Stubble-Mulch Tillage and Planting in Crop Residue in the Great Plains

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MEMBER ASAE

BOTH wind and water erosion occur in the Great Plains. The climate is variable and cyclic. Wet years with considerable water erosion may be followed by dry years with serious wind erosion and limited soil moisture for crop production. Cultural practices generally used in the production of the principal crops, wheat and sorghum, tend to expose the soil during certain times of the year, leaving it vulnerable to erosion. Stubble mulch farming is extensively practiced in the Great Plains because it manages plant residues so the soil surface is protected and is thus one of the most effective conservation practices available today to control erosion and conserve moisture in the semiarid climate.

Information is presented on (a) requirements of tillage and planting equipment for stubble mulching (b) kinds of equipment and sequences of operations used, (c) performance characteristics of equipment in terms of residue conservation, soil cloddiness, weed control and crop yield, and (d) problems associated with stubble-mulch tillage and planting in the Great Plains. The discussion is restricted to wheat and sorghum culture. The paper was prepared at the request of the Cultural Practices Equipment Committee, Power and Machinery Division, of the ASAE to fulfill what the Committee considered to be a need for a current discussion of tillage and planting methods used in the Great Plains.

Requirements of Tillage and Planting Equipment

For effective stubble mulching, tillage equipment must (a) leave crop residues on the land surface, (b) maintain as rough and cloddy a soil surface as compatible with good seed germination and crop production, and (c) provide a mulch and effective weed control to conserve soil moisture. Planting equipment generally must meet these requirements and, in addition, must place seeds through the mulch into moist, firm soil.

Because of the everpresent erosion problems in the Plains and the effectiveness of vegetative protection in controlling erosion, maintaining residues on the land surface is the most important of the three basic requirements. Figs. 1 and 2 show approximate quantities of flattened small grain and sorghum residue required to hold wind and water erosion to an arbitrary, tolerable amount of 5 tons per acre per annum for three different soils. The graphs were prepared by solving the water erosion equation (17)

$$A = RKLSCP \quad [1]$$

for the following values of the variables:

- A, average annual soil loss in tons per acre
- K, soil-erodibility factor = 0.49, 0.32, and 0.17 for soils identified in figs. 1 and 2
- C, cropping-management factors = 0.55, 0.45, 0.25, 0.17, and 0.10 for Fig. 1, and 0.55, 0.45, 0.35, and 0.30 for Fig. 2
- R, rainfall erosion factor = 100 (held constant)
- L, length of slope = 400 ft (held constant)
- S, steepness of slope = 8 percent (held constant)
- P, erosion control practice = 0.6 (held constant)

and the wind erosion equation [3]

$$E = f(IKCLV) \quad [2]$$

for these values of the variables:

- E, average annual soil loss in tons per acre
- I, soil erodibility index = 134, 86, and 38 for soils of Figs. 1 and 2
- V, vegetative cover = 1,000, 3,000, 6,000, and 8,800 for Fig. 1, and 250, 500, 2,000, and 5,000 for Fig. 2
- K, soil surface roughness = 1.0 (held constant)
- C, climatic factor = 100 (held constant)
- L, width of field = 400 ft (held constant)

The substantial quantities of residue shown to be required to control erosion emphasize the importance of the requirement that the machines leave residues on the land surface.

Planting equipment has a strong influence on residue conservation because of its effect on previous crop residue while a succeeding crop is being planted and because it controls plant population and row spacing. Figs. 3 and 4 illustrate the influence of row spacing and plant population on wind erosion.

Methods of Operation

The methods of operation used in stubble mulching in the Plains depend on the crops grown and on whether summer fallowing is practiced. If summer fallowing is practiced and the crop is winter wheat, it is harvested with combines in late June or early July and the stubble is allowed to stand through the succeeding fall and winter. The quantity of residue left on the land surface depends on the climatic situation during the previous growing season and can range from 1,000 lb up to about 6,000 lb per acre. Tillage starts in May and is carried out periodically as weed growth dictates through the summer. The land is planted to wheat in late September or early October.

If continuous wheat is grown, tillage starts immediately after harvest and wheat is planted in September.

If sorghum is grown in rotation with wheat, the wheat stubble is allowed to stand through the winter, tillage is started in April and May, and sorghum is planted in late May or early June. Grain sorghum is harvested with combines that leave a stubble ranging from 8 to 15 in. high and from 500 to 4,000 lb per acre. Sorghum stubble land may be left undisturbed or may be undercut with subsurface sweeps and left to stand through the winter. Tillage starts in April or May with planting in late May or early June if the next crop is sorghum, or continues through the summer if the succeeding crop is winter wheat.

Kinds of Tillage Machines Used

Tillage machines used for stubble mulching in the Great Plains can be classed into two types: (a) those that stir and mix the soil, and (b) those that cut beneath the surface without stirring or turning the tilled layer.

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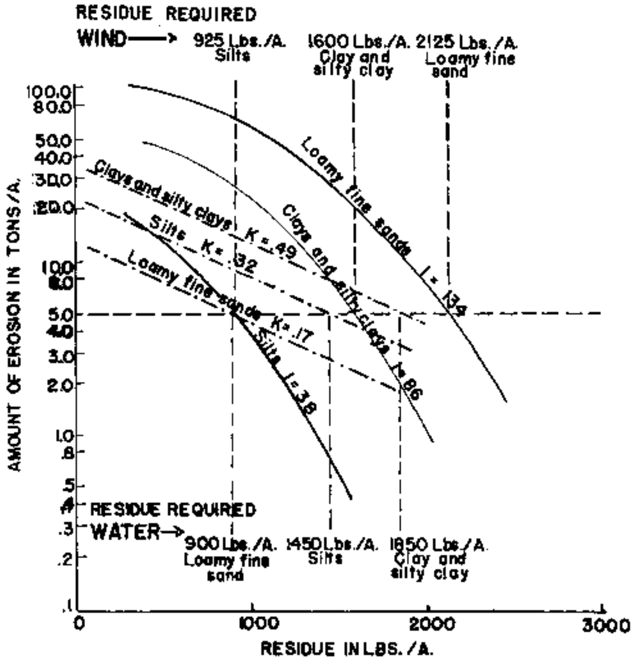

FIG. 1 Approximate quantities of small grain residues required to hold erosion to an arbitrary tolerable amount of 5 tons per acre per year under the slope, soil, and vegetative conditions specified in areas with wind erosion climatic and rainfall erosion factors equal to 100.

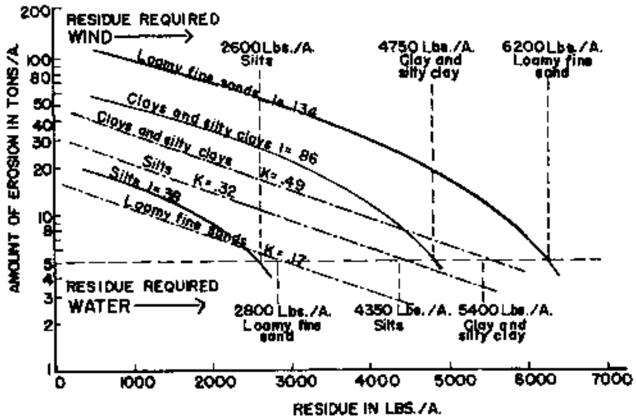

FIG. 2 Approximate quantities or sorghum residues required to hold erosion to an arbitrary tolerable amount of 5 tons per acre per year under the slope, soil, and vegetative conditions specified in areas with wind erosion climatic and rainfall erosion factors equal to 100.

Stirring or mixing machines include:
- One-way disks
- Tandem disk harrows
- Offset disks
- Field cultivators
- Chisel plows
- Chisel plows with rodweeder attachments
- Rotary hoes
- Skew or mulch treaders

Subsurface machines include:
- Straight blades
- Rigid-frame V-sweeps
- Flexible-frame V-sweeps
- Rodweeders with semichisels or shovels
- Plain rodweeders.

Kinds of Planting Machines Used

Major types of planters used to plant small grains in mulch include semideep-furrow, single- and double-disk drills; deep-furrow drills with shovel-, shoe-, or hoe-type openers, and seeding attachment on one-ways and cultivators.

Row crops are planted in mulch with surface planters equipped with furrow openers, listers operated at shallow depths, till-planters, seeding attachments on cultivators and one-ways, and sometimes with small grain drills with part of the seed spouts plugged to give desired spacing.

Performance Characteristics of Tillage and Planting Machinery

Tillage

The particular tillage machines used and the sequences in which they are used vary widely in the Plains. Generally, in tilling summer-fallow wheat stubble, about four operations at approximately 1-month intervals are required for weed control. The initial tillage, in April or May, usually is accomplished with a one-way disk or a large V-sweep machine. Subsequent cultivations may be with the same machines, but oftener small (32-in.) V-sweeps, rodweeders with shovels, or chisels and plain rodweeders are used for the second, third, and fourth operations. Each kind of machine available for stubble mulch tillage has a different effect on residue conservation, soil cloddiness, and weed control, all of which in turn affect crop yield.

Residue Conservation Several investigators (1, 2, 6, 20, 21) have evaluated residue conservation characteristics of different machines commonly used for stubble mulching in small grain residue in the Plains. Table 1 presents a composite of the results. The wide variations in the data are due to the amount of residue conserved on the land surface by the implements depending on factors related to the residue itself such as height and length of stubble, amount of pretillage residue during initial operations (Table 2) and previous positioning or orientation of residue (Table 3) and on factors relating to the implements, such as speed and depth of operation, angle and concavity of disks, and width, pitch, and angle of sweep blades. The data of Table 4 take into account effects of these factors and present information on the quantity of

TABLE 1. RESIDUE MAINTAINED WITH TILLAGE IMPLEMENTS*

Type of implement	Average maintained after each tillage operation	Range maintained†
	Percent	Percent
Subsurface implements:		
Blades (36 in. or wider)	90	70 to 113
Sweeps (24 in. to 36 in.)	90	60 to 112
Rodweeders—plain rod	90	80 to 115
Rodweeders—with semichisels	85	55 to 105
Mixing implements:		
Heavy-duty cultivator (16 in. to 18 in. sweeps)	80	50 to 100
Heavy-duty cultivator (2 in. chisels 12 in. apart)	75	....
One-way disk (24 in. to 26 in. pans)	50	30 to 90
Tandem or offset disks	50	....

* Data from Anderson (1, 2). Woodruff and Chepil (20), Fenster (6), and Woodruff et al. (21).
† Maintenance values greater than 100 percent mean that more residue was brought to the surface than was buried.

TABLE 2. EFFECTS OF DIFFERENT HEIGHTS AND AMOUNTS OF WHEAT STUBBLE RESIDUE ON PERCENTAGES RETAINED AFTER TILLAGE*

Pretillage stubble, lb/a	Percentage retained on surface with stubble height of: 12 in.			18 in.		
	One-way	8 ft V-sweep	2 in. chisel	One-way	8 ft V-sweep	2 in. chisel
2000	57	86	81	....	....	....
3200	54	75	65	58	85	80
4400	31	58	40	56	78	70
5600	....	....	....	47	69	55

* Data from Woodruff et al (21).

TABLE 3. EFFECTS OF ORIENTATION AND PREVIOUS POSITIONING OF RESIDUE ON PERCENTAGES RETAINED AFTER CULTIVATION TILLAGE*

Implement	Previous positioning	
	Mixing	Subsurface
	Percent conserved	
32 in. sweeps	110	86
Rodweeder with shovels	102	100
8 ft V-sweep	93	116
Plain rodweeder	88	85
One-way disk	70	53

* Data from Woodruff et al (21).

TABLE 4. PERCENTAGES AND QUANTITIES OF WHEAT RESIDUE CONSERVED FOLLOWING FOUR DIFFERENT SUMMER-FALLOW TILLAGE SEQUENCES AT ALLIANCE, NEBR.*

Tillage sequence		Residue remaining after operation	
Operation	Machine used	Percent of pretillage	Amount, lb per acre
0	Pretillage	100	3600
1	One-way	55	1980
2	8 ft V-sweep	51	1845
3	32 in sweeps	53	1910
4	Rodweeder	42	1510
0	Pretillage	100	3600
1	8 ft V-sweep	76	2735
2	32 in. sweeps	66	2375
3	Rodweeder	61	2195
4	Rodweeder	57	2050
0	Pretillage	100	3600
1	2 in. chisels	67	2410
2	32 in. sweeps	61	2195
3	Rodweeder	63	2270
4	Rodweeder	59	2120
0	Pretillage	100	3600
1	One-way	55	1980
2	One-way	39	1405
3	32 in. sweeps	43	1550
4	Rodweeder	37	1330

* Data from Fenster et al (8).

residue that four different, commonly used sequences of tillage could be expected to conserve.

Tillage machine effects on sorghum residue conservation have not been studied as extensively as small grain residues. Research at Akron, Colo (7), and Manhattan, Kansas (18), investigated the effect of fall as opposed to spring tillage of sorghum residue. The Colorado studies showed no advantage and many disadvantages for fall tillage in areas where wind erosion is critical. However, the Kansas studies showed that fall disking of sorghum stubble increased stands and grain yields. The Colorado investigation showed that amounts of sorghum residue were reduced by 31 to 34 percent by winter weathering, which was about equal to the reduction caused by tillage machines (Table 5).

Soil Cloddiness Research on the effects of stubble-mulch tillage implements on surface soil cloddiness has produced extremely varying results. The cloddiness that will be produced by

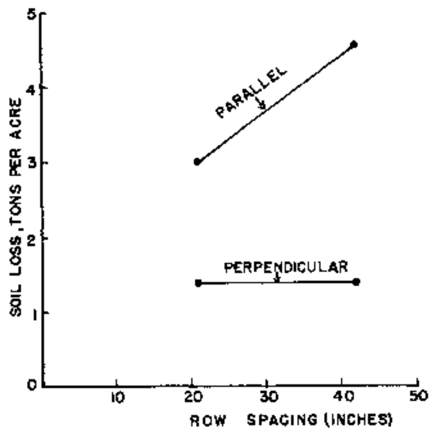

FIG. 3 Effect of row spacing on soil loss as measured with a portable wind tunnel parallel and perpendicular to row direction. Skidmore et al (16).

any given implement is mainly determined by the soil moisture and density at tillage and the force pattern of the particular tillage point (12, 13). Measurements of soil cloddiness after initial tillage of undisturbed wheat-stubble land produced the results shown in Fig. 5, but generally it has not been possible to find any significant difference in cloddiness produced by different implements or different sequences of implements in subsequent tillage (8, 11, 19, 20).

Weed control The degree of stirring action, the temperature, the soil water content, the kind of weeds present, and the stage of growth all influence weed control attainable with any tillage machine (11). There is considerable variation in control between years for the same implement, but generally better weed control is obtained with implements that invert and mix the top soil layer such as one-way disks, than with subsurface sweeps (6, 7, 11, 20, 23). Table 6 shows the weed control obtained in Nebraska by initial tillage with five different implements.

Cheatgrass and downy brome are particularly troublesome weeds with stubble mulching in the winter wheat areas (14). Cheatgrass population is influenced by methods of tillage and by cropping systems. Studies at Alliance, Nebraska, showed significantly better control of downy brome with tillage sequences using a one-way disk in combination with sweep implements than with sequences employing sweeps exclusively (Table 7). Research at St.

TABLE 5. EFFECTS OF FIVE DIFFERENT TILLAGE SEQUENCES ON SORGHUM RESIDUE MANAGEMENT AT AKRON, COLO.*

Tillage implement and date used				Residue remaining September 2 at end of fallow†
May 16	June 12	July 6	August 3	
				Percent
Rodweeder with shovels	Rodweeder with shovels	48 in. sweeps	Rodweeder	45
48 in. sweeps	48 in. sweeps	48 in. sweeps	Rodweeder	41
Chisels	Chisels	48 in. sweeps	Rodweeder	36
One-way	One-way	48 in. sweeps	Rodweeder	21
Tandem disk	Tandem disk	48 in. sweeps	Rodweeder	17

* Data from Greb and Black (9).
† Pretillage residue amounted to 860 lb per acre May 16 after a 34-percent loss during winter.

TABLE 6. WEED CONTROL OBTAINED ON TWO DIFFERENT YEARS AT ALLIANCE, NEBR., BY INITIAL TILLAGE OF WHEAT STUBBLE WITH FIVE INDICATED IMPLEMENTS*

Implement	Percent control	
	1961	1959
One-way disk	99	88
Two-inch chisels	83	87
Rodweeder with shovels	47	80
Eight-foot V-sweep	44	80
32 in. V-syeeps	41	63

* Data from Fenster et al (8).

TABLE 7. EFFECT OF TILLAGE SEQUENCE IN 1961 ON RESULTANT DOWNY BROME POPULATION IN WHEAT CROP IN MAY 1962 AT ALLIANCE, NEBR.*

Tillage sequence†	Average number of plants per 12-ft strip‡
N-S-RW-RW	162
N-S-S-RW	113
N-OW-S-RW	62
OW-CH-S-RW	47
OW-OW-S-RW	26

* Data from Fenster et al (8).
† N, 8 ft V-sweep; S, 32 in. V-sweeps; RW, plain rodweeder; OW, one-way disk; CH, rodweeder with shovels.
‡ Twelve-foot strip between 14-in. drill rows.

John, Kansas*, indicates that a serious cheatgrass problem develops in continuous wheat on sandy stubble-mulched land but it presents essentially no problem when the land was summer fallowed between wheat crops or if a wheat-cowpea rotation is followed.

Crop Yields Results from studies to evaluate the effects of tillage on crop yields have varied. Some investigators (15) have reported higher yields on land tilled with subsurface sweeps than on land tilled with disks or plows. Others (4) have reported higher yields on one-wayed land than on subsurface-sweep tilled land. Zingg and Whitfield (23) summarized stubble-mulch farming results in the western states and concluded that the trend is for stubble mulching to yield more than clean tillage when the climate is semiarid and less than clean tillage when the climate is subhumid.

Examination of year-to-year effects of tillage on winter wheat yields indicates that yields are generally related to weed control and to soil moisture at time of planting. Table 8 shows yield data for five different four-operation tillage sequences for a dry year (1961) and a relatively wet year (1962). Soil moisture was extremely critical at planting time in 1961 but was not in 1962. As a result, yields were sharply reduced in 1961 on land tilled with sweeps, which gave poor weed control. However, there was no significant difference in yields in 1962 when soil moisture was not critical even though weed control on subsurface-sweep-tilled land was poor.

Planting

Quantitative data on the performance characteristics of planting machines

* Annual report, (1964), Sandyland Experiment Field, St. John, Kans. (Kansas Agricultural Experiment Station).

TABLE 8. WINTER WHEAT YIELDS IN RELATION TO TILLAGE SEQUENCE FOR A DRY (1961) AND A WET (1962) YEAR AT ALLIANCE, NEBR.*

Tillage sequence†	Yield, lb per acre	
	1961	1962
OW-OW-S-RW	1902	2426
OW-N-S-RW	1404	2334
N-OW-S-RW	1212	2406
S-S-RW-RW	648	2082
N-S-S-RW	414	2142

* Data from Fenster et al (8).
† OW, one-way disk; S, 32 in. V-sweeps, RW, plain rodweeder; N, 8 ft V-sweep.

used in the Plains are meager, especially on small grain drills. Comparisons of an 8-in-row space, single-disk drill, a 10-in.-row space hoe drill equipped with closed-type packer wheels, and a 12-in. row space semideep-furrow drill at St. John, Kansas*, showed that wheat yields from the hoe drill plantings were consistently and significantly higher than from plantings with the other drills. Observation and experience indicates that semideep-furrow, single-disk drills, and deep-furrow drills with shovel, shoe, or hoe-type openers are most satisfactory for drilling in stubble mulch (10). Such innovations as V notches in the openers to permit moist soil to flow into the furrow and cover the seed, use of large rubber wheels and hydraulic hitches to lower draft and reduce side slipping, chrome plating of shovels to give lighter draft and better clearing of mulch, and use of closed- rather than open-type packer wheels all have improved the performance of small grain drills.

Row crops have been most successfully planted in mulch with surface planters equipped with furrow openers, listers operated at a shallow depth, and till-planters. Fairbanks et al (5) compared till-planter, plow-plant, lister, and surface planter methods of growing corn and sorghum and reported no significant difference in yield among methods, more lodging with the till-planter, and better residue placement and more effective erosion control with the till-planter. Sticker et al (18) studied the effects of press wheels on row-crop planters and found 8, 23, and 34 percent increases in sorghum stands, respectively, for seed-firm, drive press, and seed-firm with drive press wheels.

Problems Associated with Stubble-Mulch Tillage and Planting in Crop Residue

The main problems associated with stubble-mulch tillage and planting in crop residue are: (a) machine operating difficulties, i.e., clogging, adjustments, and drilling and planting through bunched residues, (b) weed control, (c) preserving sufficient residue to control erosion when residues are meager, (d) toxic effects of mulch, and (e) possible insert and plant disease.

Tillage-machine operating difficulties can be lessened if great care and patience are exercised in making adjustments, using weights, selecting tillage points, and in operating at correct speeds and depths. Experience has also shown that fewer problems will be encountered if the tillage equipment has the following desirable functional and design features:

Adequate vertical spacing between frame and tillage point – minimum of 18 to 20 in.

Adequate horizontal spacing between standards – minimum of 24 in.

Effective coulter action – minimum diameter 18 to 20 in.

Proper tillage point design – 60 to 70-deg V angles with 37-deg pitch on subsurface sweeps – 24-in. diameters with 3-in. concavity on disks.

Correct speeds of operation – 4 to 5 mph best for most implements.

Adequate depth adjustments preferable with hydraulic controls and depth-gage wheels.

Adequate disk-angle adjustments.

Flexible implement frames and widths–5 to 8-ft sections desirable for better performance on uneven land.

Availability of a variety of adaptable equipment to regulate amounts of residue conserved, to obtain weed control, and to operate under a wide range of soil conditions.

Problems encountered in drilling and planting in heavy or bunched mulches can be alleviated by using stubble choppers prior to initial tillage, disk implements during initial and cultivation tillage, and skew or mulch treaders after the last tillage operation and before seeding. Problems associated with drilling small grains also will be lessened if the drills meet these requirements:

1 Permit row spacing of 7 to 14 in., preferably 14 in. for heavy residues.

2 Have at least 20 in. of clearance between front and rear ranks of openers.

3 Have at least 17 in. of vertical clearance between frame and bottom of shoe.

4 Have a shoe width of no more than 6 in.

5 Have press wheels that pack seed firmly – close-type wheels are better than open-type.

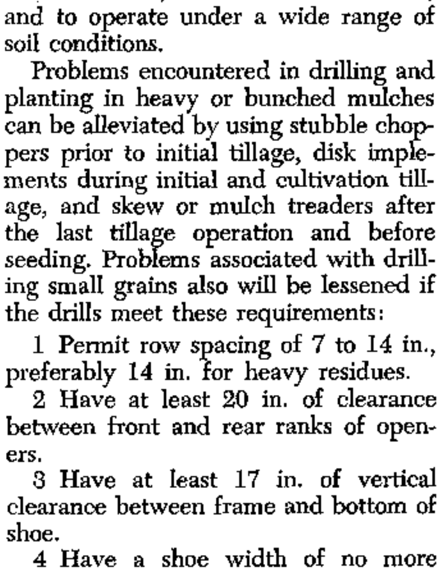

FIG. 4 The effect of plant population on soil removed from sorghum stubble as measured in a portable wind tunnel. Skidmore et al (16).

Effective weed control is difficult to attain with stubble-mulch tillage because most of the machines used do not invert the surface soil layer. Weed seeds are not buried and weeds that have already established a substantial root system are merely cut off beneath the surface, leaving the root in contact with the soil so it continues to grow, especially if rain immediately follows tillage. Installation of "fingers" or rods on the back of subsurface sweeps increases the intensity of the tillage action and shakes the soil from the weed roots, thus providing better weed kill. More effective weed control in stubble mulching also can be obtained by using herbicides. Fenster et al (7) reported that Atrazine† (2-chloro-4-ethylamino-6-isopropylamino-S-triazine), Prometone (2-methoxy-4,6-bis(isopropylamino)-S-triazine) applied at 2 lb per acre satisfactorily controlled weeds during the fallow period in an alternate wheat-fallow rotation. Fairbanks et al. (5) found that Simazine (2-chloro-4, 6-bis(ethylamino)-S-triazine) applied at 4 lb per acre immediately behind the till-planter controlled weeds in sorghum and corn but the chemical reduced sorghum seedling emergence. Armbrust‡ found that Diuron (3-(3,4-dichlorophenyl)-1,1-dimethyl urea) and Prometryne (2,4-bis(isopropylamino)-6-methylmercapto) applied at 2 lb per acre or Dacthal (dimethyl tetrachloroterephthalate) applied at 12 lb per acre gave good seasonal weed control in sorghum stubble at Big Springs, Texas.

The problem of preserving sufficient residue to control erosion when initial residues are meager occurs frequently in the Plains. During dry years the quantity of residue remaining immediately after wheat or sorghum harvest may be insufficient to provide effective erosion control. If the usual number of tillage operations are then carried out during the summer fallow season, these already sparse residues are reduced to insignificant quantities for protection of the succeeding crops. Use of herbicides to control weeds, thereby eliminating mechanical destruction by tillage, is showing considerable promise as a method of preserving residue. Minimum tillage is another way of attempting to conserve more residue. However, preliminary investigation indicates that while less tillage conserves residues, excessive soil moisture is used because of poor weed control so wheat yields are drastically reduced (Table 9). It is apparent that more investigations and studies are needed before minimum tillage could be recommended.

† Trade names are included for the benefit of the reader and do not infer endorsement or preferential treatment of the product mentioned by the U.S. Department of Agriculture.

‡ 1964 Annual Report, Big Spring Field Station, Big Spring, Tex., USDA, ARS-SWC.

The compounds associated with residue that are toxic to plant growth have not been identified (14). However, there is evidence of retarded plant growth with stubble mulching, and studies by McCalla (14) have shown that plant residues contain substances and that microorganisms produce substances that reduce germination and growth of plants.

Only extremely limited and conflicting data are available on insects and plant diseases in relation to stubble mulching. Investigators in South Dakota have shown that moldboard plowing is more effective than subsurface tillage in controlling grasshoppers, but other studies have concluded that insect control on stubble mulching is no more difficult than on clean tillage (14). There has been some evidence of increased incidence of root rot in wheat on stubble mulch at Cherokee, Okla., but 8 years of data from Alliance, Nebr., show that the problem is more severe on clean tillage than on stubble mulch. So diseases have not been proved to be more of a problem with stubble mulching than with plowing (14).

Summary

Stubble-mulch farming is practiced extensively in the Great Plains because it is one of the most effective conservation practices available to control erosion and conserve moisture in a variable and cyclic climate.

This paper presents information on (a) requirements of tillage and planting equipment for stubble mulching, (b) kinds of equipment and sequences of operations used, (c) performance characteristics of equipment in terms of residue conservation, soil cloddiness, weed control, and crop yield, and (d) problems associated with stubble-mulch tillage and planting in the Great Plains.

Tillage equipment must (a) leave crop residue on the land surface, (b) maintain as rough and cloddy a soil surface as is compatible with good seed germination and crop production, and (c) conserve soil moisture by providing a mulch and effective weed control. Planting equipment generally must meet those requirements and in addition must place seeds through the mulch into moist, firm soil.

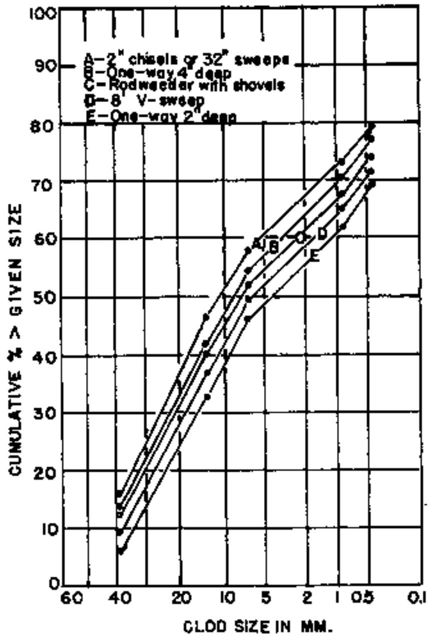

FIG. 5 Size distribution of clods produced by six different tillage implements during initial tillage of a fine, sandy loam soil. Curves represent 3-yr-average data for each implement. Woodruff et al (22).

Two types of tillage machines are used for stubble mulching in the Plains: (a) those that stir and mix the soil and (b) those that cut beneath the surface without stirring or turning the tilled layer. With either type, the quantity of residue conserved is a function of quantity, height or length, and previous positioning of pretillage residue. Subsurface sweeps conserve more residue than mixing-type implements such as one-way disks. Soil cloddiness is mainly influenced by the amount of soil moisture at tillage and the particular action of the last implement used on the soil. Better weed control is attained with mixing implements than with subsurface sweeps. Crop yield is closely related to weed control and soil moisture and, therefore, somewhat related to tillage.

Major types of planters used for small grains include semideep-furrow, single- and double-disk drills; deep-furrow drills with shovel-, shoe-, or hoe-type openers; and seeding attachments on one-ways and cultivators. Hoe drills are better adapted than disk drills to plant seed through heavy residues. They also provide maximum ridging, concentrate residues in the ridges, and place seed in a good moisture environment. Row crops are planted with surface planters equipped with furrow openers, listeners operated at shallow depths, till-planters, and seeding attachments on cultivators and one-ways.

Problems associated with stubble-mulch tillage and planting in the Plains include clogging; adjustments of machines; drilling in heavy, bunched residue; weed control; sparse residue at the beginning of the tillage season, and toxic effects.

TABLE 9. EFFECTS OF SEVERAL DIFFERENT EXPERIMENTAL MINIMUM OR SKIP TILLAGE SUMMER-FALLOW TREATMENTS ON RESIDUE CONSERVATION, MOISTURE USE, AND CROP YIELD AT COLBY, KANSAS*

Tillage sequence†	Amount of residue retained at end of tillage season, lb per acre	Soil moisture losses from 5-11-64 to 8-5-64, in.	Wheat yield, bu per acre
N-*-*-(M + TD)	1140	4.87	3.5
OW-*-*-(M + TD)	1090	4.83	3.9
S-Chemical fallow‡	2230	2.83	6.6
OW-OW-*-MR	804	2.12	20.8
N-S-RW-RW	900	1.18	25.3
OW-S-RW-RW	520	0.95	29.7

* Unpublished data from Woodruff and Harris.
† N, 8 ft V sweep; *, skip operation no tillage; M, rotary mower; TD, tandem disk; OW, one-way disk; S, 30 in. V sweeps; MR, rodweeder with chisels; RW, plain rodweeder.
‡ 2,4D (2,4-dichlorophenolyacetic acid) applied at a rate of ½ lb ester per acre.

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