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Soil water storage and precipitation storage efficiency of conservation tillage systems

D.L. Tanaka and R.L. Anderson

ABSTRACT: Surface residues associated with no-till and minimum-till fallow systems have an influence on soil water storage. Soil water storage, precipitation storage efficiency, and the relationship of soil water storage and precipitation for seasonal segments of fallow were determined for no-till (NT), minimum-till (MT), and stubble-mulch (SM) winter wheat-fallow methods. The study was conducted on a Williams Loam (fine-loamy, mixed, Typic Argiborolls) near Sidney, Montana for 8 fallow seasons. Fallow methods did not significantly influence long-term soil water storage during the after-harvest (August-October 31) or over-winter (November 1-May 1) segments because after-harvest weed control was not needed. Precipitation storage efficiencies were greatest for the over-winter segment (59%) and least for the summerfallow segment (13 to 20%). No-till and MT stored 12% (12-14 mm more) more soil water and increased precipitation storage efficiency 16% when compared to SM for the 14-month fallow season. By using fallow segment relationships for precipitation and soil water storage, producers may be able to go to more intensive cropping systems that take advantage of additional soil water.

Wheat (*Triticum aestivum* L.) production in the semi-arid Northern Plains is limited by low and variable precipitation. Fallow is used in wheat production areas receiving 400 mm (16 in.) or less annual precipitation to increase soil water storage, reduce the likelihood of crop failure, control weeds, increase nutrient availability, and as a substitute for a diversified crop rotation. Fallow has evolved from dust-mulch fallow to stubble-mulch fallow from 1916 to 1975, with minimum-till and no-till fallow gaining in popularity from 1975 to the present.

Mathews and Army (1960) summarized almost 50 years of soil water storage data obtained using dust-mulch fallow for the Great Plains and found that precipitation storage efficiency (the percent of precipitation stored in the soil during fallow) decreased from the northern to the southern Great Plains. They concluded that precipitation storage efficiency was not likely to improve unless a method was devised to reduce soil water evaporation. Soil water loss due to deep percolation in these dry areas was negligible. During the past several years, new fallow techniques and methods with less tillage, reduce surface residue burial which increase the quantity of surface residue and protect the soil from erosion (Fenster and Peterson 1979). In addition, surface residues suppress evaporation and increase precipitation storage efficiency. For example, in the central Great Plains precipitation storage efficiency has increased from 16% for dust-mulch fallow to almost 50% for no-

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Interpretive summary

Increasing popularity of no-till and minimun-till fallow systems has greatly incresed quantities of surface residue for soil water storage and wind and water erosion control. In the Northern Plains, long-term winter wheat-fallow systems that included no-till, minimum-till, and stubble mulch fallow methods were examined. Soil water storage and precipitatin storage efficiencies were the greatest for the over-winter segment and least for the summer fallow segment. The greater quantities of surface residue for no-till and minimum-till fallow is the key to improved soil water storage and precipitation storage efficiency when compared to stubble-mulch fallow. Producers may be able to use more intensive cropping systems that take advantage of additional soil water by using fallow segment relationships for precipitation and soil water storage.

Key words: crop residue, erosion, fallow, minimum-till, precipitation storage efficiency, soil water, stubble-mulch, winter wheat.

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till fallow in 70 years (Good and Smika 1978; Greb et al. 1979; Greb 1983). Surface residue loss during the 14-month winter wheat fallow period was 20 to 30% for no-till fallow compared to a loss of 50 to 80% for stubble-mulch fallow (Fenster and Peterson 1979; Tanaka 1986).

The objectives of our research were: (1) to determine precipitation storage efficiency and soil water storage for long-term (8 fallow seasons) winter wheat-fallow systems by fallow segments, and (2) develop relationships between precipitation and soil water storage by fallow segments for stubble-mulch (SM), minimum-till (MT), and no-till (NT) fallow methods in the Northern Plains. The purpose of this paper is to show long-term trends in soil water storage and precipitation storage efficiency as influenced by fallow methods in the Northern Plains, and to project soil water storage by fallow segments to be used for cropping systems that crop more than every other year.

Material and methods

Long-term winter wheat cropping systems studies were initiated 11 km (6.38 mi) northwest of Sidney, Montana in the spring of 1980 on a Williams loam (fine-loam, mixed, Typic Argiborolls), that can hold about 340 mm (13.40 in) of plant available water in the 1.7 m (5.58 ft) soil profile. Four replications each of SM, MT, and NT fallow method were arranged in a randomized complete block design with crop and fallow plots present each year. Plot size was 7.3 x 40 m (23.94 x 131.20 ft).

The 14-month fallow season began after-harvest in July or August and was divided into seasonal segments of: (1) after-harvest (harvest through October 31); (2) over-winter (November 1 through April 30); and (3) summerfallow (May 1 to seeding another winter wheat crop about September 10).

Stubble-mulch plots were tilled with a 2.1 m (6.89 ft) V-blade (similar to an undercutter or sweep plow) in late May to a depth of approximately 100 mm (3.94 in) followed by two or three additional rodweeder operations in late June through August as needed to control weeds. A rodweeder has a rod that rotates opposite the direction of travel to remove weeds with shallow tillage and was operated at a depth less than 40 mm (1.58 in). The seedbed was prepared and weeds controlled with a tandem disk harrow operated at a depth of approximately 50 mm (1.97 in) prior to seeding winter wheat.

Weeds on MT and NT plots during fallow from the fall of 1981 to seeding winter wheat in 1982 were controlled using glyphosate (Roundup)[1] as needed (3 to 5 times) at rates of 0.4 to 0.8 kg a.i.ha^{-1} (Tanaka 1985). Beginning in 1982, pronamide (Kerb) plus chlorsulfuron (Glean) at rates of 560 and 14 g a.i. ha^{-1}, respectively, were applied in late September of each year on MT and NT plots to control weeds. On MT, a V-blade tillage in late June and a V-blade or rodweeder operation prior to seeding were substituted for herbicide applications. On NT, glyphosate was applied one or two times during fallow, as needed for additional weed control.

Stubble on all treatments was left standing during the after-harvest and over-winter segments of the fallow season. The quantity of surface residue at harvest was determined by removing all above ground phytomass from 0.42-m^2 (4.52 ft^2) in two locations per plot. Samples were thrashed and grain weight was subtracted from phytomass weight to determine residue. Surface residue included leaves, stems, and head parts with almost no residue from previous crops. Quantity of surface residue prior to seeding wheat was determined by sampling two 1-m^2 (10.76 ft^2) areas per plot (Whitfield et al 1962). Only residue on the soil surface was determined with partially buried residue severed at the soil surface.

In situ soil, water content to a depth of 1.7 m (5.5 ft), in 0.20-m (.66 ft) increments, was determined by use of a neutron moisture meter (1 access tube per plot). The neutron moisture meter calibrations were checked periodically against gravimetric soil water samples under dry and wet soil conditions. The coefficient of variation associated with soil water content measurements was about 5% (data not shown). The first measurement had a 0.20-m (.66 ft) depth and accounted for soil water in the upper 0.30 m (.98 ft) of soil. Soil water contents were determined for 8 fallow seasons from 1981 through 1989.

Soil water storage for each segment was calculated by subtracting soil water content at the end of each seasonal segment from soil water content at the beginning of the segment. Soil water storage for the 14-month fallow season was calculated by

Table 1. Precipitation for seasonal fallow segments at Sidney, Montana from 1981 through 1989

Fallow season	Seasonal segment After-harvest (Aug.-Nov.)	Over-winter (Nov.-May)	Summer fallow (May-OCt.)	14-month fallow (total)
	mm			
1981-1982	105	128	161	394
1982-1983	109	44	126	279
1983-1984	44	63	116	223
1984-1985	48	68	163	279
1985-1986	112	148	197	457
1986-1987	105	64	178	347
1987-1988	54	81	93	228
1988-1989	53	110	113	276
Study avg.(8 yr)	80	84	146	310
Long-term (41- yr avg)	93	82	222	397

Table 2. Monthly average precipitation and precipitation adjacent to the study from 1981 to 1989 at Sidney, Montana

	Long-term avg (1949-1989)	1981	1982	1983	1984	1985	1986	1987	1988	1989	Study avg
	mm										
January	10	1	27	8	12	2	6	2	26	0	11
February	9	5	12	3	1	2	16	3	29	0	9
March	13	5	39	12	12	14	14	18	18	30	20
April	28	27	25	1	17	33	37	19	2	60	28
May	50	25	55	19	5	45	64	74	16	48	44
June	69	91	61	40	75	9	53	32	18	22	50
July	45	41	24	47	5	29	61	46	11	7	34
August	38	40	20	14	15	52	8	25	3	32	26
September	33	15	22	15	26	29	90	28	47	4	34
October	21	20	67	15	4	31	7	1	4	51	25
November	11	10	3	8	13	50	16	5	7	15	16
December	11	15	17	13	4	25	1	0	13	36	16

[1]Only research results are reported. Mention of pesticides does not constitute a recommendation for use by USDA, nor does it imply registration under FIFRA as amended.

subtracting soil water content prior to seeding another crop from soil water content at harvest of the previous crop. Precipitation storage efficiency, the percent of precipitation stored during each fallow segment, was calculated by dividing the soil water storage for each replication-treatment-year combination by the precipitation received during the segment. The 8-year fallow season average was determined by summing each combination for a particular treatment. Precipitation was measured adjacent to the study using a standard 203-mm (8-in) diameter. weighing gauge.

Soil water storage and precipitation data were used to develop regression relationships where (Y) is the predicted mm of soil water storage for the given mm of precipitation (X). Relationships, their statistical significance, and least significant differences (LSD) were determined using GLM (General Linear Models) at a probability level of 0.05 (SAS Institute 1987).

Results and discussion

Precipitation for the eight fallow seasons was about 78% of the long-term average of 397 mm (15.64 in) (Table 1). Of the eight fallow seasons, two had about 397 mm (15.64) or more precipitation and five were less than 300 mm(11.82 in). All summer segments of the 14-month fallow season were drier than the long-term average because of less than average precipitation for May, June, and July (Table 2). Precipitation for the summer segment was 47% of the 14-month total precipitation during the study compared to 56% of the 14-month total precipitation for the long-term.

The quantity of surface residue after-harvest was not different among fallow methods, except for the 1984-1985 and the 1988-1989 fallow seasons (Table 3). In these years, greater quantities of residue from previous crops remained on NT compared to MT and SM. Prior to seeding, NT had significantly more residue than MT or SM for all fallow seasons. In all but 3 years, NT had at least twice the quantity of surface residue as SM. Management of crop residue is the key to increasing precipitation storage efficiency for the entire fallow season by suppressing evaporation (Smika 1990). With careful crop residue management, the 20% average precipitation storage efficiency discussed by Mathews and Army (1960) for dust-mulch fallow in the Great Plains can be exceeded (Greb 1983).

Table 3. Quantity of winter wheat surface residue after harvest and prior to seeding for NT, MT, and SM fallow methods from 1981 through 1989 at Sidney, Montana

Fallow period	NT	MT	SM	†LSD 0.05
	kg ha⁻¹			
1981-1982				
After harvest	3670	—*	3670	†NS
Prior to seeding	2650	—	960	860
1982 1983				
After harvest	5340	5240	4520	NS
Prior to seeding	3080	2130	1530	520
1983 -984				
After harvest	3850	3740	3760	NS
Prior to seeding	3380	2490	2180	580
1984-1985				
After harvest	3270	2700	3170	500
Prior to seeding	2470	1180	1100	570
1985-1986				
After harvest	2440	2060	2020	NS
Prior to seeding	1640	560	360	220
1986-1987				
After harvest	2760	2770	3100	NS
Prior to seeding	1690	770	290	151
1987-1988				
After harvest	4040	4110	3840	NS
Prior to seeding	2540	1480	740	410
1988 1989				
After harvest	2000	1680	1640	230
Prior to seeding	—	—	—	—
Average				
After harvest	3420	3180	3220	—
Prior to seeding	2490	1440	1020	—

*Indicates no data was available

†LSD-least significant difference at the 0.05 probability level; NS-not significantly different

Fallow method did not influence soil water storage for the after-harvest (August-November) or over-winter (November-May) seasonal segments (Table 4). Soil water differences were not expected during these seasonal segments because stubble was left undisturbed on all treatments until spring. The precipitation storage efficiencies for the after-harvest and over-winter segments were about 38% and 59%, respectively. In the Central Great Plains, Nielsen and Anderson (1993) found precipitation storage efficiencies for the after-harvest segment ranged from 38% for SM to 58% for NT and during the over-winter segment efficiencies ranged from 62% for SM to 82% for NT. In the Northern Great Plains, Willis and Carlson (1962) found 70 to 80% of precipitation that fell on frozen soil was lost as runoff during the over-winter segment (30 to 20% precipitation storage efficiency). A practical method to reduce runoff during the over-winter segment and increase precipitation storage efficiency may be to perform a late fall tillage similar to the research that Papendick (1987) reviewed. He found that in the Pacific Northwest where annual precipitation was 350 mm (13.79 in), soil water storage during the over-winter segment, when compared to NT, was enhanced with a paraplow tillage operation prior to the soil freezing.

The summerfallow segment had the lowest soil water gain and precipitation storage efficiency even though about half of the 14-month fallow precipitation was received during this segment (Tables 1 and 4). Differences in surface residue during the early part of the summerfallow segment (May and June) can result in significant soil water storage differences since May and June are the highest precipitation months (Tanaka 1985). The likelihood of storing significantly more soil water during the summerfallow segment for NT and MT plots when compared to SM plots was greatest when the quantity of surface residue was at least 3,700 kg/ha (3,304.10 lb./a.) after-harvest or at least 2,500 kg/ha (2,232.50 lb./a.) when the first tillage for weed control occurred in mid-May (Tanaka 1986). In the northern Great Plains, the most rapid drying after a rain, during the summerfallow segment, occurs on a bare soil surface. Surface subtracting soil water content prior to seeding another crop from soil water content at harvest of the previous crop. Precipitation storage efficiency, the percent of precipitation stored during each fallow segment, was calculated by dividing the soil water storage for each replication-treatment-year combination by the precipitation received during the segment. The 8-year fallow season average was determined by summing each combination for a particular treatment. Precipitation was measured adjacent to the study using a standard 203-mm (8-in) diameter. weighing gauge.

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Precipitation during the summerfallow segment was erratic, with frequency and distribution below the long-term average (Table 5). Precipitation amounts less than 2 mm (.08 in) are usually not very effective in keeping the soil surface wet and contributions to the soil water reservoir are minimal or nonexistent during this high evaporative segment (Aase and Tanaka 1987). As the number of tillage operations increased from NT to SM, the r^2 values decreased. This may be the result of tillage causing increased evaporation when soils are wet as well as reducing quantities of surface residue. Figure 1 indicates that when soil water storage was >120 mm (4.728 in) for the after-harvest plus over-winter segments, precipitation storage efficiency for summerfallow was <10%. This data also suggests that the efficiency of storing precipitation once 100 mm has been stored is very low. Not only is precipitation storage efficiency lower with greater quantities of stored soil water, but this increased soil water storage does not result in increased winter wheat grain yield in winter wheat-fallow systems (Wilhelm et al. 1982; Tanaka and Aase 1987). Our long-term data agrees with Brown et al. (1981) who suggests cropping when soil water storage at seeding time is 50 to 100 mm (1.97 to 3.94 in).

Conclusions

Long-term trends indicate NT and MT can save 12% more soil water and increase precipitation storage efficiency 16% when compared to SM during the 14-month fallow season. Greater surface residue on NT and MT plots was the key to improved soil water storage and precipitation storage efficiency for the 8 fallow seasons which were drier than average. Average or above-average precipitation would enhance residue production and the benefits of surface residues. Improved efficiencies and average or above-average precipitation could result in movement of water and nutrients below the rooting depth of cereals in wheat-fallow systems and could cause saline seep conditions (Halvorson and Black 1974). Therefore, production systems that reduce the frequency of fallow may be needed to take advantage of the additional soil water. Intensive cropping may use precipitation more efficiently and control soil erosion better than the present wheat-fallow systems.

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