RESIDUE MANAGEMENT AND PARATILLAGE EFFECTS ON RAIN INFILTRATION

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ABSTRACT

Dryland winter wheat (Triticum aestivum L.) and grain sorghum [Sorghum bicolor (L.) Moench] are grown on the semiarid North American Great Plains using the wheat-sorghum-fallow (WSF) cropping sequence. When used with WSF, no-tillage (NT) or stubble mulch tillage (SM) management reduces evaporation and increases yields. However, soil consolidation with NT, increases runoff compared to SM. Our objectives were to characterize the effects of paratill (PT) on rain infiltration into a Pullman clay loam soil (fine, mixed, superactive, thermic Torrertic Paleustoll) with either NT or SM management. Six contour-farmed level-terraced watersheds were dryland cropped using a WSF rotation with NT or SM management and divided into subplots (four replications) that were paratilled to a 0.35-m depth at 0.75-m intervals following sorghum harvest. Approximately 8 months later (before planting wheat), steady infiltration of rainwater was determined for each tillage combination using a rotating disk rainfall simulator with a 48 mm h⁻¹ intensity. Cumulative infiltration was 32.4 ± 3.9 mm for SM compared with 21.9 ± 2.5 mm for NT, but PT caused no significant increase in infiltration, i.e., infiltration with PT was 26.7 ± 5.7 compared to 27.5 ± 7.4 mm without PT. Measured cone penetrometer resistance and bulk density decreased with PT to treatment depth with NT management; however, the SM sweep operations may have consolidated PT soil. We conclude that because rain infiltration was rapidly regulated by the formation of a soil surface crust, PT will not increase infiltration into clay loam soils managed with SM or NT residue systems.
INTRODUCTION

Stubblemulch tillage (SM) and no-tillage (NT) crop residue management are effective means of reducing evaporation and, thus, conserving precipitation for dryland crop production (Steiner, 1994; Jones & Popham, 1997). Because of limited wheat (*Triticum aestivum* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] yields under dryland conditions, the corresponding residue production is also limited. When residue production is too small to adequately intercept raindrop impact, soil crusts form, which reduces infiltration (Baumhardt et al., 1993) and water conservation. Compared to NT residue management, the use of SM maintains higher infiltration rates by fracturing infiltration limiting soil crusts and, consequently, reduces storm runoff (Jones et al., 1994). By reducing evaporation, the NT residue management system, however, results in significantly greater profile soil water contents compared to SM (Jones et al., 1994). Residue management that limits evaporation and maintain infiltration on clayloam soils may contribute towards increased water conservation and crop production levels.

Infiltration limiting soil crusts are fractured with SM tillage, but some residues (10 - 15%) are also incorporated. Paraplow tillage, PT, loosens the soil without incorporating surface residues so that soil porosity, and root and water penetration are increased, while most crop residues remain at the soil surface (Mukhtar et al., 1985; Busscher et al., 1988). Unger (1993) reported a similar initial reduction in soil density and penetration resistance to a depth of 0.3 m with PT on a Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) that, in some cases, was less than in NT plots for up to 4 years. He reported that the benefits of infrequent PT were not consistently retained by the soil. Cumulative ponded infiltration was increased with PT (Mukhtar et al., 1985; Clark et al., 1993), but these effects may not apply under raindrop impact conditions associated with natural or simulated rain.

We hypothesized that PT performed every 3 years (after sorghum harvest when the soil was dry) would destroy soil crusts, roughen the soil surface, and increase infiltration on NT managed fields during the first year. The research objectives were to determine the effects of PT on infiltration of simulated rainfall into soil under SM or NT residue management conditions.

MATERIALS AND METHODS

The research was conducted at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, USA, on six contour-farmed level-terrace watersheds. These watersheds, described by Hauser et al. (1962), range in area from 2.3 to 4.1 ha and have a gently sloping (1-2%) Pullman clay loam soil. They were cropped in a wheat – fallow – grain sorghum (WSF) rotation, which produces two crops in 3 years with an 11-month fallow (noncropped) period preceding each crop (Fig. 1.). Each phase of the WSF sequence was present each year. Winter wheat, TAM 107\(^1\) (Foundation Seed, College Station, TX), was sown on all wheat plots in late September or early October at a 40 kg ha\(^{-1}\) rate to achieve 2.5x10\(^6\) plants ha\(^{-1}\)

\(^1\) The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA – Agricultural Research Service. Mention of a pesticide does not constitute a recommendation for use nor does it imply registration under FIFRA as amended.
using a high-clearance grain drill with hoe openers and press wheels at a 0.3-m row spacing. Grain sorghum, Dekalb hybrid “DK41Y” (DeKalb, IL), was seeded in rows 0.75 m apart during early to mid-June at 80,000 seed ha⁻¹, using ‘Max-Emerge™’ (John Deere, East Moline, IL) unit planters. Growing season weed control consisted of 1.7 kg a.i. ha⁻¹ propazine [6-chloro-N,N’-bis (1-methylethyl)-1,3,5-triazine-2,4-diamine] applied pre-emergence after sorghum planting and 0.6 kg a.i. ha⁻¹ 2,4-D [(2,4-dichlorophenoxy) acetic acid] applied on growing wheat in late February during some years to control flixweed [Descurainia sophia (L.) Webb ex Prantl].

The six watersheds were divided into two groups that received either NT or SM residue management. On the NT watersheds, weeds were chemically controlled during fallow (Table 1), resulting in no soil disturbance except for seeding the crops and one paratillage operation performed every 3 years on subplots. Weeds were controlled on SM watersheds using a 4.6-m-wide Richardson sweep plow (Sunflower Man. Co., Inc., Beloit, Kansas, USA) that had one 1.5- and two 1.8-m-wide overlapping V-shaped blades and an attached mulch treader. Beginning in 1988, paratillage (PT) and no-paratillage (NO-PT) subplots (35 X 40 m, 4 replications) were superimposed over both the NT and SM management system areas following sorghum harvest. Thus, 3 years elapsed between each PT treatment. The paratillage implement (Tye
Table 1. Chemical weed control applications for the NT, no-tillage, system used at Bushland, TX, with the 3-y wheat-fallow-sorghum rotation.

<table>
<thead>
<tr>
<th>WSF Rotation Sequence Stage</th>
<th>Chemical Application</th>
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<tbody>
<tr>
<td>Fallow wheat harvest (July-Y1)</td>
<td>3.36 kg a.i. ha(^{-1}) atrazine(^{†})</td>
</tr>
<tr>
<td>Before sorghum planting (June-Y2)</td>
<td>0.84 kg a.i. ha(^{-1}) 2,4-D(^{‡})</td>
</tr>
<tr>
<td>Seasonal weed control in sorghum (June – Y2)</td>
<td>0.56 kg a.i. ha(^{-1}) glyphosate(^{§})</td>
</tr>
<tr>
<td>Mid-fallow sorghum (Feb.-Y3)</td>
<td>1.68 kg a.i. ha(^{-1}) propazine(^{¶})</td>
</tr>
<tr>
<td>Before wheat planting (Oct.-Y3)</td>
<td>0.023 kg a.i. ha(^{-1}) chlorosulfuron(^{#})</td>
</tr>
<tr>
<td>Any weed control during fallow periods</td>
<td>0.37 kg a.i. ha(^{-1}) 2,4-D</td>
</tr>
<tr>
<td></td>
<td>0.56 kg a.i. ha(^{-1}) glyphosate</td>
</tr>
<tr>
<td></td>
<td>0.37 kg a.i. ha(^{-1}) 2,4-D</td>
</tr>
</tbody>
</table>

\(^{†}\) atrazine = [6-chloro-N-ethyl-N’-(1-methylethyl)-1,3,5-triazine-2,4-diamine]  
\(^{‡}\) 2,4-D = [(2,4-dichlorophenoxy) acetic acid]  
\(^{§}\) glyphosate = [N-(phosphonomethyl) glycine]  
\(^{¶}\) propazine = [6-chloro-N,N’-bis (1-methylethyl)-1,3,5-triazine-2,4-diamine]  
\(^{#}\) chlorosulfuron = [2-chloro-N[[4-(methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl] benzenesulfonamide]

Co., Lockney, Texas, USA), consisting of four paratill legs mounted on a tool bar at 0.75-m intervals and preceded by residue cutting coulters, was operated at a 0.35-m depth.

Infiltration was measured in September 1991, approximately 9 months after paratillage, near the end of the fallow after sorghum and just prior to sowing wheat. Cistern stored rainwater [pH of 7.3, electrolyte concentration of 16.0 mg kg\(^{-1}\), and a SAR of 0.02 (mmol L\(^{-1}\)) \(^{-1/2}\)] was applied at a rate of 48 mm h\(^{-1}\) to undisturbed nearly level residue treatment plots using a rotating-disk rainfall simulator with an impact energy of 22 J mm\(^{-1}\) m\(^{-2}\) (Morin et al., 1967). This intensity approximates the 40 mm h\(^{-1}\) of the average 60-minute duration rainstorm in this region (Frederick et al., 1977) with an impact energy of approximately 80% of natural rainfall. The infiltration measurement area was contained within a 1.5-m\(^2\) by 0.2-m high metal frame pressed 50 mm into the soil. Runoff water captured by the frame was removed by a peristaltic pump and collected in a graduated cylinder for measurement during water application. Infiltration, calculated as the difference between applied water and collected runoff, was measured until a quasi-steady state infiltration rate had been achieved (at about 100 mm rain).

Other measurements included soil core samples for determining gravimetric soil water content and bulk density to a depth of 0.75 m. Cone penetration resistance was measured using the methods of Unger and Jones (1998) to a depth of 0.30 m with a hand penetrometer that recorded the depth and resistance force (Bush Soil Penetrometer SP10, Findlay Irvine, Penicuik, UK). Cumulative infiltration and other data were analyzed according to
analysis of variance methods (SAS Inst., 1988), while infiltration rate, recorded as a function of applied water depth, data were fitted using nonlinear regression methods described by Baumhardt et al. (1990).

![Graph showing soil penetration resistance](image)

**Fig. 2.** Soil penetration resistance, PR, plotted with depth for no paratillage, PT, and stubble mulch, SM, (A) or no-tillage, NT, (B) residue management and the corresponding PT used with SM (C) or NT (D). The PR through soil loosened by PT was reduced for NT; however, PR of soil receiving SM tillage was unaffected by PT.
RESULTS AND DISCUSSION

Penetration Resistance and Bulk Density

Paratillage is used to loosen the soil thereby reducing soil density and penetration resistance. Soil penetration resistance data shown in Fig. 2 for SM and NT residue management systems with PT and NO-PT are consistent in magnitude with the values reported by Unger and Jones (1998). Stubblemulch tillage typically loosens the soil to 0.10-m depth, which reduces the penetration resistance regardless of the PT treatment (Fig. 2A and Fig. 2C). The peak penetration resistance did not exceed 2 MPa over the entire 0.30 m depth. Penetration resistance with depth in the SM plots was similar for the PT and NO-PT plots, thus suggesting that recompaction of the soil below the SM tillage depth occurred after 9 months. Penetration resistance in the NT plots with NO-PT (Fig. 2B) increased rapidly below 0.05 m depth to a maximum resistance of about 2.4 MPa. A benefit of SM tillage was to significantly reduce penetration resistance compared to NT plots with NO-PT. However, penetration resistance to a depth of 0.10 m for NT plots receiving PT was similar to either SM treatment. Compared to SM treatments, penetration resistance in NT plots was greatly reduced at depths below 0.10 m with PT (Fig. 2D). The corresponding peak

![Graph showing mean soil density plotted with depth for different tillage and residue management systems.](image)

Fig. 3. Mean soil bulk density plotted with depth for stubble mulch, SM (□), and no-tillage, NT (○), residue management with or without paratillage, PT, (filled). Soil was loosened above the PT depth and the near surface soil density was reduced by SM compared to NT.
penetration resistance was reduced to about 1.5 MPa. The effect of PT to reduce penetration resistance for more than 9 months was significant for the NT residue management system.

The corresponding soil bulk densities measured to a depth of 0.75 m in SM and NT residue management plots with or without PT are shown in Fig. 3. Soil was less dense with PT for both SM and NT residue management systems at the 0- to 0.30-m depth, that is, in the tillage zone. Soil density at the 0- to 0.10-m depth was significantly less with SM than with NT, but at greater depths the effect of residue management on density diminished. These data corroborate the penetration resistance data showing that the SM sweep plow and the PT reduced soil density above the tillage depth for as long as 9 months after the tillage operation.

Rain Infiltration

The effects of residue management and paratillage on infiltration rate are shown in Fig. 4. Observed infiltration rates were variable over the range of cumulative rain applied for both the PT and NO-PT plots.

Fig. 4. The infiltration rate into stubble mulch, SM, or no-tillage, NT, soil with or without paratillage, PT, plotted as a function of cumulative rain. While PT did not affect infiltration rate, NT reduced infiltration rate compared to SM tillage resulting in earlier runoff.
and resulted in no significant differences in infiltration rates for PT compared to NO-PT. While the use of profile loosening tillage, PT, resulted in significantly lower bulk density, the expected large differences in the initiation of runoff from the plots or infiltration rate were not observed. The corresponding measured cumulative infiltration after applying 48 mm rain with PT was 26.7 ± 5.7 compared to 27.5 ± 7.4 mm without PT. The resulting non-significant difference between PT treatments suggest that rain infiltration was not governed by the soil profile characteristics, unlike that reported for ponded infiltration (Mukhtar et al., 1985; Clark et al., 1988). During infiltration measurements into chisel tilled soil, Baumhardt et al. (1993) reported reduced infiltration due to rapid formation of surface crusts and soil profile reconsolidation.

Infiltration rate declined more rapidly with NT than with SM tillage, resulting in runoff with NT after application of about 3 mm of rain compared to about 15 mm of rain with SM. The delay in runoff for the SM tillage plots may have been due to the increased porosity of the less dense surface. Once runoff began, however, the mean infiltration rate in both SM and NT plots declined to quasi steady final infiltration rates of 8 mm h⁻¹ for NT compared to 5 mm h⁻¹ for SM plots.. The significant difference in cumulative infiltration of 32.4 ± 3.9 mm for SM compared to 21.9 ± 2.5 mm for NT was measured after the application of about 60 mm rain. We attributed this difference, primarily, to the infiltration before runoff began. Because of the similar final infiltration rates, we conclude that infiltration was regulated at the soil surface by the presence of or the rapid formation of a soil crust.

SUMMARY AND CONCLUSIONS

The effect of PT in NT or SM residue management systems was to reduce soil density and penetration resistance. Penetration resistance with depth in the SM plots was largely unaffected by PT after 9 months, which was attributed to recompaction of the soil below the SM tillage depth. Paratillage did, however, reduce penetration resistance in the NT plots. Differences in soil bulk density were similarly dependent on the position relative to the tillage depth, that is, the soil density was reduced in the tillage zone. While the PT treatment decreased penetration resistance and soil bulk density, it did not increase infiltration rate or amount of simulated rain. Rain infiltration into SM residue management system plots, however, was greater than in NT plots, which developed a soil crust shortly after rain application began. We conclude that because rain infiltration was rapidly regulated at the soil surface by the formation of a crust, PT will not increase infiltration into clay loam soils managed with SM or NT residue systems.

REFERENCES


