Mechanical Tillage for Conservation Fallow in the Semiarid Central Great Plains 1/ 2/

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Erratic rainfall and high winds are characteristic of the semiarid Central Great Plains. With these climatic conditions, annual dryland cropping gives unstable production. However, the use of fallow to minimize the influence of erratic precipitation has reduced the risk and largely stabilized winter wheat (Triticum aestivum L.) production in the area (14). The first recorded farmer use of fallow in the United States was in 1902 near McDonald, Kansas (12). Experiment station results with the use of fallow date back to 1910 (26). All crop residues were buried with moldboard plows in the early fallow systems. Moldboard plows were used largely because no other suitable tillage implements were available and because most early dryland farmers were accustomed to bare or clean-tilled soil. Also, the shallow disk planting equipment existing at that time would not seed through residue on the soil surface.

Although bare fallow resulted in higher soil water contents and generally stabilized crop production, it left the soil surface exposed and vulnerable to erosion by the frequent high-velocity winds of the area. During the 1930's when soil erosion by wind was a serious problem throughout the Great Plains, the practice of stubble mulch conservation farming was introduced in Canada and Nebraska. Conservation farming has been defined as "a system that is consistent with maintenance of a protective cover of crop residue on the soil surface at all times" (3). The conservation farming system has some disadvantages, and many farmers still will not use it. The purpose of this report is to compare basic aspects of bare and conservation mulch fallow systems where only mechanical tillage has been used. Results reported were collected in experiments conducted since 1960 at Akron, Colorado; Colby, Garden City, and Oakley, Kansas; Alliance, North Platte, and Sidney, Nebraska; and Archer Wyoming.

Experimental Results

Water conservation is the major purpose for fallow; therefore, this aspect will be considered in greatest detail. Comparison of the bare and conservation mulch fallow systems (the two basic systems) from seven Central Great Plains locations show an average of 1.0 more inch of water is stored with mulch than when the soil surface is bare during fallow (Table 1).

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2/ Proceedings of Conservation Tillage Workshop, Great Plains Agricultural Council Publication No. 77, Aug. 10-12, 1976, Fort Collins, CO. pp 78-91.

3/ Soil Scientist, USDA, Akron, Colorado 80720

Table 1. Net soil water gain at end of fallow for bare and conservation mulch fallow systems at 7 Central Great Plains locations.

Location	Soil Surface Conditions Bare	Mulch
	inches	
Akron, Colo. (6)*	5.61	6.82
Colby, Kans. (4)	4.52	5.56
Garden City, Kans. (6)	3.39	3.53
Oakley, Kans. (4)	3.24	5.14
N. Platte, Nebr. (8)	5.75	7.99
Alliance, Nebr. (8)	1.13	1.24
Archer, Wyo. (2)	1.10	1.67
Avg. All Locations	3.53	4.56

* Denotes years of experimental results.

These results comprise 38 years of experimental results. Actual increases range from 0.11 to 2.24 inches.

Delaying the initial tillage until spring (delayed fallow) has been advocated as an acceptable conservation practice. However, time of initial blade tillage during fallow can influence soil water storage in both fallow systems. Blade tillage after harvest at Akron resulted in 0.65 inch more soil water stored than when initial tillage was delayed until spring (Table 2). Tillage after harvest destroyed weeds that would have continued to use water until all available soil water was exhausted or the weeds were killed by frost. Although the single after harvest blade tillage increased water storage over no tillage, in wet years volunteer wheat and late germinating weeds may reduce water storage (Table 3).

Table 2. Effect of time of initial fallow tillage on end of fallow soil water content, Akron, Colo.

Time of Tillage	Soil Water Content
	in.
After harvest	8.39
Early spring (Apr. 1)	7.65
Mid-spring (May 1)	7.84

Table 3. Soil water storage during fallow as affected by tillage treatments after harvest, 1967-1970, Akron, Colo.

After harvest tillage treatment*	Soil Water Storage: Start of fallow to fall dormancy	Soil Water Storage: Total fallow period
	in.	in.
None	1.1	3.5
Disk - 1 wk.	1.3	2.5
Blade - 1 wk.	2.2	4.6
Blade - 5 wk.	2.0	4.2
Blade - 1 and 5 wk.	2.5	5.0

* Tillage the next spring and summer was the same on all treatments.

Soil water storage was highest both during the fall and the total fallow period where two blade tillages were performed.

How long the soil surface is bare during fallow affects total fallow period soil water storage. Burying the straw immediately after harvest resulted in 1.04 inches less stored soil water than when the straw was buried the following spring (Table 4). Spring burial of the straw resulted in 0.70 inch less water storage than when a straw mulch was maintained on the soil surface throughout fallow. The increased soil water storage for spring straw burial is attributed to the ability of standing wheat stubble to trap snow for subsequent soil water storage (21). The absence of standing stubble for snow water storage is also evident at Akron, Colo. where after harvest disk tillage was used (Table 3). Storage efficiency of snow water is usually greater than 50% and can exceed 100% due to trapping of snow by the standing stubble. During the summer months, net soil water gain is frequently very small (9, 10). However, with mulch, soil water

Table 4. Effect of time of straw burial during fallow on soil water content at the end of fallow, North Platte, Nebr.

Time of Straw Burial	Soil Water Content
	in.
After harvest	9.37
Early spring (Apr. 10)	10.41
No burial (cons. mulch)	11.14

loss will be minimized, thereby maximizing soil water storage. At Archer, Wyoming 50.5% of the incident solar radiation was reflected with bare soil, whereas 59.5% was reflected with a straw mulch on the soil surface. This reflection of 9% more radiation reduced evaporative potential, which in turn reduced soil water loss by 0.024 inch/day during 26 selected days beginning June 6 and ending August 30 (Table 5). At Akron standing wheat

Table 5 - Effect of straw position during fallow on soil water loss per day during fallow at Akron, Colorado and Archer, Wyoming.

Straw Position	Location		
	Akron*	Archer**	Avg.
	in/day		
All flat	0.022	--	--
All standing	0.017	0.044	0.031
Half standing - half flat	0.021	0.062	0.042
Bare soil	0.026	0.086	0.050

* July 24 to August 21 period - 29 days.

** June 9 to June 13; June 23 to June 30; July 17 to July 21 and Aug. 23 to Aug. 30 period - 26 days.

stubble reduced daily soil water loss by 0.009 inch/day compared to bare soil during a 29-day period starting July 24 and ending August 21 (Table 5). The position of the residue during the evaporative time also had some influence on soil water loss. Standing stubble was more effective in reducing soil water loss than where all residue was flat, probably because the stubble reduced wind velocity at the soil surface, which decreased turbulent transfer of water vapor to the atmosphere. The value of residue on the soil surface for soil water conservation is further emphasized by research at Akron and North Platte where increasing mulch from 3000 lbs/A to 6000 lbs/A increased soil water an average of 0.4 inch for each 1000 pounds of residue on the soil surface (Table 6). These amounts of residue most likely affected water storage by influencing evaporation losses. A thick layer of residue would reduce evaporation losses by slowing water vapor diffusion through the residue to the atmosphere.

Soil erosion by wind is a significant problem to agriculture in the Central Great Plains. Summer fallow has a reputation for being a major contributor to wind erosion. In the wheat-fallow rotation commonly used in the Central Great Plains, wind usually does not erode soil on the fallow land itself, but rather soil planted to wheat where the conservation mulch system was not used during fallow (11). Average annual soil loss per acre is 2.1 times higher from wheat planted in bare soil than from wheat planted in a conservation mulch (11). Therefore, the use of a conservation mulch

Table 6. Effect of initial fallow period residue rate on soil water content at the end of fallow at Akron, Colo. and N. Platte, Nebr.

	Location		
Residue Rate	Akron	N. Platte	Avg.
lbs/Ac.	in.		
3000	6.3	8.2	7.3
6000	7.4	9.3	8.4

may be necessary on most cropland to meet the legal restraints placed on air pollution from soil erosion by the passage of the Clean Air Act as amended in 1970 (PL 91-604).

Modern small grain planters can plant in straw mulches (24), therefore, we have little excuse for soil erosion by wind where straw production exceeds 2500 pounds per acre per crop. The amount of flattened residue needed for soil protection varies with soil texture (Table 7).

Table 7. Amounts of wheat residue required to prevent soil erosion by wind.

Texture Group	Residue Required	Ground Cover
	lbs/ac.	%
1. Course - sands & loamy sands	2200	69
2. Moderately coarse and fine - sandy loam, silty clay, and clays	1600	50
3. Medium and moderately fine - silt loam silt, and silty clay loams.	950	30

Also given in Table 7 is the approximate percentage of ground cover these residue amounts provide (6). Experiments conducted at 6 locations in the Central Great Plains compared bare and conservation mulch fallow systems. Tillage implement used and sequence of operation greatly influence the amount of residue destroyed by tillage during fallow (4, 22). Disregarding differences in initial mulch amounts and differences in tillage during fallow, the 6 locations averaged 1510 pounds of mulch per acre on the soil surface (Table 8), which provided approximately 47% soil surface coverage.

Table 8. Residue amounts on the soil surface at the end of bare and conservation mulch fallow systems at 6 locations in Central Great Plains locations.

Location	Texture Group	Fallow System Bare	Fallow System Mulch 1/
		— Pounds/Ac.	—
Colby, Kansas	3	420 2/	930
Garden City, Kansas	3	590 2/	2360
Oakley, Kansas	3	330 2/	1760
Alliance, Nebraska	2	0 3/	1350
North Platte, Nebraska	3	0 3/	1530
Archer, Wyoming	2	500 4/	1100
Average		310	1510

1/ All tillage operations were with subsurface equipment.

2/ Initial tillage operation was a tandem disk operated at approximately 5 inches deep with subsequent tillage with subsurface equipment

3/ Initial tillage operation was a moldboard plow operated at approximately 6 inches deep with subsequent tillage with subsurface equipment.

4/ Initial tillage operation was a oneway disk operated at approximately 4 inches deep with subsequent tillage with subsurface equipment.

Except for Colby, all locations having texture group 3 soils were able to maintain sufficient residue on the soil surface for wind erosion protection. The coarser textured soils in group 2 produced insufficient residue for soil protection.

A high percentage of soil aggregates greater than 0.84 mm (approximately 1/32 inch) in diameter will also protect soil from wind erosion. Soil aggregates this size and larger are not easily moved by wind. Results from 5 Central Great Plains locations show that a higher percentage of the soil surface aggregates are nonerodible with conservation mulch than when bare fallow practices are used (Table 9). The higher percentage of nonerodible aggregate fraction of the surface soil with conservation mulch practices is expected for two reasons. First, each operation of disk implements causes larger increases in erodible aggregates than blade implements (20, 23). Second, nonerodible soil aggregates are highly correlated with the concentration of fats, waxes, and oils in the soil ($r^2 = 0.74$). In turn, the concentration of fats, and oils in the soil are closely related to straw mulch rates up to 6,000 pounds per acre

Table 9. Percent nonerodible soil aggregates from 5 Central Great Plains locations using bare and conservation mulch tillage fallow systems.

Locations	Fallow Systems	
	Bare	Mulch
	%	
Akron, Colo.	66	72
Garden City, Kans.	51	80
Oakley, Kans.	55	66
N. Platte, Nebr.	60	64
Alliance, Nebr.	57	76
Avg. All Locations	58	72

(20). Thus the combined affects of absence of disk implements and the presence of straw mulch on the soil surface effectively increased the nonerodible soil aggregates in the surface soils at these 5 Central Great Plains locations. Tests have shown that to control wind erosion by nonerodible aggregates, the surface soil must contain a minimum of 67% soil aggregates larger than 0.84 mm in diameter (25). Two of the locations did not meet this minimum amount; therefore, in many instances the combined effects of surface mulch plus nonerodible aggregates may be needed to successfully control soil erosion by wind.

One of the criticisms of the conservation mulch fallow system has been that nitrate accumulation during fallow is decreased as compared with that on bare fallow. Data from 6 Central Great Plains locations support this general conclusion (Table 10). Lower NO_3-N accumulation

Table 10. Soil nitrate-N at the end of fallow at 6 Central Great Plains locations using bare and conservation mulch fallow systems.

Location	Fallow System	
	Bare	Mulch
	lbs/Ac.	
Akron, Colo. (6)*	122	114
Colby, Kans. (3)	82	52
Garden City, Kans. (1)	56	39
Oakley, Kans. (6)	62	72
Alliance, Nebr. (4)	113	107
N. Platte, Nebr. (6)	75	79
Avg. All Locations	85	77

* Denotes sampling depth.

with the mulch system may in part be due to NO_3-N tieup in decomposition of the residue. Research at Akron and North Platte has shown, however, that the tieup largely occurs in the first two cycles of a wheat-fallow rotation when going from a bare system to a mulch system. This probably occurs because of residue accumulation in the surface 3 inches of soil, which tends to reach an equilibrium after about two wheat-fallow cycles (8).

A more likely reason for lower NO_3-N accumulation with the mulch system than with the bare system is NO_3-N utilization by weed growth after harvest. When good fall weed control is practiced with the mulch system, soil nitrate accumulation can be equal to or greater than that with bare fallow (Table 11). Much of the difference in total fallow period NO_3-N accumulation occurred in the period from harvest to fall dormancy.

Table 11. Soil nitrate accumulation during fallow as affected by tillage treatments after harvest, Akron, Colo.

After harvest tillage treatment*	Soil Nitrate Accumulation: Start of fallow to fall dormancy	Soil Nitrate Accumulation: Total fallow period
	lb/ac.	lb/ac.
None	13	52
Disk - 1 wk.	15	62
Blade - 1 wk.	20	66
Blade - 5 wks.	16	67
Blade - 1 and 5 wks.	26	78

* Tillage the next spring and summer was the same on all treatments.

Approximately 75 pounds of nitrate-N per acre is removed from a 6-foot depth to produce a 40-bushel-per-acre grain crop with acceptable protein and straw levels. Considering that three of the sampling depths reported in Table 10 were less than 6 feet, nitrate-N in the soil of both systems should have been ample to produce 40 bushels of grain per acre. Support of this conclusion has been found at North Platte, Nebraska (16) and Colby, Kansas (13), where the application of nitrogen fertilizer would equalize soil nitrate-N levels between bare and mulched soils. However, grain yields were increased more by the fertilizer on the bare soil than on the mulched soil. Thus the mulch was having a depressing effect other than lower soil nitrate-N levels. Research at North Platte (15, 17) conclusively showed that in years when soil warms rapidly in the spring, the soil temperature in the crown zone of the wheat plant remains below the optimum for growth longer with mulch than with bare soil. The below-optimum crown zone soil temperature reduces tiller number per plant, number of heads per plant, number of spikelets per head and weight per head (15). Information obtained from eight locations in the Central Great Plains has shown that this situation would not occur in more than one year out of 10. However, the critical minimum temperature for reproductive development of wheat is not the same for all varieties and new varieties are being released annually, some of which are being developed specifically for the conservation mulch system.

Grain yields are occasionally less from the mulch system than from the bare system, but the overall average from 8 Central Great Plains locations shows a 2.5-bushel advantage for the mulch system (Table 12).

Table 12. Grain yield at 8 Central Great Plains locations with bare and conservation mulch fallow systems.

Location	Fallow System	
	Bare	Mulch
	bu/ac.	
Akron, Colo. (4)*	35.3	43.8
Colby, Kans. (4)	27.1	28.2
Garden City, Kans. (6)	19.8	23.6
Oakley, Kans. (4)	36.0	39.0
Alliance, Nebr. (8)	21.9	21.6
N. Platte, Nebr. (8)	40.0	43.0
Sidney, Nebr. (6)	38.3	38.8
Archer, Wyo. (2)	19.2	19.2
Avg. All Locations	29.7	32.2

* Denotes number of years of results.

The 2.5-bu/ac. average increase is not great, but two of the locations had either no difference or a slight decrease with mulch and three of the remaining six locations had at least one year with lower yields from the mulch than from the bare system. Also, most of the data available for this report did not contain information on weed control. Good weed control in the conservation mulch system is sometimes difficult to obtain with mechanical tillage; therefore, the assumption has been made that had good weed control been obtained in all experiments the mulch yield advantage would have been greater, as was found at Akron, Colo. (8.5 bu/ac). The total 42 years of results encompassing the entire Central Great Plains show the superiority of the mulch fallow system compared to the bare fallow system for winter wheat production in the area.

Lower protein content of grain produced on the mulch fallow system compared to the bare fallow system is another of the criticisms of using the mulch system. Research from 6 Central Great Plains locations show an average of 0.3% lower protein grain harvested where the conservation mulch system was used (Table 13). The lower grain protein level with

Table 13. Protein content of grain grown on conservation mulch and bare fallow systems at 6 Central Great Plains locations.

Location	Fallow System: Bare	Fallow System: Mulch
	%	%
Akron, Colo.	13.1	12.9
Colby, Kans.	15.3	15.0
Garden City, Kans.	16.2	15.8
Oakley, Kans.	13.0	13.0
Alliance, Nebr.	13.0	12.4
N. Platte, Nebr.	16.2	16.1
Avg. All Locations	14.5	14.2

the mulch than with the bare fallow system would be expected. Research has shown higher soil water at seeding and lower soil nitrate-N levels at seeding are major factors influencing grain protein levels (19). Each inch increase in soil water at seeding has the potential to decrease grain protein 0.7% and each pound/acre decrease in nitrate-N in the soil at seeding has the potential to decrease grain protein an average of 0.1% (19). Soil temperature at the crown depth of the wheat influences N uptake by wheat, which ultimately influences the grain protein content (17). In the soil temperature range between 46 and 68^{o}F, each degree decrease lowered grain protein 0.2%. Thus even when soil temperature reductions with mulch are not severe enough to affect yield, they may decrease grain protein level.

Smika and Greb (19) reported that most stored soil water is at depths that contain little available nitrate-N. Therefore, the wheat will use the stored soil water with little N uptake. However, research has shown that when N is available and moves into the soil with the water stored in the 24- to 36-inch soil depth, the N is very effective for producing grain with high protein content (18). Nitrogen can be made available for movement into this soil depth through properly timed fertilizer applications or through total weed control during the after harvest to fall dormancy period (7).

Poor control of fall-germinating grassy weeds such as downy brome (Bromus tectorum L.) and volunteer wheat has been one of the criticisms of the conservation mulch system. At Alliance, Nebraska (5) grassy weed control was lower with sweep tillage compared to oneway tillage. However, none of the tillage treatments included a double fall tillage, which at Akron, Colo. has very effectively controlled fall weed growth (Table 14).

Table 14. Weed control during fallow as affected by tillage treatments after harvest at Akron, Colo. and Alliance, Nebr.

Tillage Treatments	Weed Control	
	Akron, Colo.	Alliance, Nebr.
	%	
Disk or oneway	43 (1)*	16 (1)*
Single sweep	46 (1)	11 (1)
Single sweep	36 (5)	64 (12)
Double sweep	67 (1 & 5)	--

* Denotes weeks after harvest when tillage operation performed.

At Alliance, single tillage operations one week after harvest reduced weed growth only an average of 14%. A single tillage 12 weeks after harvest reduced weed growth 64%, which was nearly as effective as the double tillage at Akron. However, during this 12-week period the weeds were using water and N (see Tables 3 and 11), thereby reducing total accumulation of these two important factors for winter wheat production.

During cold, wet spring seasons, grassy weeds and volunteer wheat are difficult to control with blade or sweep tillage alone. Therefore, weed control the previous fall is important for a successful conservation mulch tillage system. There is no evidence that "one-tillage-implement" farming is necessary for a conservation mulch system. A properly adjusted oneway can provide the necessary weed control without significantly reducing the protective residue (5, 22).

The final comparison of the conservation mulch and bare fallow systems to be included in this report deals with the power requirement for tillage operations for the two systems. Information on this subject is minimal, but studies at Alliance, Nebraska (1) and Archer, Wyoming (2) indicate that horsepower-hour per acre requirements are less for operation of subsurface conservation implements than for the oneway disk, the implement predominately used in the bare fallow system (Table 15). The custom contract rate for oneway tillage operation is higher than that for subsurface tillage operations, again reflecting the higher cost for developing bare fallow than for maintaining conservation mulch.

Table 15. Power requirements for tillage implement operation at Alliance, Nebr. and Archer, Wyo. and Nebr. custom farm rates.

Implement	Location: Alliance	Location: Archer	Avg.	Custom Rate
	— Hp-hr/A.	—		$/Ac.
Oneway - 5-inch depth	10.12	7.88	9.00	4.00
Blade - 5-inch depth	6.16	4.37	5.26	2.10
Rodweed (with semichisels) - 3-inch depth	2.86	3.81	3.33	1.60
Chisel - 6-inch depth	9.02	17.73	13.38	2.30

CONCLUSIONS

Research from 8 Central Great Plains locations show advantages for the conservation mulch fallow system over the bare fallow system for soil water storage, soil surface protection against wind erosion with both residue and nonerodible aggregates, grain yield production, and power requirement for tillage implements. The conservation mulch fallow system results in slightly lower soil nitrate-N levels at the end of fallow and tends to produce grain with lower protein content than the bare fallow system. Also, under certain climatic conditions, grassy weed control can be a problem. These shortcomings can be overcome by other management practices such as fertilization, use of implement best adapted to the existing climatic conditions, and selection of crop varieties adapted to the conservation mulch system. The use of herbicides to replace some or possibly all tillage operations necessary for fallow offers tremendous potential under many conditions for increasing the adaptability of the conservation mulch system. Because the experimental data reported were obtained on small plots, they do not adequately reflect the possible savings that would be obtained on a large field that might blow because of lack of mulch or of soil aggregates produced by mulch. I can see no reason why some form of the conservation mulch fallow system is not practiced on every acre of fallow land every year in the Central Great Plains.

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