | | 8.1 | 0.8 | 9.0 | |
| 7482 | 8.0 | | | | | | | 24.0 | | | | | 6.5 | 0.6 | 7.2 | |
| 7483 | 8.0 | | | | | | | 24.6 | | | | | 7.7 | 0.4 | 8.1 | |
| 7484 | 8.1 | | | | | | | 24.4 | | | | | 6.9 | 0.9 | 7.9 | |
| 7485 | 8.1 | | | | | | | 25.0 | | | | | 6.6 | 0.7 | 7.4 | |
| 7486 | 7.9 | | | | | | | 28.2 | | | | | 5.8 | 0.5 | 6.3 | 0.5 |
| 7487 | 8.0 | | | | | | | 25.7 | | | | | 5.0 | 0.7 | 5.8 | 1.8 |
| 7488 | 8.0 | | | | | | | 24.7 | | | | | 5.7 | 0.5 | 6.2 | 3.6 |
| 7489 | 8.0 | | | | | | | 24.6 | | | | | 10.2 | 0.3 | 10.5 | 7.8 |
| 7490 | 8.2 | | | | | | | 15.4 | | | | | 21.2 | 0.2 | 21.4 | 27.9 |
| 7491 | 8.2 | | | | | | | 12.8 | | | | | 14.3 | 0.8 | 15.2 | 41.6 |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND | H2O CONT | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | dS/m | % | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7479 | | | | | | | | | | 1.33 | 1.52 | 0.046 | 32.3 | |
| 7480 | | | | | | | | | | 1.34 | 1.58 | 0.056 | 31.4 | |
| 7481 | | | | | | | | | | 1.43 | 1.66 | 0.051 | 27.3 | |
| 7482 | | | | | | | | | | 1.47 | 1.72 | 0.054 | 24.9 | |
| 7483 | | | | | | | | | | 1.47 | 1.73 | 0.056 | 26.1 | |
| 7484 | | | | | | | | | | 1.46 | 1.73 | 0.058 | 26.6 | |
| 7485 | | | | | | | | | | 1.46 | 1.78 | 0.068 | 26.8 | |
| 7486 | | | | | | | | | | 1.41 | 1.75 | 0.075 | 28.9 | |
| 7487 | | | | | | | | | | 1.43 | 1.78 | 0.076 | 29.9 | |
| 7488 | | | | | | | | | | 1.43 | 1.80 | 0.080 | 29.0 | |
| 7489 | | | | | | | | | | 1.37 | 1.65 | 0.064 | 33.1 | |
| 7490 | | | | | | | | | | 1.37 | 1.56 | 0.044 | 33.0 | |
| 7491 | | | | | | | | | | 1.23 | 1.50 | 0.068 | 39.9 | |

# Site G6, S09TX441-104

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

| | | | |
|---|---|---|---|
| SOIL SERIES: | Rotan | PEDON NUMBER: S09TX441-104 | 10/22/09 |
| SOIL FAMILY: | Pachic Paleustolls; fine, mixed, superactive, thermic | | |
| LOCATION: | Taylor County | | |

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH (cm) | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS % | ORGN C % |
| | | | % | | | | | | | | | | | | |
| 7492 | 0-13 | Ap1 | 0.6 | 1.1 | 4.8 | 8.5 | 9.2 | 24.2 | 20.8 | 39.2 | 14.1 | 36.6 | CL | 4 | 1.61 |
| 7493 | 13-30 | Ap2 | 0.8 | 1.3 | 4.0 | 6.9 | 7.8 | 20.8 | 20.9 | 36.6 | 14.3 | 42.6 | C | 3 | 1.06 |
| 7494 | 30-73 | Bt1 | 1.0 | 0.8 | 3.4 | 6.4 | 7.4 | 19.0 | 21.3 | 36.2 | 15.6 | 44.8 | C | 3 | 0.77 |
| 7495 | 73-93 | Bt2 | 0.7 | 1.0 | 3.0 | 5.6 | 6.8 | 17.1 | 23.7 | 38.5 | 13.7 | 44.4 | C | 2 | 0.69 |
| 7496 | 93-110 | Bk1 | 1.5 | 1.1 | 2.4 | 4.5 | 4.9 | 14.4 | 29.0 | 44.4 | 12.4 | 41.2 | SiC | 7 | 0.72 |
| 7497 | 110-128 | Bk2 | 1.3 | 1.0 | 2.5 | 4.7 | 5.3 | 14.8 | 32.9 | 46.4 | 12.4 | 38.8 | SiCL | 8 | 0.80 |
| 7498 | 128-152 | Btk1 | 0.8 | 1.1 | 2.8 | 4.9 | 5.8 | 15.4 | 36.4 | 47.3 | 14.2 | 37.3 | SiCL | 3 | 0.62 |
| 7499 | 152-187 | Btk2 | 1.1 | 1.2 | 2.8 | 5.1 | 5.4 | 15.6 | 40.5 | 50.6 | 12.7 | 33.8 | SiCL | 3 | 0.45 |
| 7500 | 187-215 | Btk3 | 0.9 | 1.0 | 3.3 | 5.9 | 6.7 | 17.8 | 34.6 | 46.2 | 12.7 | 36.0 | SiCL | 3 | 0.53 |
| 7501 | 215-244 | Btk3 | 1.1 | 1.1 | 3.8 | 6.8 | 7.4 | 20.2 | 30.0 | 43.2 | 13.3 | 36.6 | CL | 3 | |
| 7502 | 244-279 | BC | 1.2 | 1.3 | 2.8 | 5.1 | 8.0 | 18.4 | 37.1 | 48.4 | 12.2 | 33.2 | SiCL | 5 | |
| 7503 | 279-310 | C | 1.6 | 1.2 | 1.9 | 4.1 | 7.3 | 16.1 | 42.9 | 51.6 | 11.7 | 32.3 | SiCL | 12 | |
| 7504 | 310-330 | C | 0.3 | 0.5 | 1.0 | 1.6 | 3.1 | 6.5 | 38.7 | 47.5 | 16.2 | 46.0 | SiC | | |

| | | NH4OAc EXTR BASES | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | pH (H2O) | CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
| | 1:1 | Meq/100g | | | | | | | | % | | | % | | | |
| 7492 | 7.7 | | | | | | | 37.8 | | | | | 3.7 | 0.3 | 4.0 | |
| 7493 | 7.9 | | | | | | | 36.9 | | | | | 7.0 | 0.8 | 7.9 | |
| 7494 | 8.0 | | | | | | | 39.4 | | | | | 8.3 | 0.8 | 9.2 | |
| 7495 | 8.1 | | | | | | | 34.2 | | | | | 20.9 | 1.3 | 22.3 | |
| 7496 | 8.3 | | | | | | | 19.6 | | | | | 41.7 | 0.5 | 42.2 | |
| 7497 | 8.2 | | | | | | | 18.6 | | | | | 40.7 | 0.0 | 40.7 | |
| 7498 | 8.3 | | | | | | | 18.4 | | | | | 41.2 | 0.3 | 41.5 | |
| 7499 | 8.4 | | | | | | | 15.7 | | | | | 43.3 | 2.0 | 45.4 | |
| 7500 | 8.4 | | | | | | | 16.9 | | | | | 35.2 | 0.6 | 35.9 | |
| 7501 | 8.5 | | | | | | | 17.4 | | | | | | | | |
| 7502 | 8.6 | | | | | | | 14.5 | | | | | | | | |
| 7503 | 8.6 | | | | | | | 12.5 | | | | | | | | |
| 7504 | 8.6 | | | | | | | 18.6 | | | | | | | | |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND | H2O CONT | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | dS/m | % | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7492 | | | | | | | | | | 1.16 | 1.56 | 0.104 | 42.0 | |
| 7493 | | | | | | | | | | 1.22 | 1.54 | 0.081 | 38.5 | |
| 7494 | | | | | | | | | | 1.34 | 1.81 | 0.105 | 33.1 | |
| 7495 | | | | | | | | | | 1.38 | 1.82 | 0.097 | 32.5 | |
| 7496 | | | | | | | | | | 1.24 | 1.43 | 0.049 | 35.2 | |
| 7497 | | | | | | | | | | 1.19 | 1.40 | 0.056 | 36.0 | |
| 7498 | | | | | | | | | | 1.20 | 1.40 | 0.053 | 36.1 | |
| 7499 | | | | | | | | | | 1.51 | 1.72 | 0.044 | 24.5 | |
| 7500 | | | | | | | | | | 1.49 | 1.84 | 0.073 | 27.6 | |
| 7501 | | | | | | | | | | 1.52 | 1.82 | 0.062 | 25.3 | |
| 7502 | | | | | | | | | | 1.60 | 1.85 | 0.050 | 22.5 | |
| 7503 | | | | | | | | | | 1.62 | 1.86 | 0.047 | 22.3 | |
| 7504 | | | | | | | | | | 1.67 | 2.04 | 0.069 | 23.1 | |

# Site G7, S09TX441-3041

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

SOIL SERIES: Hamby PEDON NUMBER: S09TX441-3041 10/22/09
SOIL FAMILY: Typic Paleustalfs; fine, mixed, active, thermic
LOCATION: Taylor County

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS | ORGN C |
| | (cm) | | % | | | | | | | | | | | % | % |
| 7603 | 0-15 | Ap | 0.1 | 0.7 | 23.5 | 45.7 | 7.9 | 77.9 | 7.8 | 14.9 | 2.5 | 7.2 | LFS | | 0.88 |
| 7604 | 15-21 | Ap | 0.1 | 1.0 | 24.2 | 47.4 | 7.4 | 80.1 | 7.1 | 12.9 | 2.2 | 7.0 | LS | | 0.27 |
| 7605 | 21-40 | E | 0.1 | 1.0 | 23.8 | 48.4 | 7.2 | 80.5 | 6.9 | 11.1 | 2.1 | 8.4 | LFS | | 0.16 |
| 7606 | 40-59 | Bt1 | 0.1 | 0.4 | 11.2 | 32.7 | 7.7 | 52.1 | 7.8 | 12.4 | 25.1 | 35.5 | SC | | 0.31 |
| 7607 | 59-84 | Bt2 | 0.1 | 0.4 | 11.3 | 31.5 | 8.2 | 51.5 | 9.2 | 14.2 | 25.8 | 34.3 | SCL | | 0.24 |
| 7608 | 84-98 | Bt3 | 0.1 | 0.4 | 11.9 | 33.1 | 9.1 | 54.6 | 10.4 | 16.5 | 21.3 | 28.9 | SCL | | 0.18 |
| 7609 | 98-113 | Bt3 | 0.1 | 0.4 | 11.7 | 32.7 | 9.7 | 54.6 | 10.1 | 17.2 | 20.3 | 28.2 | SCL | | 0.19 |
| 7610 | 113-135 | BC | 0.1 | 0.4 | 13.1 | 35.4 | 9.8 | 58.8 | 9.0 | 16.0 | 17.8 | 25.2 | SCL | | 0.14 |
| 7611 | 135-159 | BC | 0.1 | 0.3 | 11.7 | 32.0 | 11.3 | 55.4 | 9.5 | 19.4 | 17.3 | 25.2 | SCL | | 0.11 |
| 7612 | 159-180 | C | 0.1 | 0.2 | 9.0 | 24.8 | 14.4 | 48.5 | 9.9 | 24.5 | 17.5 | 27.0 | SCL | | 0.13 |
| 7613 | 180-205 | C | 0.2 | 0.2 | 3.7 | 10.8 | 18.0 | 32.9 | 14.3 | 36.6 | 16.4 | 30.5 | CL | 1 | 0.13 |
| 7614 | 205-230 | C | 0.2 | 0.2 | 2.2 | 9.6 | 27.0 | 39.2 | 14.0 | 33.7 | 12.8 | 27.1 | CL | | 0.08 |

| | | NH4OAc EXTR BASES | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | pH (H2O) | CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYPSUM |
| | 1:1 | Meq/100g | | | | | | | | % | | | % | | | |
| 7603 | 6.9 | | | | | | | 5.7 | | | | | | | | |
| 7604 | 6.8 | | | | | | | 3.3 | | | | | | | | |
| 7605 | 6.4 | | | | | | | 2.5 | | | | | | | | |
| 7606 | 5.2 | | | | | | | 15.9 | | | | | | | | |
| 7607 | 5.1 | | | | | | | 17.1 | | | | | | | | |
| 7608 | 5.2 | | | | | | | 15.3 | | | | | | | | |
| 7609 | 5.4 | | | | | | | 14.8 | | | | | | | | |
| 7610 | 5.9 | | | | | | | 13.5 | | | | | | | | |
| 7611 | 6.7 | | | | | | | 14.9 | | | | | | | | |
| 7612 | 7.2 | | | | | | | 16.1 | | | | | | | | |
| 7613 | 8.2 | | | | | | | 19.8 | | | | | 1.5 | 0.3 | 1.8 | |
| 7614 | 8.4 | | | | | | | 18.5 | | | | | 2.1 | 0.3 | 2.4 | |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND | H2O CONT | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | dS/m | % | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7603 | | | | | | | | | | 1.50 | 1.65 | 0.032 | 20.9 | |
| 7604 | | | | | | | | | | 1.48 | 1.61 | 0.028 | 21.3 | |
| 7605 | | | | | | | | | | 1.57 | 1.70 | 0.027 | 17.7 | |
| 7606 | | | | | | | | | | 1.50 | 1.75 | 0.053 | 25.8 | |
| 7607 | | | | | | | | | | 1.43 | 1.78 | 0.076 | 29.0 | |
| 7608 | | | | | | | | | | 1.59 | 1.87 | 0.056 | 22.5 | |
| 7609 | | | | | | | | | | 1.65 | 1.97 | 0.061 | 21.1 | |
| 7610 | | | | | | | | | | 1.71 | 1.98 | 0.050 | 18.7 | |
| 7611 | | | | | | | | | | 1.74 | 2.01 | 0.049 | 18.3 | |
| 7612 | | | | | | | | | | 1.67 | 1.93 | 0.049 | 20.6 | |
| 7613 | | | | | | | | | | 1.55 | 1.86 | 0.063 | 24.1 | |
| 7614 | | | | | | | | | | 1.56 | 1.86 | 0.060 | 23.4 | |

## Site S8, S09TX441-3042

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

SOIL SERIES: Hamby PEDON NUMBER: S09TX441-3042 10/22/09
SOIL FAMILY: Typic Paleustalfs; fine, mixed, active, thermic
LOCATION: Taylor County

| | | | PARTICLE SIZE DISTRIBUTION (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SAND | | | | | | SILT | | CLAY | | | | |
| LAB NO | DEPTH (cm) | HORIZON | VC (2.0-1.0) | C (1.0-0.5) | M (0.5-0.25) | F (0.25-0.10) | VF (0.10-0.05) | TOTAL (2.0-0.05) | FINE (0.02-0.002) | TOTAL (0.05-0.002) | FINE (<0.0002) | TOTAL (<0.002) | TEXTURE CLASS | COARSE FRAG-MENTS % | ORGN C % |
| | | | % | | | | | | | | | | | | |
| 7615 | 0-12 | A | 0.1 | 0.5 | 13.0 | 51.3 | 13.5 | 78.4 | 5.3 | 13.8 | 4.7 | 7.8 | LFS | | 0.77 |
| 7616 | 12-28 | E | 0.2 | 0.5 | 14.3 | 54.5 | 10.9 | 80.4 | 4.0 | 10.4 | 6.0 | 9.2 | LFS | 1 | 0.35 |
| 7617 | 28-43 | Btss1 | 0.3 | 0.4 | 8.8 | 34.9 | 8.5 | 52.9 | 4.5 | 8.5 | 31.7 | 38.6 | SC | 1 | 0.53 |
| 7618 | 43-58 | Btss1 | 0.1 | 0.2 | 6.1 | 30.8 | 10.2 | 47.4 | 5.2 | 10.1 | 35.5 | 42.5 | SC | | 0.50 |
| 7619 | 58-85 | Btss2 | 0.1 | 0.3 | 5.4 | 32.8 | 12.6 | 51.2 | 5.2 | 12.1 | 30.1 | 36.7 | SC | | 0.36 |
| 7620 | 85-113 | Bt1 | 0.1 | 0.2 | 4.8 | 36.5 | 16.5 | 58.1 | 5.6 | 13.9 | 22.7 | 28.0 | SCL | | 0.23 |
| 7621 | 113-138 | Bt2 | 0.2 | 0.2 | 4.4 | 38.0 | 19.7 | 62.5 | 5.5 | 14.4 | 18.1 | 23.1 | SCL | | 0.14 |
| 7622 | 138-160 | Bt2 | 0.2 | 0.2 | 3.4 | 35.5 | 22.4 | 61.7 | 6.0 | 15.6 | 17.8 | 22.7 | SCL | | 0.12 |
| 7623 | 160-175 | Bt2 | 0.1 | 0.1 | 2.5 | 37.1 | 22.1 | 61.9 | 5.7 | 15.1 | 17.7 | 23.0 | SCL | | 0.11 |
| 7624 | 175-197 | BC | 0.1 | 0.2 | 1.5 | 39.7 | 26.6 | 68.1 | 7.6 | 13.7 | 12.6 | 18.2 | FSL | | 0.20 |
| 7625 | 197-218 | BC | 0.1 | 0.2 | 1.1 | 43.7 | 28.7 | 73.8 | 7.3 | 12.6 | 8.6 | 13.6 | FSL | | 0.09 |

| LAB NO | pH (H2O) 1:1 | NH4OAc EXTR BASES CA | MG | NA | K | TOTAL | KCl EXTR AL | NaOAc CEC | ECEC | BASE SAT | ESP | SAR | CAL-CITE | DOLO-MITE | CACO3 EQ | GYP SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Meq/100g | | | | | | | | % | | | % | | | |
| 7615 | 6.6 | | | | | | | 6.1 | | | | | | | | |
| 7616 | 4.9 | | | | | | | 4.9 | | | | | | | | |
| 7617 | 6.1 | | | | | | | 19.8 | | | | | | | | |
| 7618 | 6.8 | | | | | | | 24.2 | | | | | | | | |
| 7619 | 7.2 | | | | | | | 19.1 | | | | | | | | |
| 7620 | 7.4 | | | | | | | 14.9 | | | | | | | | |
| 7621 | 7.3 | | | | | | | 12.4 | | | | | | | | |
| 7622 | 7.1 | | | | | | | 12.2 | | | | | | | | |
| 7623 | 7.0 | | | | | | | 12.3 | | | | | | | | |
| 7624 | 8.0 | | | | | | | 8.9 | | | | | 3.7 | 0.2 | 3.9 | |
| 7625 | 8.2 | | | | | | | 6.1 | | | | | 3.7 | 0.4 | 4.1 | |

| | SATURATED PASTE EXTRACT | | | | | | | | | BULK DENSITY | | | WATER CONTENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB NO | ELEC COND | H2O CONT | CA | MG | NA | K | HCO3 | CL | S04 | 0.33 BAR | OVEN DRY | COLE | 0.33 BAR | 15 BAR |
| | dS/m | % | Meq/l | | | | | | | g/cc | | cm/cm | WT% | |
| 7615 | | | | | | | | | | 1.49 | 1.57 | 0.018 | 22.5 | |
| 7616 | | | | | | | | | | 1.49 | 1.57 | 0.018 | 22.8 | |
| 7617 | | | | | | | | | | 1.45 | 1.65 | 0.044 | 25.1 | |
| 7618 | | | | | | | | | | 1.41 | 1.69 | 0.062 | 27.6 | |
| 7619 | | | | | | | | | | 1.49 | 1.72 | 0.049 | 26.0 | |
| 7620 | | | | | | | | | | 1.56 | 1.76 | 0.041 | 22.1 | |
| 7621 | | | | | | | | | | 1.59 | 1.75 | 0.032 | 19.8 | |
| 7622 | | | | | | | | | | 1.59 | 1.76 | 0.034 | 18.2 | |
| 7623 | | | | | | | | | | 1.57 | 1.75 | 0.037 | 18.2 | |
| 7624 | | | | | | | | | | 1.55 | 1.64 | 0.019 | 18.3 | |
| 7625 | | | | | | | | | | 1.59 | 1.68 | 0.019 | 16.1 | |

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