THE IMPACT OF LONGTERM CONVENTIONAL AND NO – TILLAGE MANAGEMENT ON FIELD HYDROLOGY AND GROUNDWATER RECHARGE

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ABSTRACT

No-tillage increases water conservation and crop yields, but the long-term (25 year) impact on semiarid field hydrology is not understood. Our objective was to estimate effects of SM or NT during the WSF rotation on field hydrology and potential groundwater recharge of a Pullman clay loam. Wheat (*Triticum aestivum* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] were grown in a dryland 3-year wheat-sorghum-fallow (WSF) rotation in the U.S. Southern High Plains using stubblemulch tillage, SM, or no-tillage, NT, residue management. We measured crop yield, rainfall, runoff, and chloride (Cl) concentration in borehole cores taken to a depth of ~ 50 ft. Mean wheat yield did not vary with tillage, but sorghum grain yield (3020 lbs ac^{-1}) with NT increased significantly ($P<0.05$) compared to SM tillage (2720 lbs ac^{-1}) due to greater sorghum water use with NT. The 25 year mean plant available soil water for the 6 ft. soil profile ranged from 6.6 in. for SM to 7.7 in. for NT. Rainfall runoff was significantly higher for NT compared with SM, but we observed more available soil water at planting with NT compared with SM. Dryland SM and NT crop management displaced Cl downward compared with native rangeland, but Cl displacement exceeded the rooting depth only with NT. Calculated soil water drainage with NT averaged 0.45 in. annually or almost double the .25 in. yr^{-1} flux rate estimated for the region. These downward water flux rates translate to expected groundwater recharge; however, time lags range up to centuries.

INTRODUCTION

The Texas High Plains climate features limited and erratic precipitation coupled with high potential evapotranspiration; therefore, irrigation is often used to supplement precipitation for crop production. According to the "2007 Water for Texas Plan," (Pittman et al., 2007) the saturated thickness and irrigation capacity of the Ogallala Aquifer will decline. This decline may result in deficit irrigation of crops or an increase in dryland crop production as stabilized through water conserving residue management practices. Stubblemulch tillage (SM) and no-tillage (NT) conservation tillage practices that were initially practiced to conserve soil by retaining residues on the soil surface to reduce evaporation and increase storage of precipitation as soil water for subsequent crop use (Baumhardt and Jones, 2002). Increased soil water storage resulting from use of conservation tillage has the potential to increase soil water drainage and movement of nutrients through the soil profile to depths below the root zone (Eck and Jones, 1992). One impact of water conservation in excess of the soil storage capacity would result in drainage below the crop root zone. Texas groundwater recharge is not well quantified and this unknown contributor to the Ogallala Aquifer may help offset water used for irrigation. For example, groundwater recharge through a playa lake near Tokio, TX during ~20+ years raised the water table sufficiently that one land owner saw the return of irrigated cotton production by 1997. Crop production methods such as improved residue management, which conserve precipitation as soil water may promote profile drainage that enhances groundwater recharge to maintain or extend productivity of irrigated crops.

In a study quantifying conservation tillage effects on soil water drainage, Eck and Jones (1992) measured nitrate concentrations to ~ 12 ft. They reported that no tillage residue management practices not only increased conservation of water in the Pullman clay loam soil but also enhanced movement of nitrate to depths > 10 ft in the lower profile. Increased drainage and leaching of nitrate suggests that groundwater recharge is, potentially, possible with no tillage (NT) residue management. Aronovici and Schnieder (1972) determined potential groundwater recharge beneath the Pullman clay loam soil using basins excavated into the underlying caliche layer. Their data showed that water draining from the excavated basin would reach the water table in approximately three days. Because the hydraulic properties of this caliche layer are, regionally, uniform (Baumhardt and Lascano, 1993), groundwater recharge may be regionally possible.

Groundwater recharge in the Texas High Plains was evaluated by determining the displacement of a chloride (Cl) concentration peak with depth (Scanlon et al., 2007). That is, under rangeland vegetation the lack of ongoing leaching or recharge is shown by salts accumulated in the soil profiles resulting in a Cl concentration peak in the near surface root zone. In contrast, under crop management, downward displacement of the bulge shaped Cl peak through the soil profile is attributed to increased drainage below the shallow root zone that should ultimately recharge the aquifer, (Scanlon et al., 2005, 2007). Previous studies have shown that conversion from natural rangeland to cropland in the Southern High Plains has greatly increased recharge from zero under rangeland conditions to a median value of 1 in yr^{-1} under irrigated or dryland cropland (McMahon et al., 2006; Scanlon et al., 2007). For groundwater management and conservation, the impact of conservation tillage practices on groundwater drainage below the root zone and how long it might take to recharge the aquifer can be determined with the Cl mass balance approach. The objective of this study was to quantify the long-term effects of conventional stubblemulch tillage, SM, or no-tillage, NT, during a wheat-sorghum-fallow (WSF) rotation on crop yields, storm water runoff, soil water storage, drainage below the root zone, and potential groundwater recharge through a Pullman clay loam soil.

MATERIALS AND METHODS

Six large (4.5 – 10 ac) contour-farmed graded terraces (0.5% slope) at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX (35° 11’ N, 102° 5’ W) have been cropped according to the Wheat-Sorghum-Fallow rotation since 1958 with each phase of the sequence present (Jones et al., 1985; Jones and Popham, 1997). Winter wheat was sown at 35 lbs ac^{-1} with a high-clearance 12 in. row spacing grain drill during early September to late October. Seasonal broadleaf weeds were controlled in wheat using 0.5 lb a.i. ac^{-1} 2,4-D [(2,4-dichlorophenoxy) acetic acid]. Wheat was harvested in July and plot areas remained idle for approximately 11-months until mid-June when grain sorghum was seeded in 30 in. rows at the 22,000 seeds ac^{-1}, using unit planters. Atrazine [6-chloro-N-ethyl-N’-(1-methylethyl)-1,3,5-triazine-2,4-diamine] was usually applied preplant at 3.5 lbs ac^{-1} for seasonal weed control. Grain sorghum was harvested at maturity during November and plots were fallowed approximately 10-months when wheat was planted and the rotation repeated. No supplemental N fertilizer was required to meet expected dryland yields of wheat or grain sorghum because the needed N is mineralized between crops in this rotation (Eck and Jones, 1992; Jones et al., 1997). Because the clay mineralogy of a Pullman clay loam supplies sufficient K to meet crop demand (Johnson et al., 1983) and dryland crop response to broadcast applied P fertilizer has been limited (Eck, 1969, 1988), no P or K fertilizers were applied. Beginning in 1983, these three paired-terraces received either SM (stubblemulch) or NT (no-tillage) residue management of the Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll). The SM weed control (3 - 4 tillage operations) was performed using a 15 ft.-wide sweep-plow operated at a depth of 4 in. For NT, weed control used both contact and soil active herbicides as governed by chemical residual and subsequent crop sensitivity (Baumhardt and Jones, 2002). Measurements during the 25-year study included a record of precipitation, storm-water runoff through 2.5 and 3 ft. H-flumes, and gravimetric soil water content for the beginning and end of each phase from each of the paired tillage treatments.

Infiltration into and drainage through the soil will, over-time, transport anions within the soil profile. Using Cl concentration in the soil as a marker, drainage below the root zone can be estimated from 30 to 60 ft (10-20 m) deep soil cores. A Geoprobe ™ push drill (Model 6620DT, Salina, KS) was used to collect a series of 4 ft (1.2 m) long core samples contained within plastic sleeves for subsequent analyses. These soil core analyses included: soil water content, matric potential, and the concentrations of Cl, sulfate, and nitrate as described by Scanlon et al. (2007). A Cl concentration peak displacement, relative to uncultivated rangeland vegetation, was used to define the depth of ion flushing and, subsequently, the rate drainage that should ultimately recharge the aquifer. We correlated soil water drainage to the long-term tillage treatments as corroborated with measured precipitation (standard gauges), surface water runoff, and soil water content at planting for the period of record, i.e., since 1983. Tillage effects on all parameters were compared according to a simple paired t-test (Baumhardt and Jones, 2002).

RESULTS AND DISCUSSION

Dryland residue management has the potential of increasing available soil water storage to a maximum of approximately 8 in. for a 6 ft Pullman soil profile. Under dryland conditions, this soil water is critical for crop production. The modest increase in soil water storage at wheat planting to a total of 7.7 in. with NT averaged about 1 inch more than the 6.6 in. observed for SM tillage. This was reflected in the subsequent crop water use estimated for wheat at 14.4 and 13.5 in. for NT and SM treatments, respectively. Similarly, available soil water storage at sorghum planting totaled 7.5 and 6.7 in. with NT and SM tillage, and resulted in the estimated sorghum water use of 12.8 and 12.2 in. Wheat grain yield averaged 2270 lbs ac^{-1} with NT was not significantly different from 2310 lbs ac^{-1} observed with SM tillage. In contrast, grain sorghum yield averaged 3380 lbs ac^{-1} with NT and was significantly greater than the grain yield of 3050 lbs ac^{-1} observed with SM tillage.

We estimated small but significantly (P = 0.05) different runoff amounts from both NT and SM treatments during wheat and sorghum growing season; however, during wheat growth runoff averaged only 2 % of the mean 11 in. growing season precipitation or 0.26 and 0.22 in. for NT and SM treatments, respectively. During sorghum growth, runoff from NT treatments averaged 0.47 in. compared with 0.61 in. for SM or 4.7 % and 6.1 % of precipitation for NT and SM, respectively. Measured runoff during fallow after wheat was 1.1 in. for NT and 0.8 in. for SM (6.2 % and 4.4 % of the 17.8 in. precipitation). Similarly, measured runoff of the mean 18.4 in.

precipitation during fallow after sorghum was 1.63 in. (8.9 %) and 0.82 in. (4.5 %) for NT and SM tillage, respectively. Total runoff during the WSF rotation averaged 4.6 in. for NT compared with 3.7 in. for SM. The greater runoff observed from NT than from SM plots would suggest less soil water would be available at planting; however, both available soil water at planting and summer crop yields averaged more with NT residue management. One likely explanation is that soil water evaporation for NT is sufficiently reduced compared with SM residue management to offset any differences in runoff and promote greater growth and yield.

Chloride accumulates naturally from atmospheric deposition, 0.234 ppm (mg kg^{-1}), in the long-term mean 19 in. annual precipitation. The Cl distribution for rangeland is shown in Fig. 1 for a site nearby the graded terraces. Data show Cl concentration begins transitioning at 1.1 ft. (0.35 m) with a peak bulge at approximately 3 ft. (~1.0 m) depth. The Cl concentration near the soil surface was 0 ppm (mg kg^{-1}), but increased rapidly beginning at 1.5 ft. (~0.5 m) depth. That is, the observed Cl displacement appears within the root zone; thus, indicating no water flux (drainage) through the profile. Our results show that the native range vegetation has consumed practically all the infiltrating precipitation, which resulted in no downward displacement of the Cl concentrations measured in the Pullman soil profile.

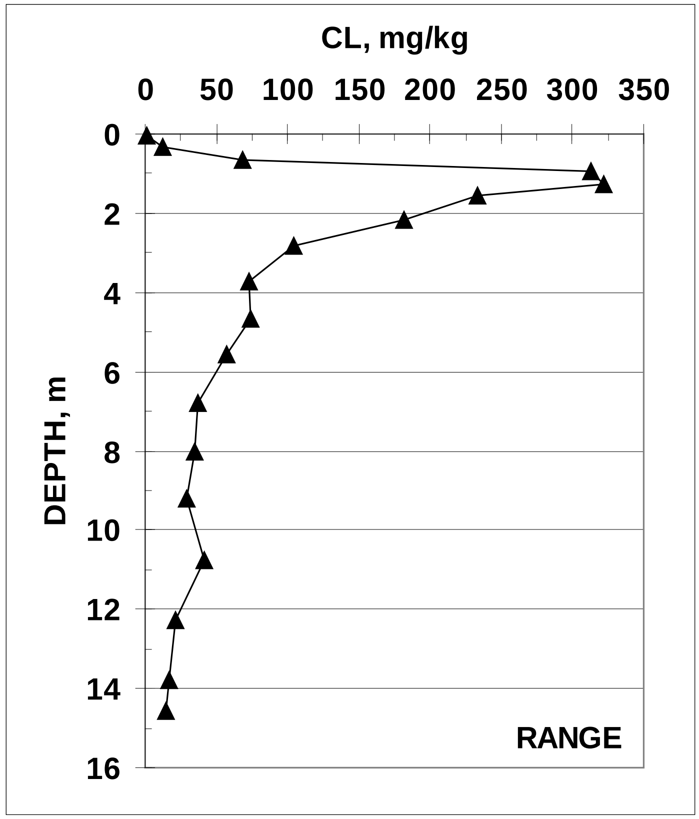

Figure 1. Chloride concentration, parts per million (mg/kg), plotted with depth, 1 m ~ 3.3 ft, for a nearby native range site.

The Cl concentration with depth is shown in Fig. 2 for SM and NT residue management of our wheat-sorghum-fallow rotation experiment that has been conducted for 25-yr. Compared with the rangeland site, the cultivated soils generally had deeper Cl peaks. The concentration of Cl was negligible for the upper 6.5 ft (2.2 m) in NT plots (Fig. 2 L) and 3 ft (0.95 m) in SM plots (Fig. 2 R). The depths where measured Cl concentrations transitioned from the negligible leached surface soil, generally, exceeded the estimated rooting depth only for the NT residue management treatment. For NT residue management, the concentration of Cl increases for an additional 6 ft (2 m) to peak at about 16 ft (5 m). In contrast, the Cl concentration displacement was approximately 10 ft (3.0 m) with SM tillage before decreasing to a common 25 ppm (mg kg^{-1}) Cl concentration in the lower profile. The calculated soil water drainage in NT plots averaged 0.45 in. (11.5 mm) annually or almost double the 0.25 in. (6.3 mm) annual drainage rate estimated for the region; however, the estimated time required to reach the water table is ~1400 years.

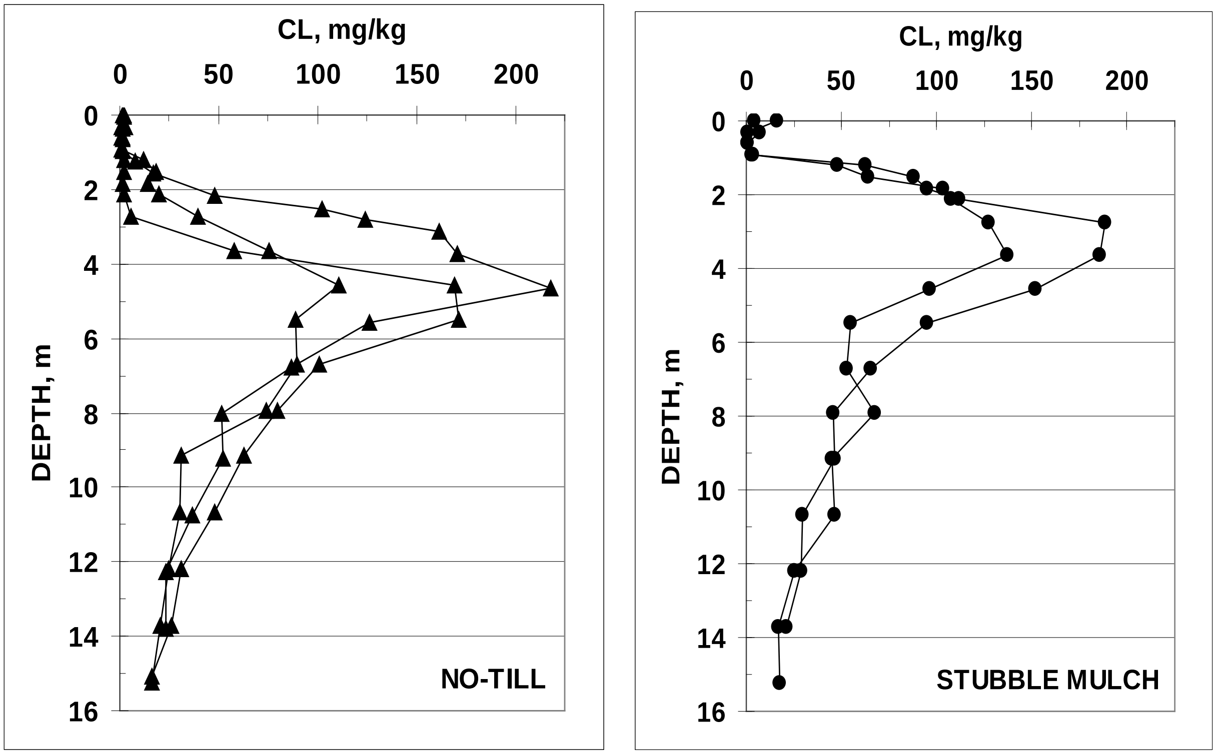

Figure 2. Chloride concentration, parts per million (mg/kg), plotted with depth, 1 m ~ 3.3 ft, for dryland Wheat-Sorghum-Fallow rotation no-till and stubblemulch tillage plots.

CONCLUSION

We measured, at planting, a consistent increase in plant available soil water of approximately 1 in. when using NT compared with conventional SM tillage. This greater soil water content did not increase grain yield of wheat that averaged 2290 lbs ac^{-1} for both tillage practices, but did result in approximately 300 lbs ac^{-1} more sorghum grain yield for NT compared with SM. Although NT tended to increase both available soil water stored during fallow and sorghum grain yield, we measured greater runoff for NT (4.6 in.) compared with SM (3.7 in.). Our data also show that Cl flushing under native rangeland was within the shallow root zone, and peaked at ~ 3 ft (1.0 m) depth. Cultivated dryland plots had Cl flushing to ~3 ft. (1.0 m) for SM tillage compared with ~ 6.5 ft (2.2 m) for NT. Because NT residue management increases precipitation stored as soil water, the Cl concentration was displaced ~ 4 ft (1.2 m) deeper than with SM during this 25-yr experiment. Calculated drainage rates in SM plots was negligible because the Cl displacement did not extend beyond the estimated rooting depth. With NT, the estimated mean annual drainage rates through the soil profile was 0.45 in. (11.5 mm) or almost double the 0.25 in. (6.3 mm) regional drainage rate. The estimated time required for no-till increased downward water flux to reach the groundwater table, however, is ~1400 years under conditions similar to those of our test.

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