RESIDUE MANAGEMENT EFFECTS ON INFILTRATION INTO SEMI-ARID DRYLANDS

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ABSTRACT

Sustainable dryland production systems rely on effective methods of storing soil water for later use by crops. Residue-retaining conservation tillage systems first developed on the southern Great Plains for wind erosion control also have the added benefit of increasing the amount of precipitation stored as soil water. Residue in these conservation tillage systems intercepts raindrop impact, which reduces soil crust formation and surface compaction. Consequently, infiltration is greater and precipitation storage in the soil increased; however, in semiarid regions, dryland crops produce limited residue amounts that can render these residue management practices ineffective. This paper reviews and contrast studies characterizing residue effects on rain infiltration and annual storm runoff measured at Bushland and Lubbock, TX.

DRYLAND CROPPING SYSTEMS

This paper reviews research characterizing conservation tillage effects on rain infiltration and storm-water runoff. The High Plains portion of the southern Great Plains is at an elevation >3300 ft (1000 m) above mean sea level and has a semiarid continental climate characterized by high winds that promote evaporation. While pan evaporation over much of the region ranges from about 70 – 100 inches (1800 – 2500 mm) per year, precipitation (rain) is erratic in both temporal distribution and amount, ranging from 16 – 24 inches (400 – 600 mm) annually. For example, the mean annual precipitation at Bushland (Fig. 1) is ~19 in. (490 mm) or, ~25% of the 90 in. (2.3 m) annual pan evaporation (Dugas and Ainsworth, 1983). Precipitation stored as soil water and/or augmenting-irrigation is crucial to stabilize and increase summer crop yields. The importance of soil water storage was shown in separate studies, where the grain sorghum [*Sorghum bicolor* (L.) Moench] yield increased about 390 lbs ac^{-1} (430 kg ha^{-1}) (Jones and Hauser, 1975) to 430 lbs ac^{-1} (480 kg ha^{-1}) (Baumhardt et al., 1985) per inch (25 mm) stored soil water. Therefore, most dryland cropping systems in the southern Great Plains rely on fallow periods between crops to store precipitation.

Much of the southern Great Plains is suited to cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), and grain sorghum crops that are often grown with an intervening fallow period. For example, the wheat-sorghum-fallow (WSF) rotation has an 11-month fallow period preceding each crop (Fig. 2) and results in two crops in three years (Jones and Popham, 1997). Soil water storage with the WSF rotation is increased with no-tillage (NT) compared to conventional stubblemulch tillage (SM). While both practices retain some crop residue, NT is a more effective means of retaining residues at the soil surface. In a more intensive dryland cropping sequence, cotton is grown as an annual summer crop where the length of growing season is adequate. Cotton does not produce adequate residue to protect the soil from wind erosion regardless of tillage system; therefore, a green fallow of wheat seeded after cotton harvest (Fig. 3) was proposed to provide needed residue (Keeling et al., 1989). This practice provides both cash and cover crops when fall and spring precipitation (or irrigation) is adequate to establish cotton and wheat crop. Baumhardt and Lascano (1999) reported that residues retained from the terminated wheat increased infiltration and reduced runoff; however, crop establishment risks severely limited the success of applying this practice under dryland conditions in years with below average precipitation.

INFILTRATION

Retaining residue at the soil surface is crucial to the overall water availability to dryland crops by reducing evaporation (Lascano and Baumhardt, 1996) and by reducing raindrop impact. That is, with interception of raindrops by residues, structural soil crust formation is reduced and consequently infiltration is increased (Duley, 1939; McIntyre, 1958; Morin and Benyamini, 1977; Baumhardt et al., 1990). Crust formation increases proportionally with increasing raindrop impact; therefore, residue retaining tillage practices typically increase infiltration and reduce runoff if residue production is sufficient.

The effects of conventional and no-tillage residue management with dryland crops on rain infiltration was measured at Bushland and Lubbock, TX in several studies using similar methods during the fallow or summer growing season. Cistern stored rainwater [pH of 7.3, electrolyte concentration of 16.0 mg kg^{-1}, and a SAR of 0.02 (mmol $L^{-1})^{-1/2}$] at Bushland or well water [pH of 7.3, electrolyte concentration of 16.0 mg kg^{-1}, and a SAR of 0.02 (mmol $L^{-1})^{-1/2}$] at Lubbock was applied using a rotating-disk rainfall simulator (Morin et al., 1967) that produced about 80% of normal rainstorm impact energy (22 J mm^{-1} m^{-2}). Water was applied for 60 minutes at 3 in. h^{-1} (80 mm h^{-1}) in Lubbock or at 2 in. h^{-1} (48 mm h^{-1}) until a steady infiltration rate was observed at Bushland. These are the average 15- and 60-minute rain intensities for this region (Frederick et al., 1977). The infiltration measurement was centered between wheel tracks (when present) and contained within a 60 in. by 60 in. square (area = 2.25 m^2) metal frame pressed 2 in. (50 mm) into the soil. Runoff water captured within the frame was removed by a peristaltic pump and collected in a graduated cylindrical tank for measurement during rain simulation. Infiltration rate and amount were calculated as the difference between applied water and collected runoff.

Cumulative infiltration after one hour for the Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) at Bushland, TX, is reported by crop and tillage practice (Table 1). Compared with NT, the SM tillage practice significantly (P=0.01) increased infiltration amount in fallowed sorghum residue plots but not in fallowed wheat residue plots. This was not attributed to differences in mean initial gravimetric water content, which were about 15% (15 g kg^{-1}) in 1994 and 23% (23 g kg^{-1}) in 2000 for the surface 6 in. (0.15 m) and did not vary with residue management. Wheat straw is less woody and smaller stemmed than grain sorghum stubble and, therefore, the residues more completely covered the soil, reduced crust formation by raindrop impact, and increased infiltration. The difference in cumulative infiltration observed between SM and NT tillage practices for the fallowed sorghum residue plots, however, suggest that continued exposure of the soil to rain during the fallow period consolidated the soil surface into a crust that limited infiltration until it was fractured by the SM tillage. Similarity in cumulative infiltration between SM and NT tillage by wheat residue treatment and SM tillage by sorghum residue treatment, further suggest that the more complete cover of residues during fallow after wheat reduced the gradual surface consolidation and crusting process.

Use of sub-soil tillage to offset the effects of surface consolidation and crusting that limited cumulative infiltration in NT but not in SM was ineffective. Residue management and one-time tillage effects on cumulative infiltration were measured during fallow after sorghum (Table 1). Infiltration with SM was greater than with NT residue management as expected, but the use of subsoil tillage resulted in no consistent change. The use of a single sweep tillage operation to fracture the soil early in the fallow period, also, did not increase infiltration. That is, tillage practices used to fracture the crusted soil surfaces did not have a sustained effect on infiltration. Because the amount of residue produced by dryland grain sorghum is limited and provides little protection from raindrop impact, infiltration is improved with periodic tillage used with SM residue management.

The three-year mean cumulative infiltration into conventionally disk tilled or NT Amarillo (fine-loamy, mixed, thermic Aridic Paleustalf) and Olton (fine, mixed, superactive, thermic Aridic Paleustoll) soil offer similar results for dryland cropping systems that produce limited residue. For example, cumulative rain infiltration was greater with disk tillage than NT for both the Amarillo and Olton soils when continuously cropped to cotton (Table 1). Cumulative infiltration after NT dryland sorghum, another limited residue producer, was the same or less than conventionally tilled cotton. Using NT systems for maintaining residue at the soil surface to intercept raindrop impact and, consequently, increase infiltration was unsupported by these data. However, the increased soil cover achieved with NT wheat, in contrast to NT cotton and sorghum, did result in comparable or greater cumulative infiltration than with conventional disk tillage. The initial surface 6 in. (0.15 m) volumetric water content was about 8% (8.0 m^3 m^{-3}) for the Amarillo and 12% (12 m^3 m^{-3}) for the Olton soils, but no residue management effect on water content was indicated.

Protecting the soil from raindrop impact with an energy barrier or with adequate wheat residue increased infiltration significantly over bare soil at Lubbock (Baumhardt and Lascano, 1996). In that study, cumulative infiltration after one hour increased with increasing residue until the amount approached 2200 lbs ac^{-1} (2.5 Mg ha^{-1}), which was sufficient to protect the soil from raindrop impact. Because additional wheat residue did not increase infiltration, they concluded that infiltration would increase with increasing residue until a threshold amount had been achieved, when further additions would not affect infiltration. Benefits of wheat residues to increase infiltration are consistent with results reported elsewhere (Alberts and Neibling, 1994); however, infiltration and crop water management in semiarid regions is governed by residue production under dryland conditions that, often, is insufficient to protect the soil.

STORM WATER RUNOFF

While residues retained at the soil surface were insufficient to increase infiltration regardless of management practices during a single observation, sustained residue management effects on infiltration can be deduced from storm-water runoff measurements. Seasonal runoff was measured during the WSF cropping sequence from gauged watersheds under conventional SM and NT residue management (Jones et al., 1994). Briefly, six contour-farmed gradedterraced watersheds ranging in area from ~ 6 to 10 acres (2.3 to 4.1 ha) with a gently sloping (1-2%) Pullman clay loam were instrumented with calibrated flumes and water level recorders. The watersheds were cropped in a WSF rotation, with each phase of the rotation present every year, using no-tillage and conventional stubblemulch tillage.

In that study, mean annual runoff measured since 1984 has averaged 1.7 inches (44 mm) more with no-tillage during the three year WSF cycle than with stubblemulch tillage. Most of the annual runoff was measured during fallow periods between crops when the available soil porespace filled. Tillage effects resulted in about 1.5 in. (40 mm) more runoff from NT than from SM watersheds during fallow after sorghum and 0.35 in. (~9 mm) more from NT than SM watersheds during fallow after wheat. This was attributed to i) greater precipitation during the spring fallow than during summer and winter fallow months, and ii) limited soil cover provided by sparse sorghum residues that favored the development of infiltration limiting soil crusts compared to more complete residue cover with wheat stubble. Runoff was limited during the wheat and sorghum growing seasons and resulted in < .25 inch (5.2 mm) difference between SM and NT residue management. This was attributed to i) crop water use that sufficiently depleted soil water to allow rain infiltration and minimize tillage effects, and ii) crop canopy cover that similarly intercepted raindrop impact for both tillage treatments.

In studies with comparable objectives, Baumhardt et al. (1993b) measured storm runoff from gauged micro-watersheds installed in field plots on Olton and Amarillo soils (Baumhardt and Lascano, 1999). Field plots were cropped to cotton in an annual cotton rotation with sorghum (Baumhardt et al., 1993b) or as continuous cotton using conventional clean tillage or a chemically terminated wheat green-fallow (Baumhardt and Lascano, 1999). Within these plots, runoff was measured from 10 ft. x 75-100 ft. (3m x 25-33m) micro-watersheds instrumented with calibrated flumes and water level recorders. These runoff measurements were made during studies of much shorter, 3-4 year, duration.

Runoff was usually measured during intense rainstorms with depths exceeding 1.5 in. (35 mm) that occurred during the fall, September and October, or summer, May through July, months. Residue cover was most effective in reducing runoff before the crop canopy had fully developed, thus closing the space between rows and intercepting raindrop impact. After cotton defoliation and harvest, very little plant material or residues were present to protect the soil, but the limited winter precipitation did not contribute to runoff. The measured runoff from an Amarillo soil cropped to conventionally tilled cotton averaged 1.8 in. (46 mm) more than from cotton grown in the terminated wheat green-fallow plots (Baumhardt and Lascano, 1999). That is, the terminated winter wheat green-fallow promoted better infiltration by providing a crop residue cover to intercept raindrops. Similarly, Baumhardt et al. (1993b) measured about 0.7 in. (16 mm) less runoff from an Olton soil cropped to cotton grown after no-till sorghum than after conventional disk tillage sorghum. Both the coarse-textured Amarillo and finer-textured Olton soils appeared to benefit from even limited residues that intercepted raindrops, reduced soil crust formation, and consequently increased infiltration.

SUMMARY

Dryland cropping systems of the semiarid southern Great Plains rely on fallow periods between crops to store sufficient precipitation in the soil for sustainable production (Jones and Popham, 1997). Because of the limited water available for dryland cropping systems in the semiarid Great Plains, both crop growth and the corresponding residue production is restricted. Consequently, the degree of protection provided against raindrop impact is inadequate and soil crust formation reduces infiltration. Soil crust formation and compaction of the surface reduces infiltration when using NT compared with conventional SM tillage regardless of soil type, but this may be more prevalent in fine textured soils. Infiltration was improved, however, when tillage practices disturbed the soil surface. When residues are limited, as in the case of semiarid dryland crop production, infiltration benefits from soil-disturbing SM tillage that fractures crusts.

Increased runoff from NT compared to SM residue management plots further corroborates infiltration measurements. That is, runoff data from Lubbock and Bushland revealed that runoff from plots with wheat residue was generally similar to runoff from conventionally managed plots, or less than from plots with sorghum or cotton residues. These results suggest that reduced runoff can be expected with the more complete residue cover achieved by wheat compared to sorghum that has not received tillage to fracture surface soil crusts. Compared to the conventional SM tillage, however, NT residue management increases the amount of water stored in the soil. The greater soil water conservation with NT is likely attributable to reduced evaporation.

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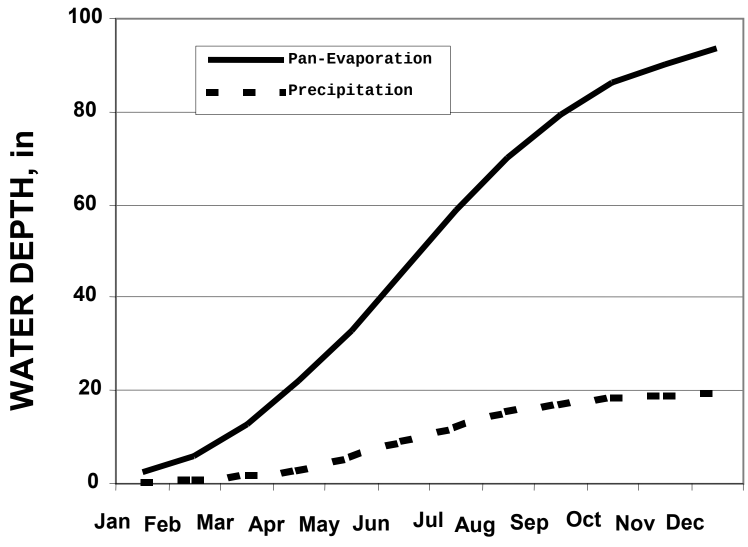
Table 1. Rain infiltration after one hour into Pullman, Olton, and Amarillo soils at Bushland and Lubbock with conventional tillage (Disk, SM) or no-tillage of cotton, sorghum, and wheat residues measured during fallow.

Location - Soil	Crop Residue	Tillage	Infiltration Amount, in. (mm)
At Bushland - Pullman	Sorghum	SM	1.69 (43)
(Jones et al., 1994)		NT	1.04 (27)
	Wheat	SM	1.73 (44)
		NT	1.65 (42)
Baumhardt and Jones (2000)	Sorghum	SM	1.34 (34)
		SM + Subsoil	1.22 (31)
		NT	0.75 (19)
		NT + Subsoil	0.91 (23)
		NT + Sweep	0.71 (18)
At Lubbock			
(Baumhardt et al. 1993a)			
Amarillo soil	Cotton	Disk	1.95 (50)
	Cotton	NT	1.78 (45)
	Sorghum	NT	1.95 (50)
	Wheat	NT	2.31 (59)
Olton soil	Cotton	Disk	2.31 (59)
	Cotton	NT	1.78 (52)
	Sorghum	NT	2.17 (55)
	Wheat	NT	2.31 (59)



MONTH

Fig. 1. Long-term monthly cumulative precipitation and pan evaporation at Bushland, TX.

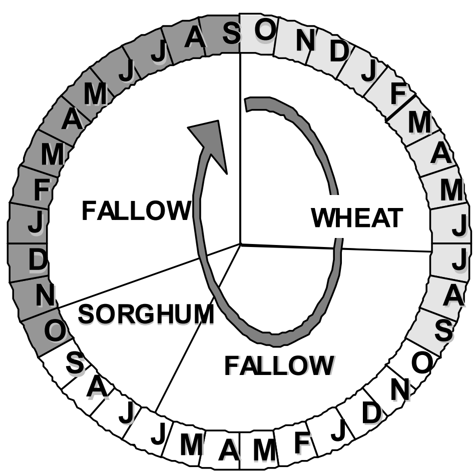


Fig. 2. The WSF crop rotation diagramed as a three year cycle beginning in October (top) with wheat establishment. Wheat is harvested 10-months later in July when the soil is fallowed until June of the second year (11-months). Grain sorghum is then grown using soil water stored during fallow to augment rainfall. After sorghum harvest in November of the third year the soil is again fallowed for 10-months when wheat is planted and the cycle repeated.

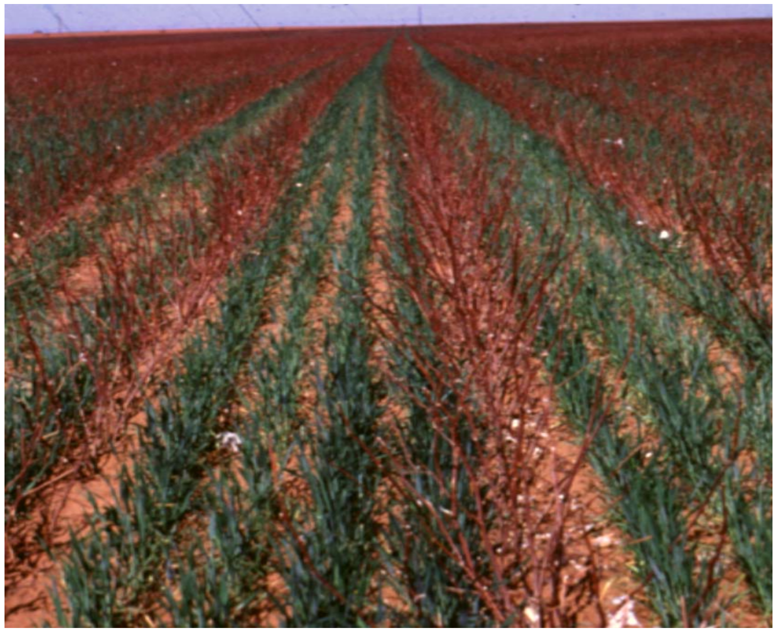


Fig. 3. Residue management of annually grown cotton with winter wheat sown as a green fallow crop after cotton harvest. Wheat is chemically terminated in the spring and cotton replanting.