LONG-TERM BENEFITS OF DEEP TILLAGE ON SOIL PHYSICAL PROPERTIES AND CROP YIELD

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ABSTRACT

Plant available water limits dryland crop yields, but deep tillage used to disrupt dense subsoil layers may increase infiltration and root distribution for more soil water. Our objectives were to quantify long-term effects of deep tilling a Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) on select soil properties and crop yield at the USDA-ARS, Conservation and Production Research Laboratory, Bushland, TX (35° 11' N, 102° 5' W). In 1971, paired 80 x 1500 ft. level conservation bench terrace plots were stubblemulch tilled or moldboard plowed to 27 in. and cropped with grain sorghum [*Sorghum bicolor* (L.) Moench] through 2004 for yield comparisons. Ponded infiltration, bulk density, and penetration resistance were measured during the summer of 2002. Deep tillage decreased initial soil profile bulk density and penetrometer resistance, but they were no longer different after 30 years. Ponded infiltration increased with deep tillage after 30 years. The mean annual grain yield increased approximately 10% in deep tilled plots compared with stubblemulch tillage because of increased infiltration and, possibly, rooting. Increased yields with deep tillage for two of 14 crops accounted for > 50% of the cumulative yield benefit, which was attributed to improved drainage of rain that flooded untilled plots. Deep tillage effects measured after > 30 years show that dense subsoil layers did not redevelop, which provides an extended period to recoup the 1971 installation costs of $65 per acre. For a Pullman soil, deep plowing may be an economical soil profile modification treatment to use with conservation systems.

INTRODUCTION

Precipitation on the semiarid North American southern Great Plains replaces, in an average year, approximately 25 % of the potential evapotranspiration for crop water use. To offset the resulting crop water deficit under dryland conditions, terrace structures have been adapted to reduce runoff of excess rain water. Hauser (1968) described a level bench terrace system constructed in 1958, which features a gently sloping (2%) watershed 1.5 times larger than the smaller conservation bench that receives the runoff (Fig. 1.). The increased soil water storage is evenly distributed in the crop root zone throughout the bench for crop use. Drainage of excess rain through the profile floods planted crops on the benches usually once in 5 years. Deep tillage may be used to fracture subsoil layers that limit infiltration and profile drainage and to enhance crop rooting for increased water availability.

The Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) is found on 3.7 million acres of the southern Great Plains region and features a very slowly permeable montmorillonitic clay subsoil layer at 8 to 24 in. depth (Unger and Pringle, 1981). Deep tillage of this soil was proposed as a way to increase infiltration of rain and irrigation by eliminating flow limiting subsoil layers and, consequently, increase the plant available water by increasing the volume of soil explored by crop roots. Generally, this deep soil profile modification and tillage treatment to depths varying from 10 to 60 in. successfully disrupted the dense subsoil layers; thus, increasing infiltration and the depth that crops removed soil water (Schneider and Mathers, 1970). The caveat stated since 1970 was that soil consolidation might mask any long-term tillage benefits.

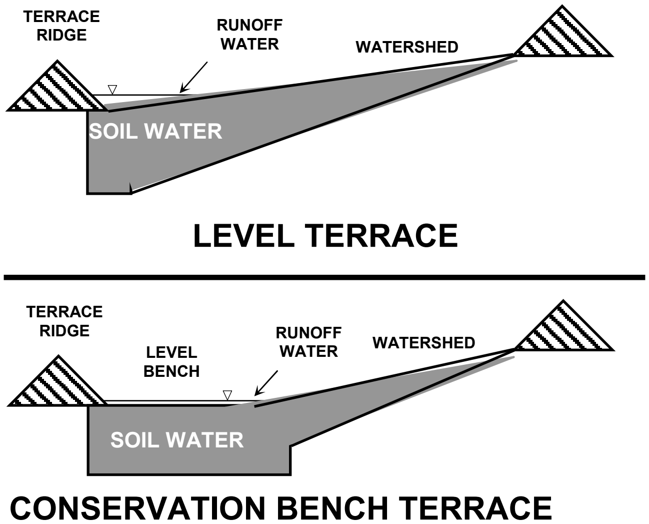

Figure 1. Cross section diagram of conventional and conservation - level bench terraces. Evenly distributing watershed runoff on benches permits annual crop production in most years.

Subsequent studies consistently show that infiltration and crop rooting are increased, which increased crop yields (Eck and Taylor, 1969; Eck, 1986; Eck and Winter, 1992; Unger, 1993). That is, deep tillage successfully reduced the effect of dense subsoil layers that restricted rain infiltration and root exploration for plant available water for some 26 years in irrigated experiments. These studies also reported consistently greater yields under limited irrigation, but dryland production systems were not evaluated. We hypothesized that tillage to a depth of 27 in. would have a sustained impact on select soil physical properties under dryland management. Our objectives were to quantify the long-term effects of deep tilling soil with a flow restricting subsoil layer on crop yield and select physical properties including infiltration, bulk density, and penetration resistance.

MATERIALS AND METHODS

The long-term (1972-2004) effects of deep tillage on crop yield and selected soil physical properties were evaluated at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, USA (35° 11’ N, 102° 5’ W) on a pair of 80 ft. wide by 1500 ft. long contour-farmed conservation bench terraces. In September of 1971, the terraces were conventionally tilled (control) or plowed to a 27 in. depth using a 40 in. single blade “large” moldboard adjusted to retain the topsoil in the profile with an estimated installation cost of $65 per acre (Fig. 2). After this primary tillage, weed control tillage for stubblemulch residue management was performed as needed using 10 to 15-ft.-wide sweep-plow implements with overlapping V-shaped blades operated at a 4 in. depth (Baumhardt and Jones, 2002).

The terrace watersheds were uniformly cropped from 1971 to present with wheat (*Triticum aestivum* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] using the wheat-fallow-sorghum (WSF) rotation described by Jones and Popham (1997) that produces two crops in 3 years with 11-month fallow (noncropped) periods between crops. The level benches received sufficient runoff from the watersheds to support annual crops that permitted paired comparisons during most years (i.e., 14 growing seasons), but only grain sorghum yields are reported. Grain sorghum, various cultivars, was seeded in single 30 in. rows during early to mid-June for a final population of 24,000 plants acre^{-1}, using unit planters. Growing season weed control relied on 1.5 lb a.i. acre^{-1} propazine [6-chloro-N,N'-bis (1-methylethyl)-1,3,5-triazine-2,4-diamine] applied pre-emergence after sorghum planting. We added 50 lb acre^{-1} N fertilizer to all benches, however no P or K fertilizers were required. Triplicate sorghum grain yield samples were hand harvested from paired rows 10-ft. long.

Figure 2. Moldboard plow used to till conservation benches to 0.70 -m depth without inverting the soil. Plow was pulled by a D-8 Caterpillar tractor.

Thirty years after deep tillage treatment, in the summer of 2002, we measured the time required for ponded infiltration of well water (pH of 7.7, electrolyte concentration of 819.0 ppm, and a SAR of 0.49) applied in 1.0 or 2.0 –in. depth increments. Our replicated (4 times) test areas were contained within a 40 in. wide by 60 in. long by 8-in. high metal frame that was pressed 2 in. into the soil. Four water applications were made with approximately 72 hours delay between each to permit drainage for a total infiltration depth of 4 and 8 in. Soil bulk density was determined in 8 in. intervals 4 in. beneath the surface to a depth of 36 in. using 4 in. long 2 in. diam. soil core samples taken from areas adjacent to the infiltration sites. Cone penetration resistance was determined approximately one week after the infiltration measurements to allow the sites to drain. We used a tractor-mounted penetrometer that recorded penetration resistance force and depth to 24 in. as described by Allen and Musick (1997). Cumulative infiltration, soil density, and penetration resistance were analyzed with an unpaired t-test while yield data were compared as paired data (SAS Inst., 1988).

RESULTS AND DISCUSSION

Soil Properties

Deep moldboard plowing disturbed the subsoil and increased pore space and size, which promoted greater infiltration. Measured infiltration after a rain in 1975 of 0.3 in. h^{-1} indicated a 6-fold increase with deep tillage compared to the control. Measured, in 2002, total time required for the observed incremental cumulative infiltration is shown in Fig. 3. Time for infiltration of 1.0 and 2.0 –in. of water did not vary with tillage because the estimated wetting front position was above most of the 8-24 in. deep flow-restricting subsoil layer. This subsoil layer impedes water movement and significantly increased differences in observed time of infiltration beginning with the 3 in. water application. This effect increased the difference in the time required for infiltration as the application depth increased. Overall, water infiltration into the deep tilled plots required 30% less time than in the untreated control plots (r^2=0.94). These data show that deep moldboard tillage eliminated a flow restricting subsoil layer and increased infiltration due to improved drainage for more than 30 years.

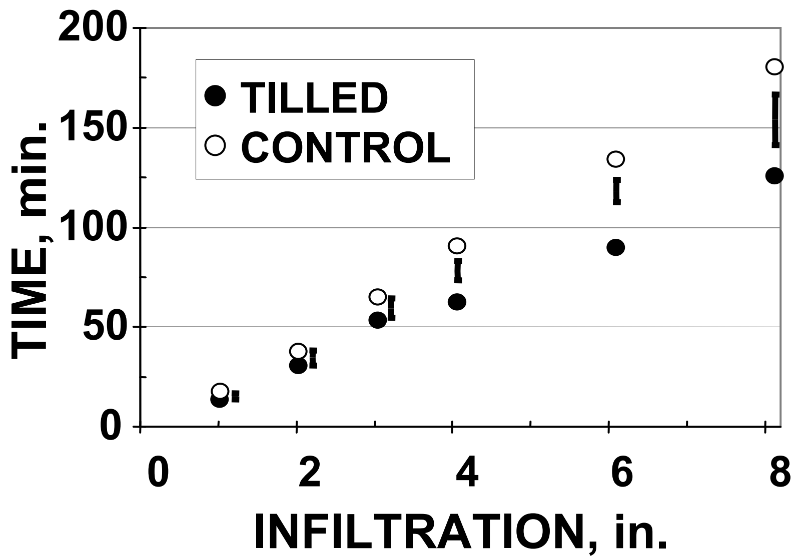

Figure 3. Total time required for the observed cumulative infiltration into deep tillage plots. Vertical bars are the least significant difference.

Soil bulk density after tillage in 1971 was expected to be lower than in control plots; however, density measured in 1975 averaged a similar 1.4 and 1.46 g cm^{-3} for the control and tilled profiles, respectively. The 2002 soil bulk density plotted with depth for tilled and control plots (Fig. 4) are similar to 1975 values except that the 12 in. tilled density was 1.35 g cm^{-3}. The resulting mean soil profile density was a constant 1.46 g cm^{-3} for control plots in 1975 and 2002. In contrast, the profile density in tilled plots was 1.40 g cm^{-3} in 1975 and 1.41 g cm^{-3} in 2002. Compared to the control, deep tillage tended to reduce soil density after 30 years, but those differences were not significant except for the 20 in. depth. Repeated tillage and traffic during the study may have contributed to soil consolidation.

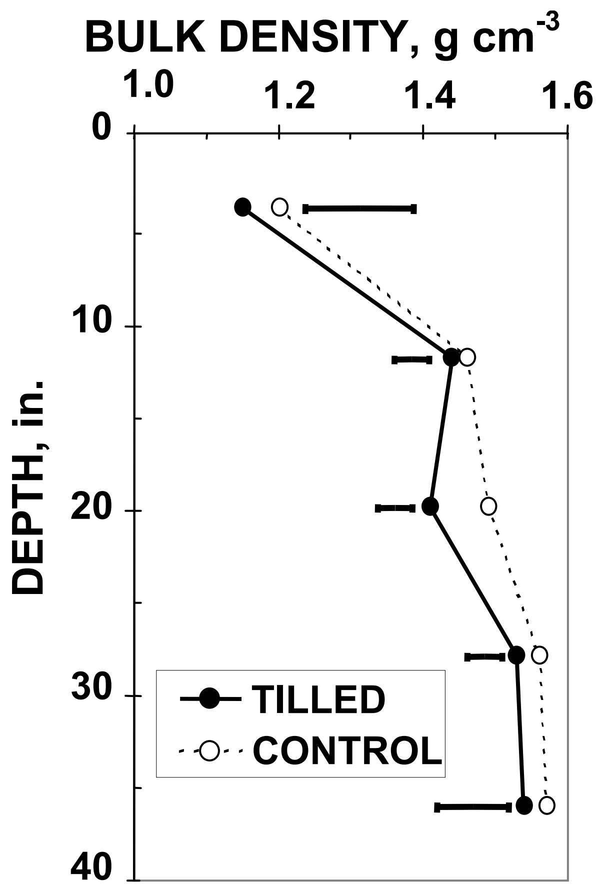

Figure 4. Soil bulk density determined with depth into tillage plots. Horizontal error bars are the least significant

We measured the indexed cone penetration resistance i.e., force per unit basal area to further assess long-term deep tillage effects to eliminate compacted subsoil layers in 2002. The cone index typically increases through dense layers. Our measured cone index was similar for both tillage treatments above the dense subsoil layers beginning at the 12 in. depth. Penetration resistance below 12 in., however, was significantly (P>0.90) less in the deep tilled compared to control plots except at the 18 in. and 24 in., near the plow bottom (Fig. 5). No corresponding 1975 penetrometer resistance data are available for comparison; however, deep tillage had a sustained impact to reduce the indexed penetration resistance through the dense subsoil. In the absence of this subsoil layer after tillage root proliferation could increase and expand the volume of soil explored by crop roots. Our study, however, did not assess the effect of deep tillage on rooting and the potential amount of soil water available to the crop.

Crop Yield

We hypothesized that deep tillage used to fracture a dense 8-24 in. subsoil layer in the Pullman clay loam will increase the volume of soil explored by crop roots and, consequently, increase the available soil water and yield of dryland crops. Annual sorghum grain yield, shown in Fig. 6., revealed no large yield response to deep tillage during the years immediately after plowing (1972-1974) when crop rooting would benefit the most. Also, we observed no gradual decline in yield differences between tilled and control plots due to soil consolidation as a result of sustained tillage and traffic on the plots. Sorghum grain yield calculated from 14 crops grown during the 1972-2004 study average 2300 lbs. acre^{-1} with deep tillage compared with 2060 lbs. acre^{-1} for the control plots. The small 14 crop mean increase of approximately 240 lbs. acre^{-1} in the deep tillage plots was significant (P>0.95) in pairwise t-tests and resulted in a cumulative increase of 3350 lbs. acre^{-1}. We speculate that these yield increases could be attributed to more prolific root growth and greater distribution in the soil profile and increased rain infiltration and storage in the soil. Conspicuously large yield increases with deep tillage compared with the control treatments were observed in 1984 (820 lbs. acre^{-1}), 1999 (990 lbs. acre^{-1}), and 2003 (750 lbs. acre^{-1}). The cumulative yield increase with deep tillage for those three years of 2560 lbs. acre^{-1} accounted for approximately 75% of the yield difference during the study.

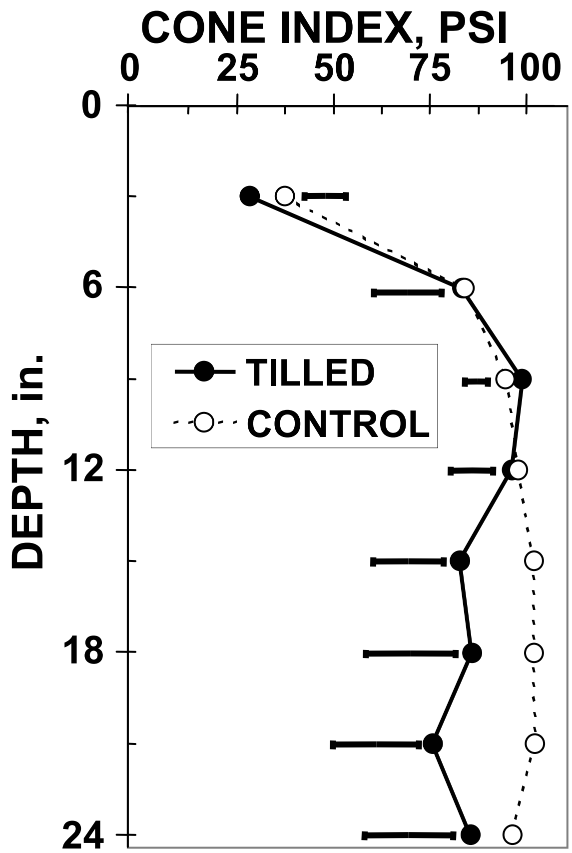

Figure 5. Indexed cone penetration resistance determined with depth into tillage plots. Horizontal error bars are the least significant difference.

To explain the large sorghum grain yield increase with deep tillage during 1984, 1999, and 2003 compared with the remaining 11 years, we reviewed growing season precipitation. During our test, annual grain sorghum yield normally increased with increasing growing season precipitation or if fallow precipitation increased the amount of stored soil water at planting (data not shown) as reported by Unger and Baumhardt (1999). The 2003 yield increase from 670 to 1420 lbs acre^{-1}

was probably due to improved storage of pre-plant precipitation in plots where deep tillage had been used. However, in 1984 and 1999 early, post planting, growing season precipitation exceeded 3 in. during brief, < three days, periods and was sufficient to flood the unplowed terrace benches (Fig. 7.). As previously shown by ponded infiltration measurements, deep tillage has a sustained effect to increase infiltration by improving profile drainage. Consequently, flooding injury to growing crops in 1984 and 1999 was prevented in deep tilled plots because of greater profile drainage that removed ponded water compared with the untilled control. Eck et al. (1977) noted a similar benefit for irrigated Alafalfa (*Medicago sativa* L.) grown on soil profiles modified to 36 in. in 1964.

Figure 7. Bench terrace flooding of seedling crops.

CONCLUSIONS

Crops grown on the southern Great Plains under dryland conditions rely on stored soil water to augment growing season precipitation.

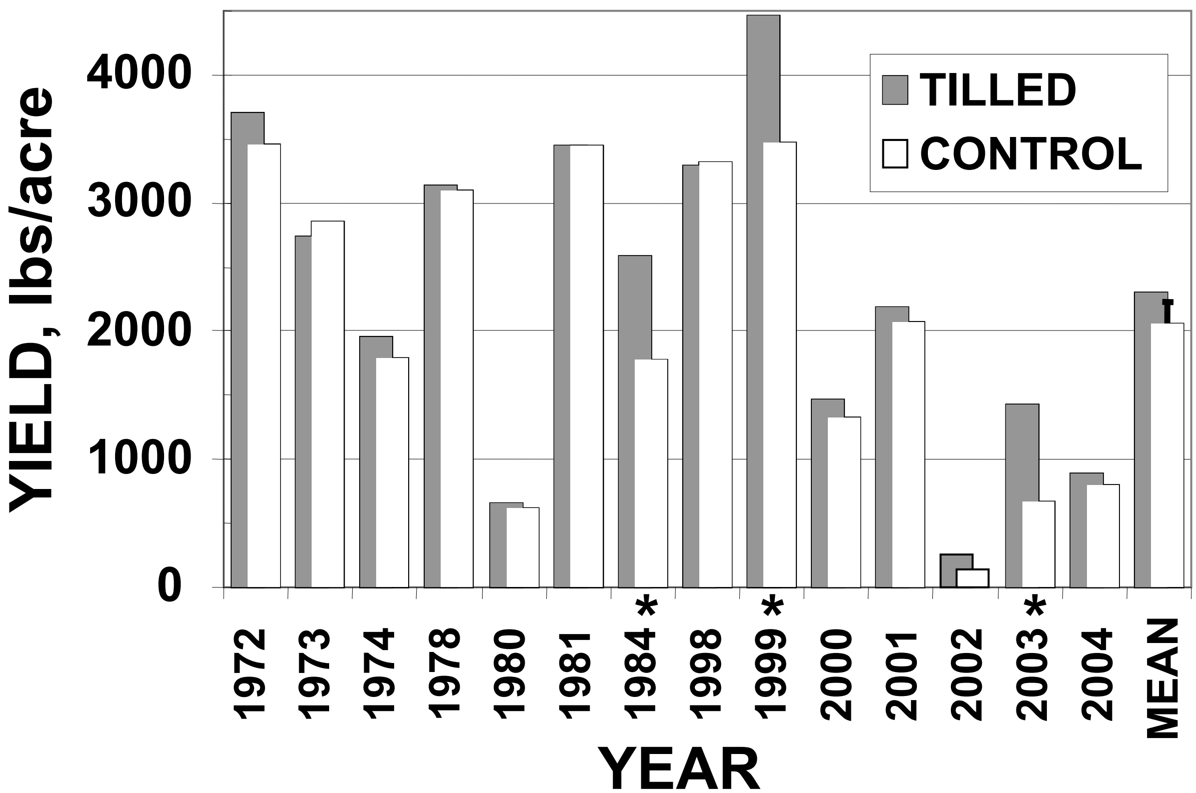

Figure 6. Sorghum grain yield for paired tillage treatments by year. Asterisks denote those years with early post planting precipitation > 3 in.

Conservation tillage retains surface residue that reduce evaporation and increase rain infiltration; however, we measured increased infiltration where deep tillage had been used to eliminate dense subsoil layers. Profile modifying deep tillage reduced soil penetration resistance and, to a lesser extent, soil bulk-density during a long-term, 30-year, evaluation. Ponded infiltration increased significantly with deep tillage because of improved drainage through the subsoil. The sustained benefits of deep tillage suggest that the dense subsoil layers did not completely redevelop after 30 years, which extends the period to recoup the 1971 installation costs of $65 per acre. Although it is difficult to characterize all the factors governing crop yield response to deep tillage treatments, increased root growth expands the soil volume a crop explores for the water needed to increase dryland yield. However, the 10% increase in mean grain sorghum yield on deep tillage plots was largely (> 50%) attributed to overcoming an infrequent problem of poor soil drainage. For a Pullman soil, deep plowing may be an economical soil modification treatment to use with conservation systems because of sustained yield increases that extend the period to recoup installation costs.

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