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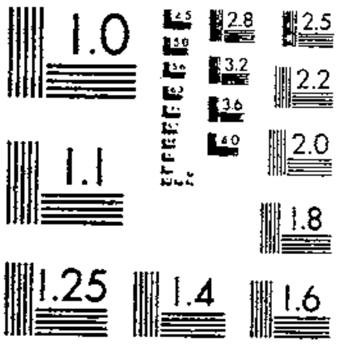

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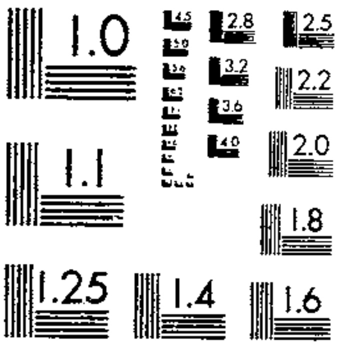

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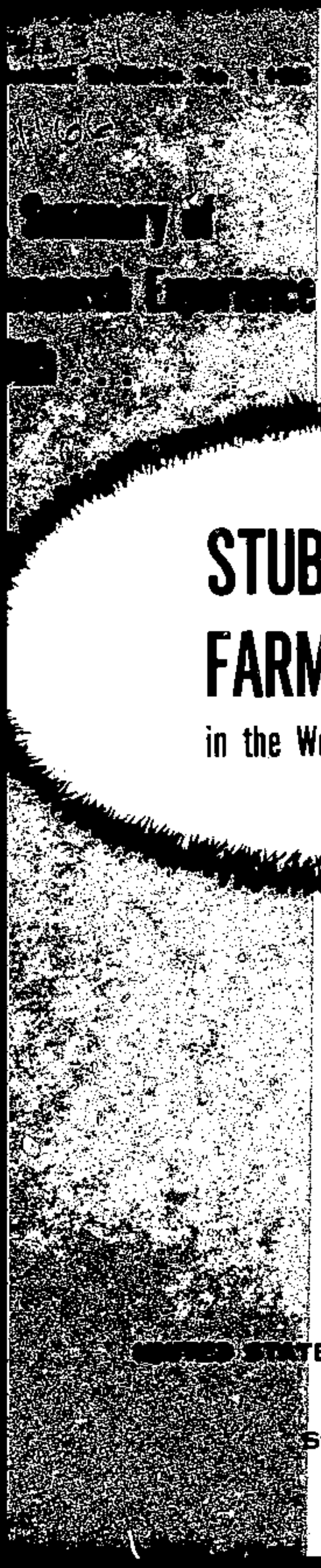

STUBBLE-MULCH FARMING

in the Western States

By
W. Zingg
and
C. J. Whitfield

UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
State Agricultural Experiment Stations

CONTENTS

The Agricultural Experiment Stations of Colorado, Idaho, Kansas, Montana, Nebraska, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Washington, and Wyoming cooperated in this study.

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A SUMMARY OF RESEARCH EXPERIENCE WITH STUBBLE-MULCH FARMING IN THE WESTERN STATES [1]

By A. W. Zingg, technical staff specialist, Soil and Water Conservation Research Division, Agricultural Research Service; and C. J. Whitfield, research liaison representative for the Great Plains Region, Soil Conservation Service–Agricultural Research Service [2]

Purpose

The purpose of this bulletin is to summarize the results of experiments dealing with stubble-mulch tillage in the Western States. Because of differences in results obtained at the various locations, it was necessary to appraise and interpret available data, in order to define conditions under which the stubble-mulch practice was successful in controlling erosion, reducing runoff, and increasing crop yields. This summary should point the way to improved methods that will overcome deficiencies in the present system. It should also emphasize the need for intensified studies on factors related to the successful use of stubble-mulch tillage.

Background

The moldboard plow was the first tillage implement used in agriculture in the Western United States. It was brought into the arid and semiarid regions from the humid regions of the Eastern States, where it had been used by early American farmers.

Breaking the sodlands of the Great Plains and farming them by "clean-tillage" methods caused trouble almost immediately. At the sites of early settlements, the soil became dissipated by drought and blowing dust. This brought to light the hazards involved in growing crops in regions subject to low rainfall and high winds.

The drought and duststorms of the 1930's brought about intensified research aimed at stabilizing the surface of the lands against the ravages of wind and water. In that decade, surveys were made in the Plains region to determine the reasons for such disasters. These surveys brought out the fact that not all lands were affected seriously. Fields having good growing crops, or residues of either crop or weed growth, were not as badly damaged as were bare fields or fields with small amounts of plant growth.

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[1] Submitted for publication February 8, 1957.

[2] The authors are indebted to a committee composed of H. A. Daniel, F. L. Duley, and J. H. Stallings, soil conservationists (research), and M. M. Oveson, agronomist and superintendent, Agricultural Research Service, for suggestions and assistance in preparing this publication.

A few experiments in which attempts were made to assess the value of residues left on the surface were started in the early thirties prior to the Dust Bowl period. Additional experiments were undertaken at many locations in the late thirties and early forties, following several years of widespread duststorms.

As a result of research and experience, it is now generally recognized that residues maintained on the surface of the soil help control wind and water erosion. Lowdermilk (*13. p. 28*) [3] states: "Leaving crop litter, which is sometimes called stubble mulch or crop residue, at the ground surface in farming operations is one of the most significant contributions to American agriculture. Certain adaptations of the method need to be made to meet the problems of different farming regions, but the new principle is the contribution of importance."

Experimental Locations

The locations of the 16 experimental stations from which results of studies were summarized for this report are shown on the map (fig. 1). Also shown are lines indicating humidity provinces according to Thornthwaite (*27*). Based on this climatic classification, 9 of the locations are in the semiarid region, 6 in the subhumid region, and 1 in the humid region. Studies of stubble mulching were conducted for short periods at locations not shown here, but data from them were not readily available for this report. The locations shown, however, cover a wide range of climatic and soils conditions in the agricultural regions of the Western States.

The following are the actual designations of the stations where the work was conducted at the 16 locations. Throughout this publication and its tables, the stations are usually referred to by the name of the location only, for convenience.

Experimental station	*Location*
United States Akron Field Station	Akron, Colo.
Tetonia Branch Agricultural Experiment Station	St. Anthony, Idaho
Fort Hays Branch Station	Hays, Kans.
Farm leased by Eastern Montana Branch Station	Froid, Mont.
North Montana Branch Station	Havre, Mont.
Central Montana Branch Station	Moccasin, Mont.
Nebraska Agricultural Experiment Station	Lincoln, Nebr.
North Platte Experiment Station	North Platte, Nebr.
United States Northern Great Plains Field Station	Mandan, N. Dak.
Wheat Land Conservation Experiment Station	Cherokee, Okla.
Oklahoma Agricultural Experimental Station (Perkins Farm)	Stillwater, Okla.
Pendleton Branch Experiment Station	Pendleton, Oreg.
Newell Irrigation and Dryland Field Station	Newell, S. Dak.
Amarillo Experiment Station	Amarillo, Tex.
Soil Conservation Experiment Station	Pullman, Wash.
Sheridan Substation	Sheridan, Wyo.

[3] Italic numbers in parentheses refer to Literature Cited, p. 29.

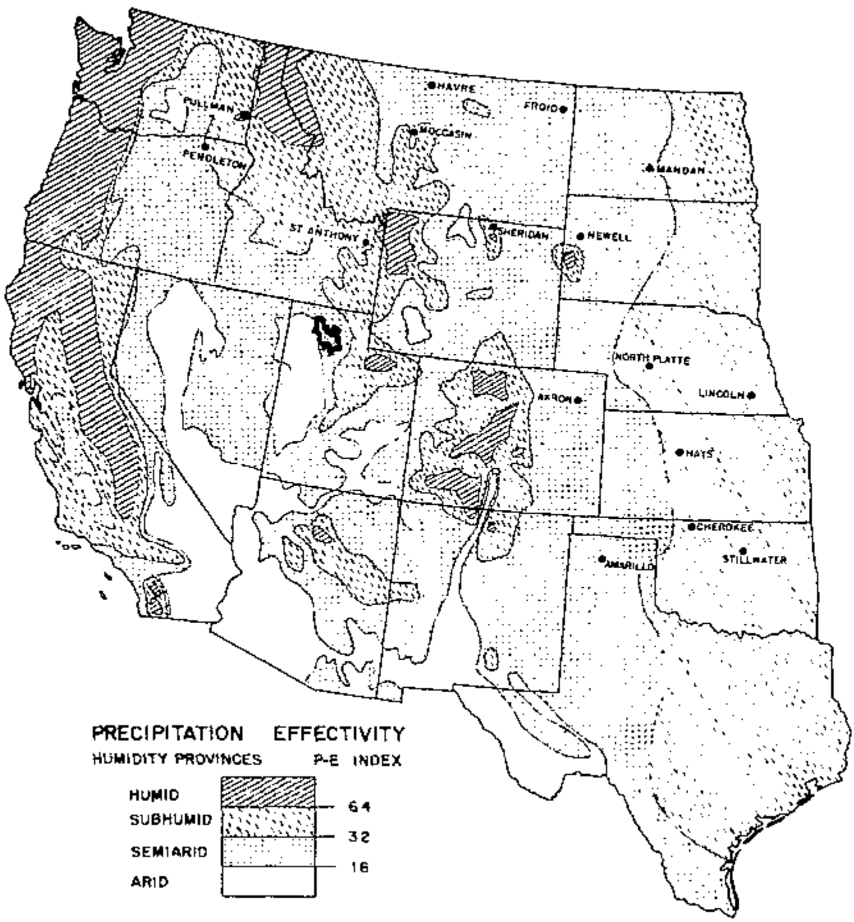

FIGURE 1.—Map of the 17 Western States, showing humidity provinces and the 16 experimental locations of stubble-mulch experiments covered by this study.

Scope of the Investigations

Investigations at the different locations were not conducted in uniform plot experiments; size of plots, methods of tillage, and other factors varied. The main objectives, however, were (1) to determine the relative merits of the moldboard plow, the one-way disk plow, and the sweep machine in the tillage operations respectively referred to in this publication as plowing, one-waying, and mulching; (2) to determine relative yields under these three tillage practices; (3) to evaluate erosion-control features of these practices; and (4) to determine the status of soil moisture, particularly in its relationship to the various tillage practices used. Special emphasis was placed on developing and evaluating methods of conserving soil and water.

Types of equipment used to perform the tillage operations varied widely. In a few early studies, the duckfoot cultivator was employed; leaving residue on the surface was incidental to the tillage practice rather than being its objective. The modified moldboard plow, commonly called the "stubby moldboard," was used to perform stubble-mulch tillage in the Palouse area of the Northwest.

At the time the early studies were initiated, equipment had not been adapted to perform stubble-mulch tillage as it is known today. At several locations attempts were made to develop "sweeps" (sweep machines) suitable for such tillage. Small sweeps were originally employed in most of the experimental studies. As better machines became available, the older types were discarded. In later years, sweeps 30 inches wide or wider came into use at most of the locations. A sweep machine in operation is shown (fig. 2).

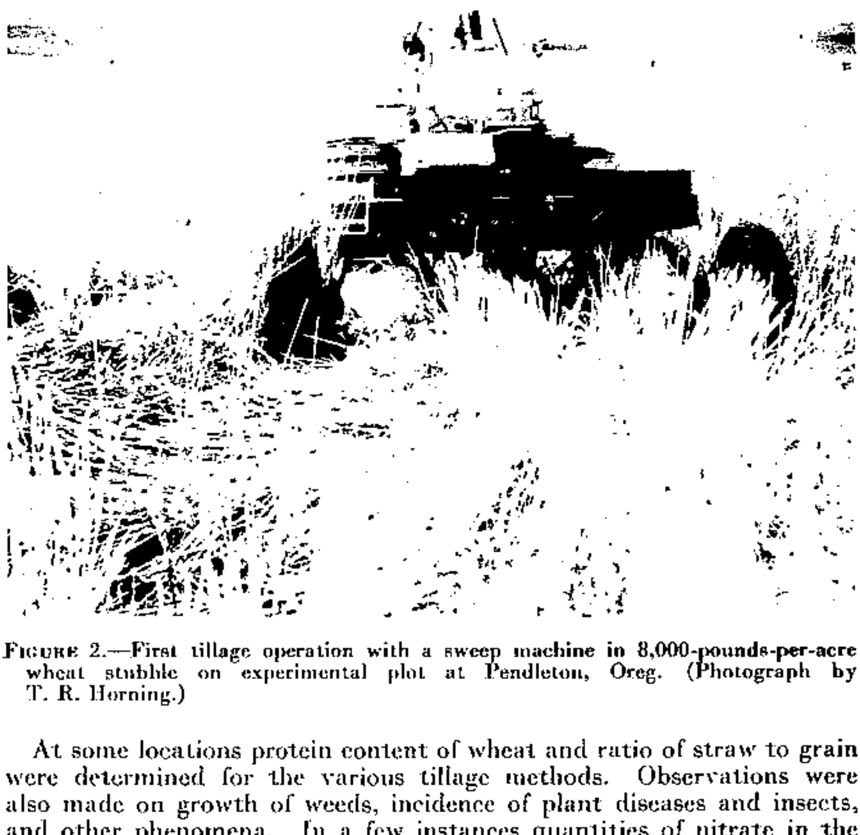

FIGURE 2.—First tillage operation with a sweep machine in 8,000-pounds-per-acre wheat stubble on experimental plot at Pendleton, Oreg. (Photograph by T. R. Horning.)

At some locations protein content of wheat and ratio of straw to grain were determined for the various tillage methods. Observations were also made on growth of weeds, incidence of plant diseases and insects, and other phenomena. In a few instances quantities of nitrate in the soil under the various methods were recorded. At certain locations such soil properties as organic matter, infiltration rate, and bulk density were measured and evaluated.

At all but a few locations wheat was the principal crop studied. At the time the experiments were initiated, fertilizer was not included as a variable.

Detailed information on the studies at the 16 locations, including yields, soil-moisture determinations, sizes of plots, and soil types, are given in appendix tables 9 through 24.

Erosion Control

Wind

Field studies in the Great Plains under conditions of severe wind erosion showed that varying amounts of anchored surface residue are required to control wind erosion on representative soils. In studies of conditions in east central Kansas by Chepil and Englehorn in March 1950,[4] it was found that 1 ton of anchored surface residue per acre was required. Again, in studies made in western Kansas in spring 1954 by Chepil and Woodruff (*3*), it was found that 500 pounds of anchored wheat gave stability. Zingg (*29*), working with a portable wind tunnel at Amarillo, Tex.. found that the erodibility of a land surface was related to the dry structure of the soil, the roughness of the ground surface, and the amount of protective vegetal cover in the form of either growing crop or plant residue.

Englehorn and coworkers (*10*) conducted further wind-tunnel studies on effects of wheat-residue cover and dry-clod structure on soil losses occasioned by wind. These studies yielded estimates of the erodibility of field surfaces, and its functional relationship to dry-soil structure and the weight of anchored wheat residue on the soil surface. Soil removed by a wind tunnel, when wind forces applied approximated those occurring under natural conditions, resulted in the formula

$$X=\frac{A^{3.5}}{2R^{0.8}},$$

Where X=soil material eroded, in pounds per acre;
A=percentage of dry surface soil particles less than 0.42 mm. in diameter; and
R=weight of wheat residue anchored on soil surface, in pounds per acre.

A limited plotting of this functional relationship is given (fig. 3), in which the weight of anchored residue required to limit erosion to given amounts is shown in relation to the dry-soil structure present. The graph indicates the difficulty of prescribing the amount of surface residue required for protection without first determining the dry-soil structure. The more erodible the soil, the greater is the amount of surface residue required to protect it. It is also apparent that succeeding increments of residue provide less protection than the first increment.

One of the primary functions of crop residues maintained on the surface is to decrease the force of wind on the soil itself. Quantitative data on the ability of crop residues to remove the direct force of the wind from the soil is given by Zingg (*31*). In studies of field surfaces, different amounts, types, and orientation of residues were found to remove 5 to 99 percent of the direct wind force from the immediate soil surface. According to Zingg (*30*), reducing the magnitude of saltation movement of erodible materials is the result of the transfer of wind forces to plant-residue cover.

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[4] Chepil, W. S., and Englehorn, C. L. report on causes and effects of wind erosion in east-central kansas in march, 1950. Agron. Dept., Kans. State Col. 1951. [Processed.]

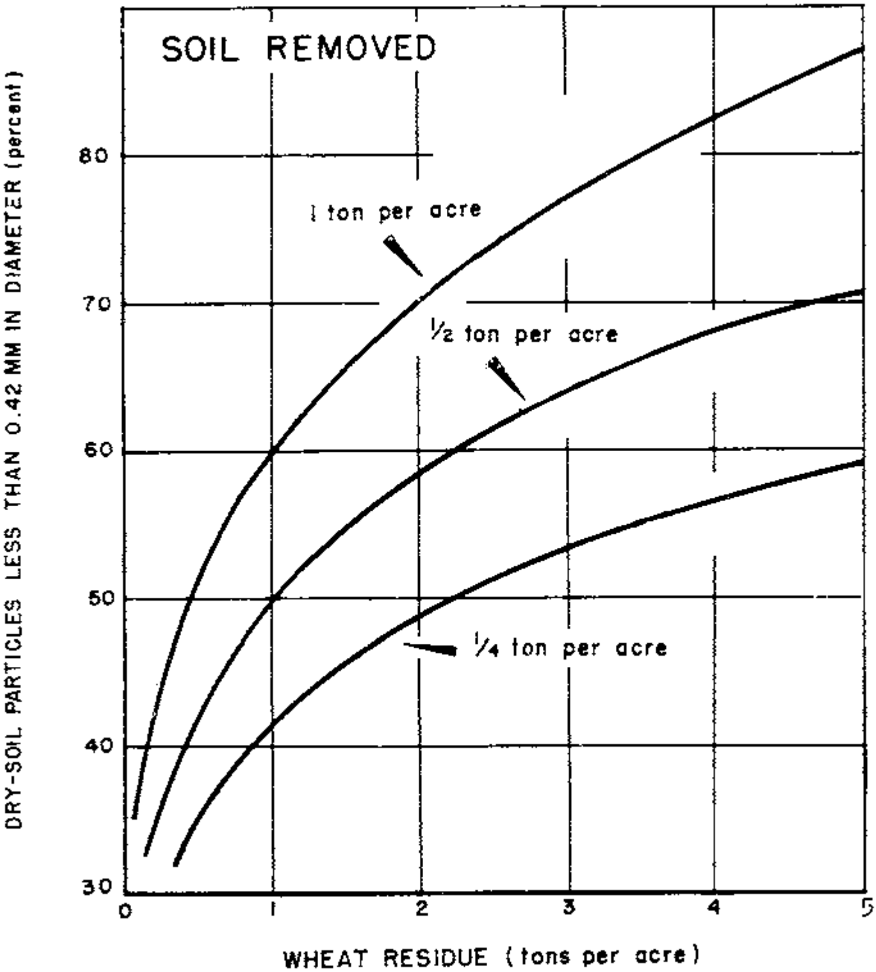

FIGURE 3.—Tons of anchored wheat residue required to limit erosion to given amounts per acre on soils of varying structure, based on wind-tunnel studies.

Water

Comparative figures on the average amounts of erosion experienced over a 6-year period at Lincoln, Nebr., and over a 10-year period at Pullman, Wash., with a mulched surface and with a moldboard-plowed surface, are shown (table 1). About 1 ton per acre of mulch was retained on the surface during these studies. The average rates of erosion, in tons per acre per year, were approximately 20 percent of those resulting from the tillage methods in which moldboard plowing was employed.

TABLE 1.—*Comparative annual average amounts of erosion for mulched and moldboard-plowed surfaces at 2 locations*

Location and literature reference	Crop sequence	Period	Soil losses in runoff when surface was—	
			Mulched	Plowed
		Years	*Tons per acre*	*Tons per acre*
Lincoln, Nebr.[1]	Corn, oats, wheat	6	1.26	6.02
Pullman, Wash.[2]	Alternate wheat and fallow, with 1 ton per acre of straw on surface of mulched plots compared with no straw on surface of plowed plots.	10	3.63	17.93

[1] DULEY, F. L., and RUSSELL, J. C. 1954. [Unpublished data.]
[2] HORNER, G. M. [EFFECT OF STUBBLE MULCH ON EROSION LOSSES AND WHEAT YIELDS, PULLMAN, WASHINGTON.] 1954. [Unpublished data.]

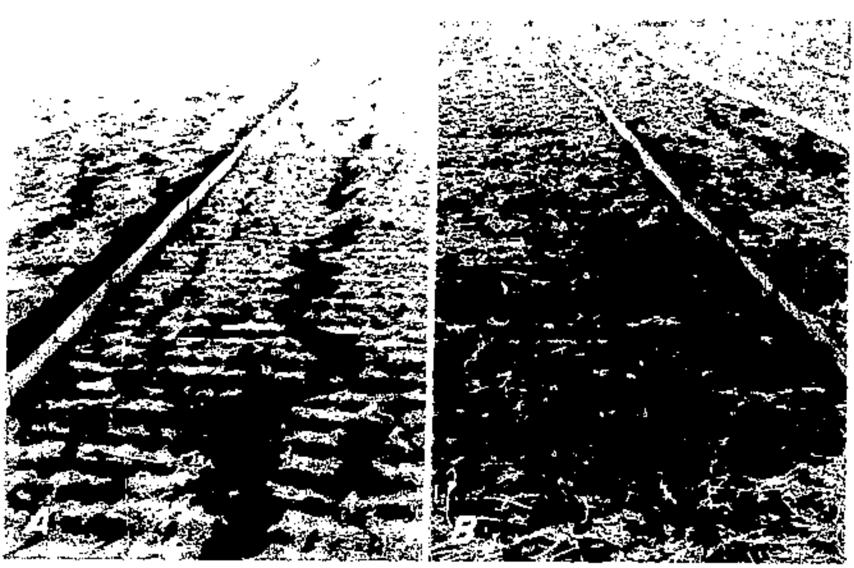

FIGURE 4.—Erosion experienced on (*A*) unmulched and (*B*) mulched experimental runoff plots at Pullman, Wash., 1954. (Photograph by G. M. Horner.)

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Protection of the soil by mulch from the impact of rainfall and flow of runoff water is somewhat analogous to the principles involved in vegetal protection from wind erosion. Ellison (*9*) indicates that residues on the surface tend to receive the direct impact of raindrops, lessen soil splash, and provide roughness as an obstacle to flow of water over the surface. Duley (*5, 8*) has shown that mulch tends to prevent compaction and sealing of the immediate soil surface. Little information is available as to quantitative effects of increasing amounts of surface mulch.

Amounts of 0, 1, and 2 tons per acre of mulch were employed in an experiment at Pullman, Wash.,[5] for a 6-year period under sweep-tillage methods. Average soil losses were 10.16, 3.63, and 0.8 tons per acre per year, respectively. A view of erosion with and without mulch at this location is shown (fig. 4).

Control of Surface Runoff

It has been determined that average annual runoff is decreased by leaving crop residues on the surface of the land. Average annual runoff losses in inches, as measured at Lincoln, Nebr., Cherokee, Okla., and Pullman, Wash., are shown (table 2). These data indicate that, on an average annual basis for the period of study, approximately ½ to 1 inch more water remained on stubble-mulched fields than on moldboard-plowed fields.

TABLE 2.—*Comparative annual surface runoff for mulched and moldboard-plowed surfaces at 3 locations*

Location and literature reference	Crop sequence	Period	Average annual runoff when surface was—	
			Mulched	Plowed
		Years	*Inches*	*Inches*
Lincoln, Nebr.[1]	Corn, oats, wheat	6	0. 70	2. 09
Cherokee, Okla.(*4*)	Continuous wheat	10	3. 92	4. 28
Pullman, Wash.[2]	Alternate wheat and fallow, with 1 ton per acre residue on surface of mulched plots.	10	. 99	1. 93

[1] See table 1, footnote 1.
[2] See table 1, footnote 2.

The effectiveness of stubble mulching, as compared with that of plow culture, may vary considerably when individual storms and their runoff are considered. Results recorded during 2 storms at Cherokee, Okla., 1950, are given (fig. 5). The first storm was on August 15 and the second 2 days later, August 17.

[5] Horner, cited in table 1, footnote 2.

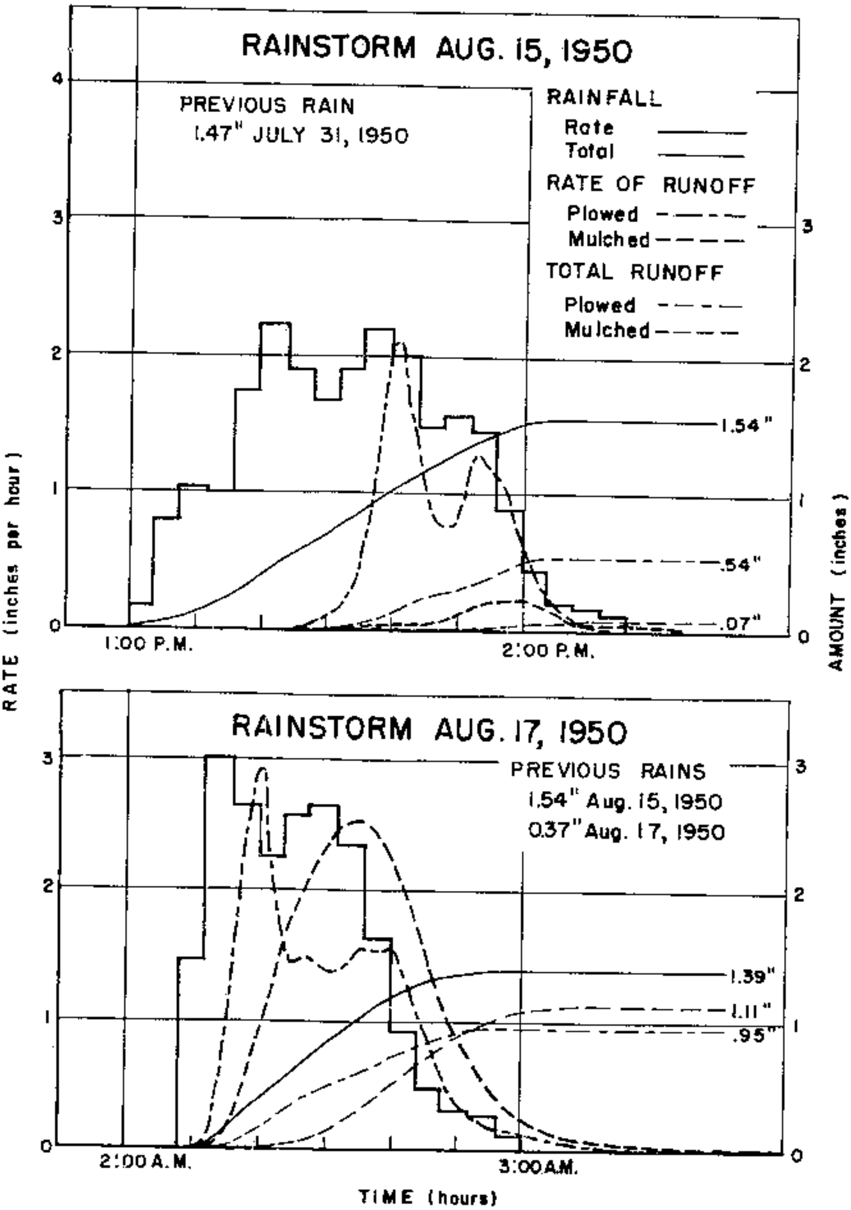

FIGURE 5.—Runoff from plowed and stubble-mulched plots at Cherokee, Okla., during 2 storms (1950), showing contrast where soil was dry at time of storm on August 15 (upper graph) and soil was wet at time of storm on August 17 (lower graph). Runoff data are the composite of 4 plots of 2 to 3 acres for each condition.

Plowed plots have a flash type runoff associated closely with rainfall intensity, as the hydrographs indicate. Where residue covers are present, as in stubble mulching, the hydrograph of runoff has a much smoother appearance and the peak is somewhat delayed, indicating the retarding influence of cover on the movement of water over the surface.

The contrast in runoff, as shown for the 2 storms, is typical for the location. On August 15 the mulched plots absorbed approximately ½ inch more water than did the plowed plots, indicating that the soil reservoir was filled to a greater extent on the mulched plots. For the storm of August 17, however, a reversal in the trend of total storm runoff is indicated; in this instance the stubble-mulch plot yielded the greater amount of total runoff.

Comparing the runoff from both storms, it is seen that the lesser total occurred on the mulched plots. However, the timing of amounts comprising the total should be taken into consideration in evaluating the influence of tillage treatment on flooding of land by small streams.

In tests made with an artificial rain machine in Nebraska by Duley (5), mulched surfaces maintained a relatively high rate of intake compared with that of bare cultivated plots, for all periods of rainfall application. This seems to indicate that only surface conditions limit deeper infiltration and percolation of water into the soil profiles studied. On other soils, such as those at Cherokee, Okla., factors other than infiltration into the immediate soil surface appear to be important to total rainfall intake.

Effects of Residues on Soil Moisture

As runoff, considered on an annual basis, is decreased where cover or residue is present on the land, more available moisture should presumably be present in the soil for subsequent plant or crop growth. Average figures for soil moisture present under different cultural treatments are shown (table 3). These averages cover a considerable period. Differences in amounts of soil moisture, as determined by samplings from plots treated by different tillage methods, were not great. Mulched surfaces tended to have a slightly higher moisture content than plowed surfaces.

At Amarillo, Tex., where increased yields were obtained from stubble mulching compared with yields from one-way disk plowing, there was a tendency for better stands of wheat to develop under the mulched condition. This seems to be associated with a higher level of moisture in the soil horizon immediately below the mulch and appears to be a possible factor in the favorable yields obtained. This is especially true in dry years, as illustrated by photographs of the wheat stand and growth for the two tillage methods in 1953 (fig. 6).

Available data on soil moisture for different locations are extremely variable and are somewhat inconclusive. The differences measured by moisture sampling do not seem to be of the magnitude indicated by the decreased runoff values secured on stubble-mulched plots. It is apparent that the mechanism of moisture movement under a mulched surface needs considerably more study before it can be fully understood. There are indications that, for a period following precipitation, the immediate surface of unmulched plots dries faster than does the immediate surface under a mulch. After a time, however, the diffusion process of the moisture transferred to the surface may occur at a greater rate or for a longer period of time on mulched than on plowed plots.

Moreover, temperature effects capable of affecting moisture movement are undoubtedly present in the soil. These, however, have not been

TABLE 3.—*Average soil moisture present under various tillage methods at several locations*

Location and literature reference	Period	Soil depth sampled	Tillage method		
			Mulching	Moldboard plowing	One-waying
	Years	*Feet*	*Percent*	*Percent*	*Percent*
Hays, Kans.[1]	3	6	19.3	18.5	17.7
Froid, Mont.[2]	11	5	13.7	13.4	13.0
Havre, Mont.[3]	11	5	12.6	12.1	12.2
Cherokee, Okla. (*4*)	10	3	11.3	11.3	....
Pendleton, Oreg.[4]	3	5	15.1	12.5	....

[1] BROWN, P. L. [STUBBLE MULCH EXPERIMENTS AT HAYS, KANSAS.] 1954. [Unpublished data, March.]

[2] AASHEIM, T. S. 1954. [Correspondence.]

[3] BAKER, L. O. [REPORT OF METHODS OF SUMMER FALLOW PROJECTS IN WHICH STUBBLE MULCH TREATMENTS ARE INCLUDED AT THE NORTHERN MONTANA BRANCH STATION, HAVRE, MONTANA.] 1954. [Unpublished data, February.]

[4] OVESON, M. M. [STUBBLE MULCH DATA FROM THE PENDLETON, OREGON, BRANCH EXPERIMENT STATION.] 1954. [Correspondence.]

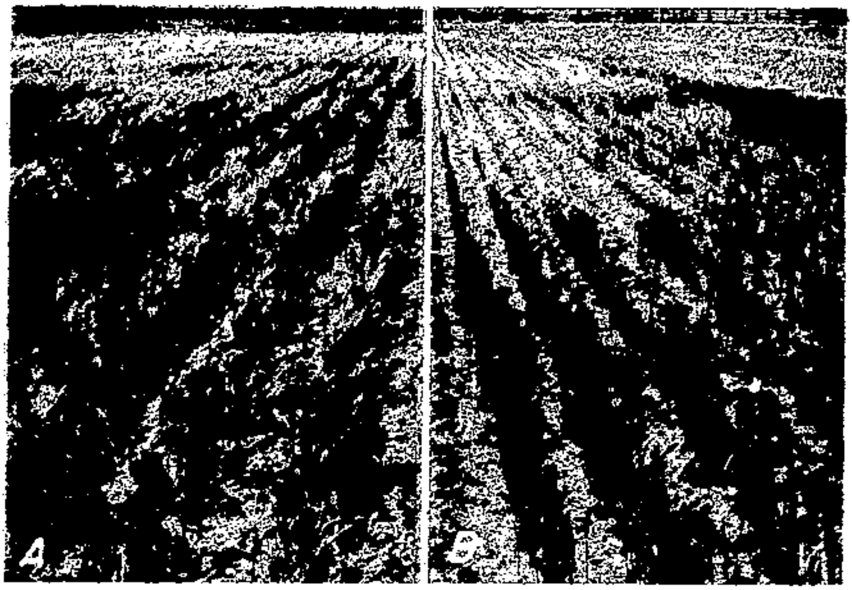

FIGURE 6.—Better stand and growth of wheat, Amarillo, Tex., 1953, on (*A*) stubble-mulched plots, as compared with (*B*) plots on which the conventional one-way disk plowing methods were used. (Photograph by C. E. Van Doren)

determined conclusively in conjunction with past studies. Lemon (*12*) presents soil-temperature data obtained from two locations in Texas under both mulched and bare surfaces. Continuous records indicated that temperatures were not reduced under a mulch in the manner expected, but were slightly increased at some depths. While lower temperatures were found under the mulch at a depth of 3 inches, higher temperatures were found at depths of 6 and 12 inches. The net result was greater total heat in the soil profile under mulch. These results led the investigators to believe that heavy plant residues on the soil tend to conserve heat under certain conditions. The phenomena may logically be expected to vary with the seasons.

In 1938 Duley and Russel (*7*) made intensive studies of soil moisture under 2-ton applications of straw as compared with disked plots with no straw cover. During the period April to September, 17.9 inches of rain fell. During this same period, moisture penetrated 4 feet without the straw. Penetrations of 5 to 6 feet were measured under mulches on different plots.

In experiments with soil columns in cylinders, Russel (*26*) reports that the main effects of mulches on evaporation persist for a period of about 2 days following a rain. He found a reduction of 0.1 inch in evaporation during the first 24 hours after wetting the soil columns. Control of evaporation in these experiments was not greatly enhanced by quantities of residue greater than 2 tons per acre. To the investigator, this indicated that the protection of a wet soil surface from solar radiation is much more important than interruption of heat flow downward or obstruction of vapor diffusion.

McCalla and Duley (*23*) found that heavy mulches, such as 8 tons of straw per acre, lowered temperatures as much as 17.7° C. at a 1-inch depth. They state further that for a period of 3 to 4 months after the application of a straw mulch at the rate of 2 or 3 tons per acre, soil temperatures may be reduced from 3° to 6° at the 1-inch depth and from 2° to 4° at the 4-inch depth. Soil temperatures at lower depths were not determined by these investigators.

McCalla (*20*) made light reflection and surface-soil temperature readings on field plots mulched with dark and bright straw. He found a close relationship between light reflection and soil temperature. The soil mulched with bright straw reflected the most light and warmed the least. When bright straw was used to completely cover the Marshall surface soil, more than twice as much light was reflected from the mulched as from the plowed land. Since a 4-ton application of straw residues covered the soil completely, no additional reflection was obtained by increasing the rates of application up to 8 tons per acre. As decomposition progressed, there was less ground coverage, and the residues became darker in color with less light reflection. Under most of the conditions of stubble mulching studied in the field, it was found that light reflection was not much greater on mulched than on plowed land.

The investigations showed that soil-moisture movement and conservation, under both mulched and bare soil surfaces, depends on many factors. These include climate, soils, amounts and characteristics of residues, soil temperatures, and length of time after rain. Such factors cannot be fully evaluated without additional intensive study.

Effects of Tillage Practices on Wheat Production

Yields

Grain

A summary of average annual wheat yields from all locations is given (table 4). The average yield figures under the three tillage methods are for wheat following fallow or in a rotation system, and also for continuous wheat. Most of the yields from one-way disk plowing are intermediate between those from stubble-mulch tillage and those from moldboard plowing. This tendency seems to hold. irrespective of whether mulch culture or plowing operations resulted in the higher yields. Although interpretation of such data is difficult. it was evident that mulch tillage gave the highest yield at some locations and moldboard plowing at others.

It is apparent that increased yields from the stubble-mulch system are associated with the locations having a comparatively dry climate. To secure definite information as to such a trend, the value of Thornthwaite's (27) P-E (precipitation to evaporation) index was determined for 8 locations. Thornthwaite's index has been widely used for humidity classification. As used in this study, the formula is:

$$\text{P–E index} = \sum_{n=\text{July}}^{\text{June}} 115 \left(\frac{P}{T-10} \right)^{\frac{10}{9}}_{n}$$

In this equation. the crop-season rainfall is considered to be that for the 12-month period beginning with July and ending with the following June. The index is a summation of data by months for this 12-month period. where n indicates the value for a given month. The value 115 is a constant chosen to make the values of the index figures from temperature data approximate those of evaporation from a free-water surface. The value of P is the amount of precipitation in inches for a given month. The value of T is the average monthly temperature in degrees Fahrenheit. The power of $\frac{10}{9}$ governs the range of values when temperature instead of evaporation is considered.

The annual crop-season precipitation in inches is given along with the values of Thornthwaite's P-E index (table 5). Also given are the number of years at each location in which the yield from stubble mulching was either increased or decreased in comparison with the yield from clean-tillage methods. The last column gives the average yield ratio (stubble-mulching yield in bushels per acre divided by clean-tillage yield) secured at each of the 8 locations. These data indicate that as the value of the P–E index increases, the relative yield of stubble-mulch methods decreases in comparison with that from clean-tillage methods.

A concept of the yield ratio with respect to values of the P-E index is graphically presented (fig. 7). The horizontal scale of *A* gives the humidity range, while the vertical scales of *A* and *B* give the ratio of yield from stubble mulching to yield from clean tillage. The points plotted in *A* are average values at each of the 8 locations. The trend line drawn through these values indicates the favorable nature of yield ratios in the semiarid region and the relatively unfavorable ratios in the subhumid and humid regions. Data by individual years from each of the 8 locations is plotted in *B*. These annual values also indicate a trend

TABLE 4.—*Summary of average annual yields of wheat under various tillage methods at 15 experimental locations*

Location and literature reference	Period	Yield of wheat following fallow or in rotation when plots were—			Yield of continuous wheat when plots were—		
		Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Years	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*
Akron, Colo.[1]	12	23. 2	23. 1	....	....	....	....
St. Anthony, Idaho[2]	14	25. 2	23. 5	23. 9	....	....	....
Hays, Kans.[3]	11	....	....	....	19. 4	20. 5	20. 6
Froid, Mont.[4] (*1*)	11	25. 9	27. 5	26. 1	....	....	....
Havre, Mont.[5] (*1*)	12	17. 4	17. 1	16. 6	....	....	....
Moccasin, Mont.[6] (*1*)	5	....	....	....	21. 2	22. 0	....
Lincoln, Nebr.[7]	16	25. 2	26. 9	....	....	....	....
North Platte, Nebr.[8]	4	26. 6	25. 1	26. 6	16. 8	15. 6	15. 1
Mandan, N. Dak.[9]	22	16. 3	17. 5	....	....	....	....
Cherokee, Okla. (*4*)	10	....	....	....	14. 4	19. 3	....
Stillwater, Okla.[10]	12	21. 8	21. 6	21. 0	....	....	....
Pendleton, Oreg.[11]	13	31. 0	36. 1	30. 2	....	....	....
Newell, S. Dak.[12]	22	20. 1	19. 7	....	....	....	....
Amarillo, Tex.[13] (*11*, *28*)	11	18. 3	....	16. 0	11. 0	....	9. 6
Pullman, Wash.[14] [15]	10	28. 9	34. 6	....	....	....	....

[1] BRANDON, J. F. 1954. [Correspondence, March .]

[2] SIDDOWAY, F. H. [STUBBLE MULCH SUMMARY, ST. ANTHONY, IDAHO.] 1954. [Unpublished data, March.]

[3] See table 3, footnote 1.

[4] See table 3, footnote 2.

[5] See table 3, footnote 3.

[6] WILLIAMS, R. M. [TRASH TILLAGE ON FALLOW WITH WINTER WHEAT AT CENTRAL MONTANA BRANCH STATION, MOCCASIN, MONT.] 1954. [Unpublished data.]

[7] Duley, F. L. 1954. [Unpublished data.]

[8] RAMIG, R. E. [SUMMARY OF STUBBLE MULCH INFORMATION AT NORTH PLATTE, NEBR.] 1954. [Unpublished data, March.]

[9] HAAS, H. J. 1954. [Correspondence, Northern Great Plains Field Station, Mandan, N. Dak.]

[10] HARPER, H. J. [EFFECT OF TILLAGE METHODS WITH AND WITHOUT A SWEETCLOVER ROTATION ON WINTER WHEAT PRODUCTION IN CENTRAL AND WESTERN OKLAHOMA.] 1952. [Unpublished manuscript.]

[11] See table 3, footnote 4.

[12] OSENBRUG, A. [SUMMARY OF TRIALS PERTAINING TO STUBBLE MULCH FARMING ON DRYLAND AT THE NEWELL, SOUTH DAKOTA, IRRIGATION AND DRYLAND FIELD STATION.] 1954. [Unpublished manuscript.]

[13] VAN DOREN, C. E., and WHITFIELD, C. J. [SUMMARY REPORT—STUBBLE MULCH STUDIES, 1942–53.] 1954. [Unpublished data.]

[14] See table 1, footnote 2.

[15] 1 ton per acre of mulch applied artificially to both subsurface-tilled and plowed plots.

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TABLE 5.—*Annual crop-season precipitation, P–E index, years of yield increase and decrease, and average yield ratio, under stubble-mulch and clean-tillage methods at 8 locations*

Location and literature reference	Years of record	Crop sequence	Average precipitation, July–June	P–E index	Years when yield was— Increased	Years when yield was— Decreased	Average yield ratio of stubble mulch to clean tillage
	Number		*Inches*		*Number*	*Number*	
Havre, Mont.[1]	12	Spring wheat on fallow	11.29	24.56	8	4	1.05
Amarillo, Tex.[2] (*11*, *28*)	11	Winter wheat on fallow	17.70	24.85	10	0	1.14
		Winter wheat, continuous			9	1	1.15
St. Anthony, Idaho[3]	14	Winter wheat on fallow	13.74	38.49	9	4	1.07
Pendleton, Oreg.[4]	13	.....do	17.56	43.74	2	11	.85
Hays, Kans.[5]	11	Winter wheat, continuous	24.27	46.28	5	6	.95
Cherokee, Okla. (*4*)	10	.....do	27.01	47.92	2	8	.75
Lincoln, Nebr.[6]	16	Winter wheat in 3-year rotation	28.33	56.56	5	11	.94
Pullman, Wash.[7]	10	Winter wheat on fallow	21.53	69.66	0	10	.84

[1] See table 3, footnote 3.
[2] See table 4, footnote 13.
[3] See table 4, footnote 2.
[4] See table 3, footnote 4.
[5] See table 3, footnote 1.
[6] See table 4, footnote 7.
[7] See table 1, footnote 2.

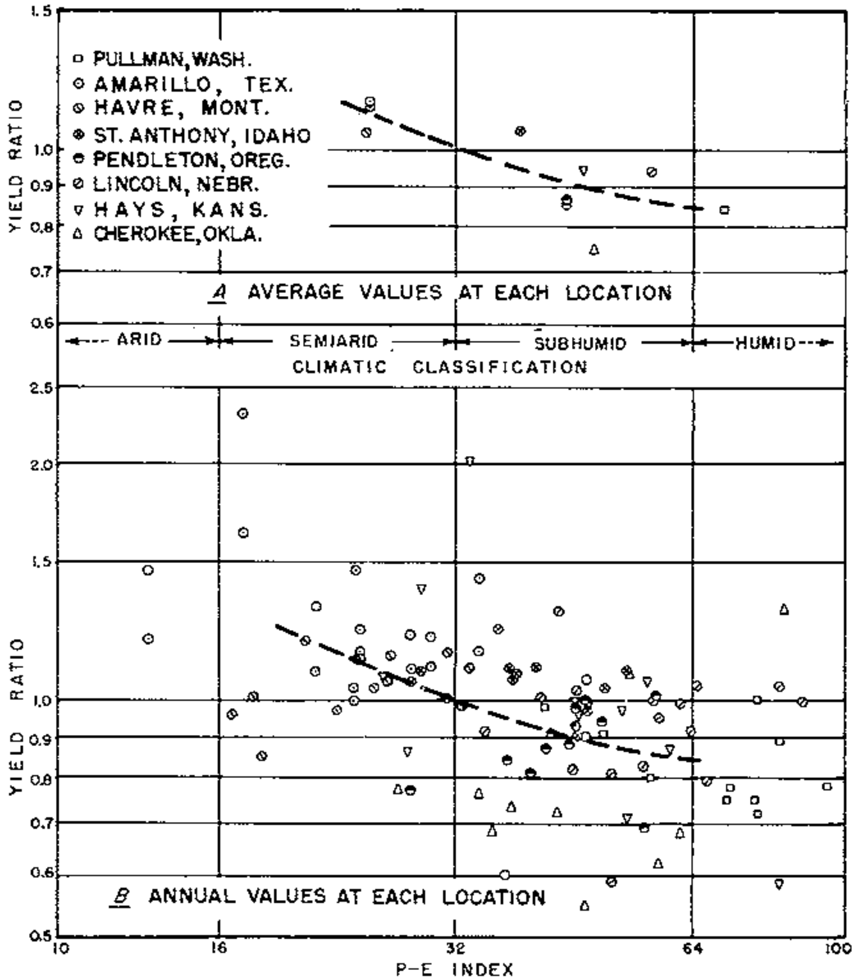

FIGURE 7.—Graphical plotting of P–E index and wheat-yield ratios, that is $\frac{\text{yield from stubble-mulch system}}{\text{yield from clean-tillage system}}$, at several locations in the West, showing: *A*, Average values at each location; *B*, annual values at each location.

toward decreased relative yield with stubble-mulch tillage compared with that from clean-tillage operations. as the value of the P–E index increases. While the range of values about a possible average trend is great, these data indicate that the practice of stubble-mulch tillage has favorable yield aspects in semiarid regions.

Straw

The records of wheat-straw production, as averaged for various periods at 6 locations, are given (table 6). Production from mulched and unmulched plots is summarized for comparison. At some of the locations, figures for the unmulched plots are the average from both moldboard plowing and one-way plowing operations.

TABLE 6.—*Wheat-straw production and ratios of straw to grain at 6 locations*

Location and literature reference	Crop sequence	Period	Straw produced		Ratio of straw to grain when plots were—	
			Mulched	Unmulched	Mulched	Unmulched
		Years	*Pounds per acre*	*Pounds per acre*		
Lincoln, Nebr.[1]	Corn, oats, wheat	16	2,573	2,856	1.71	1.78
	Oats, sweetclover, wheat	9	4,276	4,558	1.99	2.06
Mandon, N. Dak.[2]	Wheat, fallow	15	2,120	2,125	1.84	1.80
Stillwater, Okla.[3]	3 years wheat, oats, sweetclover	12	2,156	2,154	1.65	1.66
Cherokee, Okla. (*4*)	Wheat, continuous	10	2,328	2,720	2.69	2.34
Newell, S. Dak.[4]	Wheat, fallow	20	2,300	2,155	1.91	1.82
	Wheat, continuous	4	961	1,029	1.31	2.09
Amarillo, Tex.[5] (*11, 28*)	Wheat, fallow	7	2,235	2,083	1.78	1.93
	Wheat, continuous	8	1,691	1,796	1.98	2.38
Total years of data		101				
Simple averages			2,294	2,386	1.87	1.98

[1] See table 4, footnote 7.
[2] See table 4, footnote 9.
[3] See table 4 footnote 10.
[4] See table 4, footnote 12.
[5] See table 4, footnote 13.

On the basis of data presented, it is difficult to credit either tillage method with marked differences in straw production. There were substantial reductions in the straw produced under the mulched condition at Lincoln, Nebr.; also under continuous wheat at Cherokee, Okla., Newell, S. Dak., and Amarillo, Tex. On the other hand, a substantial increase in straw production was obtained at Newell, S. Dak., for wheat under a wheat-fallow system, when comparing the mulched with the unmulched condition. A simple average of these data covering 101 crop-year comparisons at the 6 locations indicates a small decrease of 3.9 percent in the straw produced under the mulch system of culture.

Ratio of straw to grain

The ratio of straw to grain, calculated from an average of straw production and grain yields for mulched and unmulched plots, is also given (table 6). In 6 of the 9 comparative figures, the straw/grain ratio (ratio of weight of straw to weight of grain) is lower under the mulched condition than under the unmulched. Overall averages are 1.87 and 1.98, respectively.

Protein Content of Grain

When values were determined experimentally, the protein content of grain produced under stubble mulching was usually less than under clean tillage. A summary of data from seven locations is given (table 7).

At 6 of the 7 locations, average values were lower under the mulch system of culture. In only one instance the 5 years of investigation

TABLE 7.—*Protein content of wheat grain at 7 locations*

Location and literature reference	Crop sequence	Period	Protein in grain when surface was— Mulched	Protein in grain when surface was— Unmulched
		Years	*Percent*	*Percent*
St. Anthony, Idaho [1]	Wheat, fallow	12	14.1	14.3
Havre, Mont.[2]	do	12	16.4	16.5
Moccasin, Mont.[3]	do	5	12.0	12.6
Froid, Mont.[4]	do	7	14.4	14.9
Lincoln, Nebr.[5]	(6)	5	13.5	13.4
North Platte, Nebr.[7]	Continuous wheat	1	12.0	12.3
	Wheat, fallow	4	12.4	13.2
Newell, S. Dak.[8]	Continuous wheat	3	12.8	15.3
Total years of data		52		
Simple averages			13.5	14.1

[1] See table 4, footnote 2.
[2] See table 3, footnote 3.
[3] See table 4, footnote 6.
[4] See table 3, footnote 2.
[5] Duley, F. L. 1955. [Correspondence, May.]
[6] Protein values are averages of 28 crop-treatment-year comparisons.
[7] See table 4, footnote 8.
[8] See table 4, footnote 12.

at Lincoln, Nebr.—was the percentage of protein in the grain higher under the mulch system. As an average for the 7 locations covering 52 years of comparative data, the reduction in protein content of wheat was 0.6 of 1 percent.

Effects of Fertilizers and Legumes Under Various Tillage Practices

The average data secured at North Platte, Nebr., over a 4-year period in which 30 pounds of nitrogen fertilizer was applied to mulched, plowed, and one-wayed surfaces, are given (table 8). The results of this experiment indicate that yields were not significantly changed by the fertilizer. The protein content of the grain, however, was increased appreciably under the wheat-fallow system. Nitrogen increased the protein content of grain under continuous wheat also, although not as much as under wheat-fallow. As an average for this period, mulching gave substantially higher yields than did moldboard plowing. Moisture rather than fertility seemed to be the limiting factor in wheat production for the period.

TABLE 8.—*Average data for a 4-year period showing effects of 30 pounds of nitrogen fertilizer on wheat yields and on protein content of wheat, for different tillage methods at North Platte, Nebr.*[1]

Crop sequence and tillage method	Yield from—		Protein content[2] of grain from—	
	Check plots	Plots with 30 pounds of nitrogen per acre[3]	Check plots	Plots with 30 pounds of nitrogen per acre
	Bushels per acre	*Bushels per acre*	*Percent*	*Percent*
Continuous wheat:				
Mulched	16.8	17.6	11.0	11.6
Plowed	15.6	15.2	11.4	11.8
One-wayed	15.1	15.5	11.1	11.7
Wheat, fallow, wheat:				
Mulched	26.6	26.5	12.4	13.8
Plowed	25.1	24.0	13.2	14.4
One-wayed	26.6	26.2	13.0	14.2

[1] See table 4, footnote 8.
[2] Protein data for continuous wheat are averages for 3-year period (1950–52) only.
[3] Amount applied each year. On wheat-fallow system, 30 pounds of nitrogen is applied on stubble after harvest and the same amount on wheat in the spring, making a total of 60 pounds of nitrogen per acre for each wheat crop.

At Pendleton, Oreg.[6] and at Cherokee, Okla. (*4*), experiments were carried on to determine the effects of applied nitrogen on wheat yields from both stubble-mulch and plowing methods of culture. The average results of these experiments are shown in graphs (fig. 8).

[6] Oveson (cited in table 3, footnote 4).

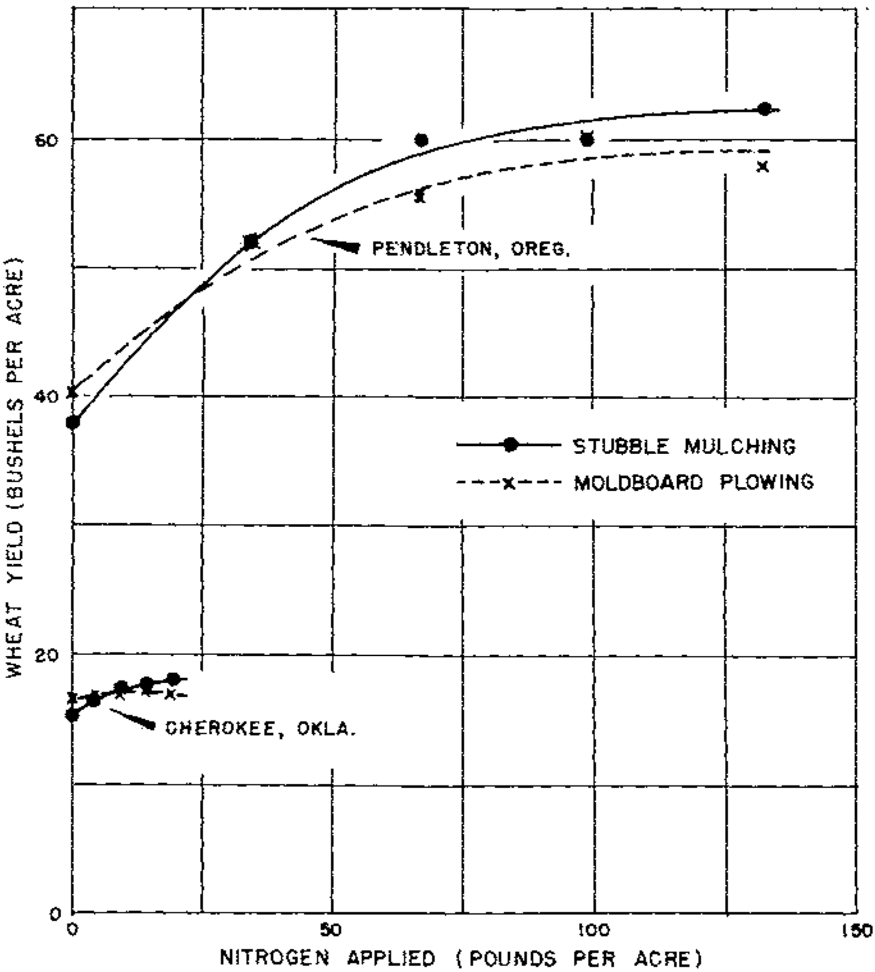

FIGURE 8.—Average trend of wheat yields under stubble mulching and moldboard plowing in relation to amount of nitrogen fertilizer applied.

The graphs show that in both instances, the stubble-mulching practice gave the lowest yields where no nitrogen fertilizer was applied. With the application of nitrogen fertilizer, a point was reached where the yields from stubble-mulching were greater than from plowing. Both locations are in subhumid areas, where fertility as well as moisture is often limiting. Both experiments were of short duration and were carried out on a new set of plots each year. Thus, cumulative effects of applied nitrogen were not reflected in the results. Furthermore, the problems experienced with weed control at Cherokee, under a system of continuous wheat, were not present in this experiment.

These results, though meager, indicate that in subhumid areas, application of nitrogen fertilizer is capable of resulting in yields under a stubble-mulch system that compare favorably with yields obtained under clean-tillage methods. To substantiate this comparison more conclusively, thorough investigations at several locations would be necessary.

Effects of Mulching Practices on Properties of Soil

Chemical Effects

Nitrates

The tendency of total wheat growth under a system of mulching to be suppressed in comparison with growth under moldboard plowing indicates the presence of lesser amounts of nitrates or, possibly, toxic chemical effects. The measurement of nitrates was not a regular part of the studies reported in this bulletin, but limited data were available from a number of locations. Where nitrates were extremely high, as at St. Anthony, Idaho, values secured during a 3-year period averaged 62 and 64 pounds of nitrates per acre in a 2-foot depth of soil under mulched and plowed surfaces, respectively. At this location, no response was obtained from the addition of nitrogen fertilizer, and no depressing effect on grain yields was noted when 4,000 pounds of wheat straw were applied as a mulch.

Determinations made in October 1942 on an experimental site at Stillwater, Oklahoma (Perkins Farm) showed a tendency for lesser amounts of nitrates to be present on the stubble-mulched plots than on those that were moldboard plowed. The average differences were not great, however, being 5.5 parts per million (p. p. m.) on the stubble-mulched plots and 5.7 p. p. m. on the moldboard-plowed plots. On a group of 11 farm fields studied in central Oklahoma, average values of nitrates in a 6-inch depth were 2.9 p. p. m. on stubble-mulched plots and 4.2 p. p. m. on moldboard-plowed or disked plots.

At Lincoln, Nebr. (*24*), the nitrate content of the 0- to 6-inch soil layer averaged 23.6 and 32.8 pounds per acre for mulched and plowed plots, respectively over a 4-year period (1939–42) under a crop rotation of corn, oats, wheat. Where sweetclover was used in the rotation (*25*), the level was 61.5 pounds per acre for mulched plots and 71.7 for plowed plots, as an average for several samplings in 1946.

The depression in nitrates may have been an indirect cause of yield increases from stubble mulching on the more fertile soils of the drier regions. Where moisture rather than fertility is normally limiting, depressions in vegetal growth possibly leave more soil moisture available for sustaining the plant through the period of grain production. This is a point capable of clarification through the addition of variable amounts of nitrogen in controlled experiments.

Available phosphorus

Limited studies of available phosphorus were made at Stillwater, Okla.,[7] and at Lincoln, Nebr.,[8] under stubble mulching and moldboard plowing. At Stillwater, the difference in available phosphorus between the 0- to 3-inch and the 3- to 6-inch depths of soil on plowed plots was only 2 p.p.m. higher in the first 3-inch surface layer than in the second. However, it was 7 p.p.m. higher in the surface layer than in the 3- to 6-inch layer when residue was left on the surface.

[7] Harper (cited in table 4, footnote 10).
[8] Duley (cited in table 4, footnote 7).

Studies in Nebraska showed a significant increase in the acid soluble and adsorbed phosphorus content of the surface inch of soil over that in the 3- to 6-inch layer of the subtilled plots. The variation in the acid soluble or adsorbed phosphorus at different depths of the plowed plots was consistently less than that of the stubble-mulched plots. There was, however, little difference in the total phosphorus content of the 0- to 6-inch depth of the plots under stubble mulching or plowing.

The foregoing data indicate that available phosphates tend to be concentrated nearer the surface on stubble-mulched plots than on plowed plots. It follows as a reasonable assumption that early seedling growth and root development of wheat after seeding will respond to this additional concentration of available phosphorus to a greater degree on mulched than on plowed areas.

Organic matter

While data are meager, there is some indication that stubble-mulch tillage is checking the rate of decline of organic matter in Great Plains soils. At Amarillo, Tex. (*11*), determinations of organic matter in a 0- to 3-inch depth made in 1949 showed levels of 2.20 and 2.11 percent for mulch culture and one-way disk plowing, respectively. These values were secured with continuous wheat after a 7-year period. Under a wheat-fallow system, comparable figures were 2.07 and 1.96 percent, respectively. After 22 years of culture at Newell, S. Dak.,[9] the organic matter in a 12-inch soil depth averaged 1.04 percent and 0.92 percent for mulched and plowed plots, respectively.

Physical Effects

Studies of plot surfaces conducted at Cherokee, Okla.,[10] showed a tendency for small-sized, water-stable particles to accumulate on the surface of subtilled plots. Measurement of water-stable particles (spring 1953) showed a subtilled surface to have 72.7 percent of water-stable aggregates of the size range <0.42>0.02 mm. compared with 65.2 percent on the surface of a plowed plot. For dry-aggregate determinations made at the same time, the surface of subtilled plots contained 60.1 percent dry clods < 0.84 mm. in size, compared with 51.2 percent for plowed plots. Thus, the surface soil of subtilled plots contained more material of sizes easily eroded than did plowed plots.

Measurements of dry-clod structure at Amarillo, Tex.[11] (spring 1954) showed greater amounts of particles <0.84 mm. in diameter on mulched than on plowed plots. Such differences ranged from approximately 5 to 16 percent for determinations made at different times during that spring; thus, the magnitude of difference was about the same as that measured at Cherokee, Okla.

In studies at Lincoln, Nebr.,[12] mulched land was found to have more water-stable aggregates >0.25 mm. in the 0- to 1-inch soil layer than did plowed land. Dry-clod-structure analysis was not made at this location; however, the fact that more small water-stable particles were found is

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[9] Osenbrug (cited in table 4, footnote 12).

[10] Zingg, A. W., Chepil, W. S., and Woodruff, N. P. [RESULTS OF PORTABLE WIND TUNNEL STUDIES AT THE WHEAT LAND EXPERIMENT STATION, CHEROKEE, OKLA.] Ann. Res. Rept., Manhattan, Kans. 1953. [Unpublished.]

[11] Van Doren and Whitfield (cited in table 4, footnote 13).

[12] Duley (cited in table 7, footnote 5).

consistent with findings reported in preceding paragraphs, that stubble-mulched soil surfaces tend to have more erodible dry particles <0.84 mm. in diameter.

McCalla (*16*, *17*) reported that when plant residues decompose on the surface of the soil, numerous byproducts are formed which favorably influence the stability of soil aggregates and the rate at which water runs through the soil. McCalla (*19*) also found that when residues decompose on the surface of the soil, aerobic types such as fungi are involved. Fungi are highly effective in improving the stability of the soil against the impact of falling water drops.

McCalla (*14*) reported that organic matter, both on the surface and in the soil, creates soil conditions favorable to the intake of water. Undecomposed residues on the surface afford protection to the soil by preventing surface sealing. McCalla (*21*) also found that organic matter in certain stages of decomposition stabilizes the structure within the soil so as to permit water to move between the aggregates.

Studies at Manhattan, Kans., by Chepil (*2*) showed that decomposing vegetal matter in the form of wheat straw or green alfalfa, mixed with the soil, initially increased both the size and proportion of water-stable aggregates. Gradually, the initial cementing materials formed by decomposition appeared to lose their sticky property, or to be destroyed and replaced by secondary materials. The coarse primary and secondary aggregates then tended to disintegrate to a more or less granulated condition. The resultant granules were essentially water-stable. They formed a friable, mellow soil but, unfortunately, a soil more erodible by wind. The investigator concluded that continual additions of vegetal matter should tend to produce wind-resistant aggregates, and thus tend to counterbalance excessive granulation and increased wind erodibility caused by secondary products of decomposition.

In general, when crop residues are employed as a protective mulch on the soil surface, the structure of the immediate soil surface is modified. Results demonstrate that such structure is more water-stable and more desirable from the standpoint of water intake and tillage. Results also indicate that the size of stable aggregates formed is small, and that they may not be resistant to wind in the absence of residue cover. This condition, however, is not necessarily undesirable from the standpoint of wind-erosion control, for the erodibility of a land surface is determined by the total effects of residues, soil structure, and surface roughness. These three factors, considered together, constitute the land-surface complex.

Decomposition of Crop Residues

McCalla (*17*) found that decomposition of crop residues left on the soil surface takes place as a result of the action of numerous organisms. Since the amount of crop residue available to protect cultivated land may be either limited or abundant, the rate of decomposition and the means of speeding or retarding it are of vital interest in the successful management of crop residues for protection of the land. According to McCalla (*18*), the rate of decomposition is important in the development or maintenance of soil structure and in the production of available nutrients, especially nitrogen. The rate of disappearance of crop residues through decomposition is influenced greatly by temperature, moisture, mineral nutrients.

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chemical composition, and maturity of residues, as well as by the number and types of micro-organisms.

The rate of decomposition of crop residues at the surface of the soil is important, because the amount of protection afforded the land is inversely related to the degree of decomposition, while the release of nutrients from plant material is directly proportional to the process. From the standpoint of protecting the land, crop residues resistant to decomposition are desirable. For the release of nutrients, a rapid decomposition process is desirable. Between the need for preserving the residues on one hand and the need for decomposing them on the other, a compromise that meets specific requirements must be worked out, especially in the more humid regions of the West.

McCalla and Duley (*22*) found that when straw was used as a mulch in the field for 6 months, a 2-ton application lost two-thirds, a 4-ton application lost one-half, and an 8-ton application lost one-third of the added material. After 18 months there was little residue left except with the 8-ton application. When 2 tons of cornstalks were left at the surface, about one-third of the material disappeared after 6 months. After 18 months, some cornstalks remained.

McCalla (*15*) found that in the maintenance of a plant-residue mulch for soil and moisture conservation, deterioration of the mulch is inevitable. Undue mixing of the residue with the soil and excessive fragmentation by tillage machinery should be avoided, as these cause rapid loss of residue. In eastern Nebraska, proper cropping sequence as well as fertilization was found to provide adequate cover.

Weed Control

Cheatgrass or downy brome (*Bromus tectorum*) caused more trouble than other weeds at locations where these studies were conducted.

In the semiarid region, little difficulty was experienced with cheatgrass or other annual weeds when a system of wheat-fallow was employed. Under this crop sequence, subsurface tillage with sweeps was found to be successful in controlling weeds. Moreover, in the drier portions of the semiarid area, little difficulty was experienced with cheatgrass under subtillage methods in which wheat was grown continuously.

Toward the eastern portions of the semiarid region, however, weed control became a problem under a system of continuous wheat. This was true at Akron, Colo.;[13] at Froid, Mont.;[14] and at North Platte, Nebr.[15] At North Platte, under continuous wheat, downy bromegrass was most serious in years when insufficient rainfall occurred prior to seeding time to germinate the weed seed. In years when sufficient rainfall occurred so that the weeds germinated before wheat-seeding time, the weeds were controlled successfully by the use of a rod-weeder.

In the subhumid area around Cherokee, Okla. (*4*), serious trouble was encountered with cheatgrass under annual cropping to wheat. At this location, heavy weed infestations occurred following years of low September rainfall; this was because their germination was delayed until after wheat seeding.

[13] Brandon (cited in table 4, footnote 1).
[14] Aasheim (cited in table 3, footnote 2).
[15] Ramig (cited in table 4, footnote 8).

At Lincoln, Nebr.,[16] and at Pendleton, Oreg.,[17] in the subhumid region, reasonable cheatgrass control was obtained through secondary tillage by use of the skew-treader following subsurface tillage operations.

At Pullman, Wash.,[18] under humid conditions, cheatgrass was a serious problem. This problem was encountered especially during the last 5 years of the experiment. Weed growth at this location was considered responsible for a large part of the yield reduction on subsurface-tilled land.

From these studies, it is apparent that the weed problem, particularly the occurrence of cheatgrass, increases from dry to humid areas. Better methods for its control are needed and should be investigated more thoroughly, under both subhumid and humid conditions.

Insects and Plant Diseases

At only one research location, trouble attributable directly to subsurface tillage was experienced with insects and with plant diseases. At Cherokee, Okla. (*4*), foot rot was a problem on mulched areas. At this location, counts showed an average of approximately eight times as many whiteheads in wheat grown on subtilled land as in that grown on plowed land. Some straw-worm damage occurred at Cherokee in 1943.

Counts of the population of greenbugs on plots with different tillage treatments at Amarillo, Tex.,[19] (*11, 28*) did not show increased numbers on subtilled plots.

Methods of Performing Stubble-Mulch Tillage

Methods of managing residue on the soil surface have varied considerably through the years, as evidenced by the procedures outlined for the different experimental locations (see appendix tables 9 through 24).

At Amarillo, Tex. (*11*), sweeps alone were used successfully. The best angle between the blades of the sweep proved to be 60°. It was found that the sweep should be operated "flat"—that is, in a horizontal position. It was also found desirable to have a rolling coulter ahead of each sweep. Under this method, the initial sweep operation was performed at a depth of 4 to 5 inches. From 1 to 2 additional subsurface-tillage operations at a shallower depth were made prior to seeding with a deep-furrow shovel type drill.

St. Anthony, Idaho, has a semiarid climate similar to that of Amarillo. The practice employed during later years of experimentation was to use a sweep machine operated at a 5- to 6-inch depth for the first tillage operation. In the wheat-fallow system, from 2 to 5 secondary operations, as necessary to control weeds, were carried out with a rod-weeder. A single-disk, press-wheel, power-lift, single-fluted, force-feed grain drill was used in seeding operations. This drill worked well when surface stubble did not exceed 2,000 pounds per acre. When heavier stubble conditions were encountered, a deep-furrow drill was used.

Subsurface tillage at Cherokee, Okla. (*4*), was accomplished by using sweeps of various types. Seeding of continuous wheat was carried out

[16] Duley (cited in table 4, footnote 7).
[17] Oveson (cited in table 3, footnote 4).
[18] Horner, (cited in table 1, footnote 2).
[19] Van Doren (cited in table 4, footnote 13).

with a semideep-furrow, disk type drill. In some years, difficulties were encountered in controlling weeds. In addition, a compacted soil condition tended to develop at sweep depth. Variable (or "flexible") tillage practices were employed in later years, to arrive at a more adaptable method of maintaining residues on the soil surface and overcoming the difficulties encountered.

A variety of subsurface tillage methods were studied under the subhumid conditions at Lincoln, Nebr. Based on these researches, Duley outlines four methods of performing stubble-mulch farming in wheat-fallow areas under varying conditions. He states (*6, p. 6*): "No one set of tools is best for all conditions. Many combinations of tillers, packers, weeders and drills may be used so as to result in a good job."

In the experimental work at Pendleton, Oreg., the practice under a wheat-fallow system was to use the sweep machine in the spring of the fallow year. The rod-weeder with tiller-bar attachment was used for secondary tillage operations. When wheat stubble was extremely heavy, a skew-treader was used before the rod weeding. To meet problems encountered in a rotation of wheat and peas, where residue weights above 6,000 pounds per acre were present, the following procedure was developed: (1) The residues were "stubble busted" after harvest, while still dry; (2) sweeping, plowing, or cultivating was done in the fall, to mix residues with the top 3 inches of soil; (3) the first tillage operation in the spring was accomplished with a high-clearance, spring-tooth cultivator; (4) rod-weeder equipment with shovels was used to bring clods,

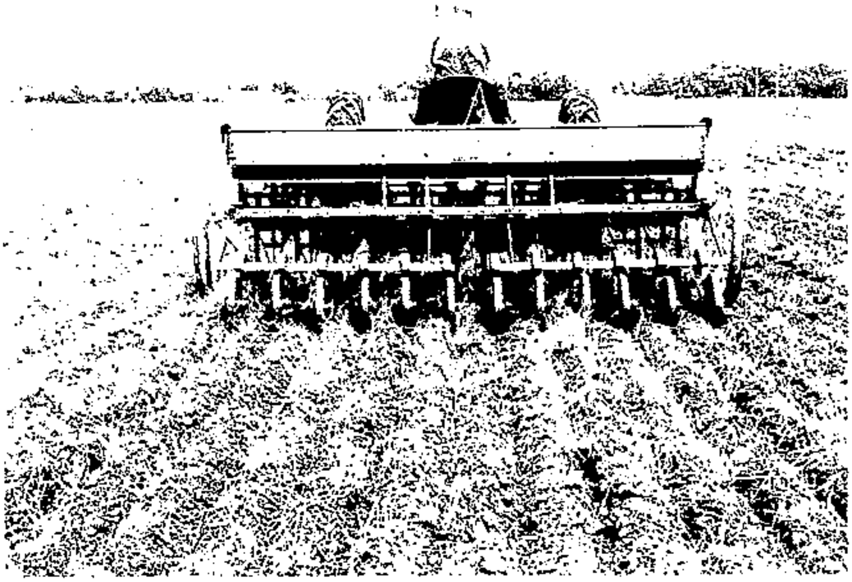

FIGURE 9.—Desirable complex (residue, roughness, soil structure) after drilling wheat (Lincoln, Nebr.). This resulted from applying stubble-mulch management methods, as set forth in this bulletin. (Photograph by F. L. Duley.)

weeds, and volunteer wheat to the surface, in order to level the ground and pack the soil below the surface; (5) a shovel type, deep-furrow drill was used for seeding wheat in the fall. A single-disk, semideep-furrow drill proved best for seeding peas.

From the foregoing account of the different methods used at a few of the experimental locations, it is apparent that a standard method for stubble-mulch tillage applicable to all locations and conditions was not developed in these studies; nor is its development likely. The objective was to provide an anchored cover of residue material after the new crop was seeded, in combination with a fairly cloddy and rough surface capable of resisting the forces of wind and absorbing rainfall. The desired condition is illustrated (fig. 9).

Certain tillage practices were found to be undesirable. The most common fault in many farm operations was excessive working of the soil. Tillage now regarded as excessive was carried out at a few of the experimental locations, with as many as 7 to 9 operations in one fallow season. It was determined that too-frequent tillage tends to destroy the residue cover, pulverize the surface soil, and in general nullify the benefits obtainable from the mulching practice. Another mistake was to maintain a constant depth of subsurface tillage; this resulted in an undesirably compacted subsurface soil condition. Varying the depth of subsurface tillage, with the first operation carried out at the greatest depth, helped to correct this condition. Occasional use of a chisel type implement to break up compaction below sweep depth was also found desirable.

Summary of Investigations

This report presents and interprets data that were readily available for studying the status of stubble-mulch tillage in the West. It was undertaken to overcome deficiencies in existing methods in certain areas, to define the conditions under which such methods were being successfully employed, and to point the way for improvement through research.

The practice of stubble mulching was demonstrated to be of practical value in controlling wind and water erosion and surface runoff. Under measured conditions in the West, the practice reduced soil losses from intense rainfall to about 20 percent of the amounts lost when surfaces were moldboard plowed. As gaged at certain locations, mulching reduced the average annual runoff by approximately ½ to 1 inch, or about one-half the amount that occurred without mulching. Studies of field surfaces showed that residues of various amounts, types, and orientation are capable of removing from 5 to 99 percent of the force of wind from the immediate soil surface.

Differences in the soil moisture under mulched and unmulched surfaces, as determined from moisture samplings, were not great. Mulched surfaces tended to have a higher moisture content than those that were moldboard plowed.

In semiarid locations the practice of leaving a stubble mulch on the surface generally resulted in small yield increases of the wheat crop. In more humid climates, small yield decreases usually resulted.

At most locations, the amount of wheat straw produced under a mulching system was slightly less than under clean cultivation. A simple

average of data covering 101 crop-year comparisons at 6 locations showed a small decrease of 3.9 percent.

The average ratio of straw to grain was lower for the wheat crop under stubble mulching than under moldboard plowing. Average values were 1.87 and 1.98, respectively.

The protein content of wheat averaged less under stubble mulching than under moldboard plowing. Average data for 7 locations, covering some 52 crop-year comparisons, showed a reduction in protein content of 0.6 of 1 percent.

In annual fertilizer experiments in the more humid regions of the West, favorable yield responses were obtained from nitrogen fertilizer. The relative yield of wheat from mulched surfaces, compared with that from unmulched surfaces, was increased by the application of nitrogen fertilizer. No response of consequence was obtained in semiarid regions.

There was a tendency for mulches on the soil surface to reduce the quantity of soil nitrates.

Available phosphorus appeared to be concentrated nearer the soil surface on mulched plots than on moldboard-plowed plots.

Measurements of organic-matter contents of soils indicated that the practice of stubble-mulch tillage serves to retard the decline of such contents in the Great Plains soils.

It was determined that both the water-stable and the dry-clod structure of soils are modified by surface mulching. The changes that occurred were found to be desirable from the standpoint of water infiltration and soil tilth. The structure formed, however, did not tend to be resistant to the action of wind.

From the standpoint of protecting the land, crop residues resistant to decomposition were found to be desirable. A rapid decomposition process, however, was found desirable for the release of nutrients. Between the need for preserving residues on the one hand and the need for decomposing them on the other, a compromise is necessary, especially in the more humid regions of the West.

Cheatgrass, or downy brome, caused more trouble than did other weeds at locations where studies were conducted. It was apparent that the weed problem in general—and cheatgrass in particular—increases as we proceed from dry to humid areas. Methods for control of such weeds need more investigation under both subhumid and humid conditions.

Except in isolated instances, the incidence of insects and diseases in the wheat crop, attributable directly to subsurface tillage, was inconsequential in the Western States.

The practice of maintaining crop residues on the soil surface, as demonstrated by research experience, was found to be generally successful in semiarid climates in maintaining yields and providing effective water- and wind-erosion control.

Conclusions

Results of the research proved conclusively that adequate plant or residue cover can be used effectively for soil protection against both wind and water erosion.

It was demonstrated in the course of these investigations that physical, chemical, microbiological, and soil climatic changes attend the practice of maintaining residues as a protective mulch on soil surfaces. These influences are evident not only in the soil, but also in plant growth. At certain locations, combinations of these factors were found beneficial to the production of crops. In other environments, the combined effects resulted in decreased yields. More intensive and well-rounded research than has been possible in the past will be necessary to explain these interrelated phenomena. Coordinated team efforts of scientists with specialized training are needed for the task.

In the drier regions of the West, the practice of leaving residues on the surface of the soil usually results either in increased yield of wheat or in little change in yield. In these regions. the practice of stubble mulching is critically needed to combat wind erosion; and it is now regarded as adaptable for this purpose throughout much of the Great Plains.

In the more humid regions of the West, the practice of maintaining crop residues on the soil surface has not been fully developed. It has been determined, however, that regulation of available soil nitrogen, control of weeds, and the adaptation of suitable cropping sequences are essential if yield decreases are to be avoided under a mulching practice.

Machinery capable of effectively managing residues on the soil surface is now available commercially. Stubble mulching is being accomplished successfully with a variety of machines rather than an implement of a given type. In general, however, experience has shown that sweeps about 2 feet wide or wider manage surface residues most efficiently. In the drier regions of the West, the sweep alone is used successfully. In the more humid regions, it seems necessary to use secondary tillage tools, such as the rod-weeder, the skew-treader, or chisels, in order to secure the desired weed control and good seed-bed and root-bed conditions for crops. Reduction of heavy straw by beaters (or "stubble busters") is practiced in the Pacific Northwest, where wheat growth is greatly enhanced by the application of fertilizers.

The large variety of conditions encountered in different climatic and soil areas, as well as great variability from year to year at a given location, make it difficult to prescribe standard tillage methods.

Chemical weed control now offers possibilities for avoiding excessive soil cultivation and destruction of residues, but studies on this subject were initiated too recently to be considered in this report. Combinations of subsurface tillage operations and chemical control appear promising, but further research is necessary for their practical application.

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Appendix.—Tabular Summaries and Detailed Information on Experiments at the 16 Locations

The mention in this publication of a commercial company or of any commercial products or equipment does not imply endorsement by the United States Department of Agriculture over other companies, products, or equipment not mentioned.

TABLE 9.—*Experimental data from Akron, Colo., under alternate winter wheat and fallow, 1942–53*

Year	Crop-year precipitation (July–June)	Winter-wheat yield [1] when plots were—		Straw yield when plots were—	
		Mulched	Plowed	Mulched	Plowed
	Inches	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*
1941–42	22.8	49.5	49.2	3,513	3,567
1942–43	15.3	19.7	21.3	4,470	5,207
1943–44	13.1	16.6	17.2	3,223	2,637
1944–45	18.9	43.8	44.3	4,007	4,457
1945–46	18.7	21.7	23.4		
1946–47	28.8	11.7	12.1		
1947–48	16.3	9.7	11.8		
1948–49	23.3	15.9	17.0		
1949–50	14.7	34.1	33.2		
1950–51	18.0	24.9	21.0		
1951–52	16.8	26.5	23.4		
1952–53	10.5	4.2	3.0		
Average	18.1	23.2	23.1	3,803	3,967

[1] Each yield figure is the average obtained from 3 plots.

ADDITIONAL INFORMATION FOR TABLE 9

Plot characteristics.—Plots were 1/10 acre in size. The soil at this location is a Rugo silt loam, on slopes of 1 to 2 percent.

Type of equipment and sequence used in performing tillage.—A duckfoot or field cultivator was used to perform subtillage at a depth of approximately 3 inches. Plowing was at a depth of 6 inches. Both operations were performed in the spring, in a delayed fallow system. Subsequent operations were with the duckfoot cultivator on mulched plots. A Dempster sweep machine with 30-inch sweeps was purchased and used in 1953.

Amount of residue retained on surface of experimental plots.—Residues tended to disintegrate with duckfoot fallowing operations, and only very small amounts were present at wheat-seeding time.

Weeds, plant diseases, and insects.—No trouble was experienced with plant diseases and insects as a result of sweep tillage. Under an alternate wheat-fallow system, no difficulties were experienced with weed control. Weeds, however, are always a difficulty with annual-cropping systems, such as continuous wheat, regardless of tillage methods.

TABLE 10.—*Experimental data from St. Anthony, Idaho, under alternate winter wheat and fallow, 1940–53*

Year	Crop-year precipitation (August–July)	P–E index	Winter-wheat yield [1] [2] when plots were—			Total soil moisture in 6-foot depth when plots were—						Nitrate nitrogen in 2-foot depth of soil at time of drilling winter wheat, when plots were—			Protein content [3] of grain when plots were—		
						Mulched		Plowed		One-wayed							
			Mulched	Plowed	One-wayed	Spring	Fall	Spring	Fall	Spring	Fall	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Inches		*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	*Percent*	*Percent*	*Percent*
1939–40	11.91	37.27	26.5	27.7	24.1										13.04	12.64	12.35
1940–41	15.96	40.42	33.0	29.2	29.9										12.51	13.29	13.66
1941–42	18.63	52.39	21.2	25.9	22.1										14.46	15.45	14.33
1942–43	13.46	46.95	17.1	18.0	17.2										15.62	16.19	15.90
1943–44	14.78	37.80	24.4	23.3	22.7										14.41	14.38	14.08
1944–45	16.49	46.96	27.9	26.8	28.9	18.3		18.6		18.6							
1945–46	12.89	38.14	29.0	26.4	26.9		17.0		17.0		17.2	61	62	64	13.03	13.51	13.66
1946–47	12.58	36.27	29.3	23.9	23.8							68	67	63	12.98	13.02	13.96
1947–48	11.18	28.94	33.2	25.8	30.4							57	62	52	13.68	14.12	13.59
1948–49	15.08	49.39	14.4	12.0	14.0										15.64	15.07	15.05
1949–50	10.91	31.06	36.0	33.6	35.5										11.24	11.34	10.74
1950–51	15.82	45.60	21.1	21.9	23.4										16.03	16.30	17.02
1951–52	14.09	39.57															
1952–53	8.59	28.05	11.5	10.8	10.9										16.19	17.52	17.63
Average	13.74	38.49	25.2	23.5	23.9										14.07	14.33	14.40

[1] Each yield figure is the average of 3 replications.
[2] L. S. D. (least significant difference) at 5-percent level, 4 bushel per acre.
[3] L. S. D. at 5-percent level, 0.37 percent.

ADDITIONAL INFORMATION FOR TABLE 10

Plot characteristics.—Plots were 133 by 32 feet. The soil is Tetonia (tentative classification) silt loam, on slopes of 4 to 6 percent.

Type of equipment and sequence used in performing stubble-mulch tillage.—The lister-bottom plow was used during the first 2 years of the experiment. Modified moldboard was the subsurface plow used until 1948. After that year, various sweep type plows were used, making this treatment a composite of various types of subsurface implements.

Amount of residue retained on surface after wheat seeding.—Approximately 2 pounds of straw were produced for each pound of wheat grain. In years when straw residues were long and heavy, some straw was left on the surface after moldboard plowing. The one-way disk left approximately 40 to 60 percent of the straw on the surface, and the subsurface plows, approximately 95 percent.

Weeds, plant diseases, and insects.—None of these problems were encountered at this station. Cheatgrass, however, was and still is a problem in some of the semiarid dryland areas of southeastern Idaho.

TABLE 11.—*Experimental data from Hays, Kans., under continuous winter wheat, 1943–53*

Year	Crop-year precipitation (July–June)	P/E index	Continuous-winter-wheat yield[1] when plots were— Mulched	Plowed	One-wayed	Date of determination	Average soil moisture in upper 6 feet of soil, when plots were— Mulched	Plowed	One-wayed
	Inches		*Bushels per acre*	*Bushels per acre*	*Bushels per acre*		*Percent*	*Percent*	*Percent*
1942–43	16.55	27.75	9.2	10.6	11.8	11/3/42	21.0	20.8	20.5
1943–44	22.99	45.14	34.2	34.2	31.9	10/6/43	18.3	17.7	17.0
1944–45	30.42	52.64	10.5	14.9	13.4				
1945–46	16.88	28.90	11.0	7.9	10.6	11/7/45	18.6	17.4	16.2
1946–47	33.14	59.80	31.7	36.4	33.8				
1947–48	21.97	55.99	33.1	31.0	31.7				
1948–49	27.92	51.76	3.3	3.4	3.6				
1949–50	15.44	33.51	21.4	10.6	20.7				
1950–51	14.29	82.25	32.0	37.6	32.4				
1951–52	22.95	45.52	34.2	35.7	33.7				
1952–53	14.45	25.84	3.0	2.8	3.2				
Average	24.27	46.28	19.4	20.5	20.6		19.3	18.5	17.7

[1] Each yield figure is the average from quadruplicate plots.

ADDITIONAL INFORMATION FOR TABLE 11

Plot characteristics.—Plots were 1/10 acre in size. The experiments were conducted on Yocemento silt loam, on a nearly level land area.

Type of equipment and sequence used in performing tillage.—Subsurface tillage was at a depth of 3 inches after harvest, a duckfoot cultivator with 12-inch sweeps being used. Subsequent tillage was given with the duckfoot as necessary, to control weeds and volunteer wheat. In years of heavy straw, a disk harrow was substituted for the duckfoot in the later tillage.

Plowing was at a depth of 6 inches, after harvest. Subsequent tillage was at a depth of 3 inches, a disk harrow being used as necessary, to control weeds and volunteer wheat. In some years, the rod-weeder was used as the final tillage implement.

One-waying operations were performed after harvest, at a depth of 4 inches. Subsequent tillage with the one-way to control weeds and volunteer wheat was performed as necessary at a depth of approximately 3 inches. In some years, the rod weeder was used as the final tillage implement.

Amount of residue retained on surface of experimental plots.—Residue on surface of subtilled plots at seeding time varied from approximately 25 to 75 percent of the amount grown. Only a trace of residue remained on the surface of plowed plots.

TABLE 12.—*Experimental data from Froid, Mont., under alternate spring wheat and fallow, 1941–51*

Year	Crop-year precipitation (July–June)	Spring-wheat yield [1] when plots were—			Soil moisture in 5-foot depth [2] at time of seeding spring wheat, when plots were—		
		Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Inches	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Percent*	*Percent*	*Percent*
1940–41	9.67	34.4	33.7	31.9	13.3	12.3	11.4
1941–42	12.46	30.0	31.3	33.1	11.9	10.2	12.1
1942–43	[3] 14.44	30.3	31.5	26.3	15.3	15.1	14.1
1943–44	12.10	26.8	27.7	29.2	13.3	11.4	11.9
1944–45	9.82	([4])	([4])	([4])	13.5	16.0	13.2
1945–46	11.17	21.8	23.6	22.9	15.1	12.5	13.9
1946–47	15.73	27.2	27.1	21.0	13.0	14.2	14.1
1947–48	13.70	([4])	([4])	([4])			
1948–49	10.19	14.5	18.7	16.6	14.4	13.9	13.4
1949–50	9.41	28.1	34.9	33.0	13.1	13.9	11.7
1950–51	[5] 8.27	19.8	18.9	18.0	13.9	14.5	14.1
Average	11.54	25.9	27.5	26.1	13.7	13.4	13.0

[1] Each yield figure is the average of 3 replications.
[2] Each moisture figure is the average of 60 determinations by 1-foot-depth increments.
[3] No record for November.
[4] No yields obtained.
[5] No record for March.

ADDITIONAL INFORMATION FOR TABLE 12

Plot characteristics.—Plots were 3 acres in area and were located on Lihen sandy loam soil, on land slopes of 4 to 6 percent.

Type of equipment and sequence used in performing tillage.—Subsurface-tillage operations were started in the spring of the year following harvest. Three cultivations were given with the sweep machine at different depths as required to control weed growth. Other cultural methods were also carried out in the spring of the fallow year.

Amount of residue retained on surface of experimental plots.—From 20 to 40 percent of the residue was retained on the surface of subtilled plots at seeding time. The plowed plots represented a black fallow condition.

Weeds, plant diseases, and insects.—More difficulty was experienced in controlling shallow-rooted weeds on subsurface fallow than on fallow worked with a one-way or a moldboard plow. No difficulties attributable to the methods of fallow were encountered with plant diseases or insects.

TABLE 13.—*Experimental data from Havre, Mont., under alternate spring wheat and fallow, 1942–53*

Year	Crop-year precipitation (July–June)	P–E index	Spring-wheat yield[1] when plots were—			Test weight of wheat when plots were—			Average protein content when plots were—			Moisture at 5-foot depth when plots were—		
			Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Inches		*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Pounds per bushel*	*Pounds per bushel*	*Pounds per bushel*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1941–42	15.05	33.34	19.1	21.3	17.4	55.5	56.7	55.7	16.5	15.4	16.0	12.9	13.3	12.6
1942–43	14.63	31.31	28.8	27.5	25.1	56.9	55.8	54.3	14.5	15.7	15.6	14.1	13.7	13.6
1943–44	8.77	17.58	27.2	26.6	26.7	58.3	57.9	57.7	15.7	16.6	15.9	13.8	13.1	13.5
1944–45	9.00	20.57	15.6	13.0	13.1	59.1	59.3	58.4	16.5	16.6	16.5	13.4	11.4	12.1
1945–46	9.51	18.13	15.2	13.8	18.0	59.7	59.7	59.6	14.5	14.7	14.6	12.5	11.5	12.2
1946–47	10.59	21.15	15.8	14.6	14.0	55.9	55.6	55.6	15.7	16.8	16.2	12.8	11.1	11.7
1947–48	11.72	22.63	8.9	8.8	9.2	50.5	49.8	51.4	19.0	19.8	19.5	11.7	11.7	12.1
1948–49	8.07	16.67	6.9	7.5	7.2	57.6	56.9	55.9	17.6	17.2	17.5	10.2	10.5	11.0
1949–50	10.52	26.15	16.5	18.5	15.5	54.7	51.0	51.7	16.3	17.7	16.7	13.0	12.2	11.5
1950–51	11.60	25.14	21.4	22.0	20.5	58.0	57.3	56.8	16.0	16.5	16.2	11.3	11.2	11.2
1951–52	13.03	32.66	14.5	15.1	14.8	60.6	60.1	60.5	15.7	16.8	16.0	12.6	11.2	12.6
1952–53	12.08	26.45	20.7	20.7	18.1	58.9	58.8	58.3	14.5	15.4	15.0	...	...	...
Average for 12 years	11.29	21.56	17.4	17.1	16.6	57.3	56.8	56.7	16.4	16.6	16.3			
Average for 11 years												12.6	12.1	12.2

[1] Each yield figure is the average from triplicate plots.

ADDITIONAL INFORMATION FOR TABLE 13

Plot characteristics.—Plots were 0.44 acre in area and located on Joplin loam soil, on very flat slopes.

Type of equipment and sequence used in performing tillage.—A 5-foot-wide blade was used for subsurface tillage. All tillage methods were started in the spring of the fallow year, and secondary tillage was performed as necessary to control weed growth.

Amount of residue retained on surface of experimental plots.—Under subsurface tillage methods, 10 to 30 percent of the residue produced was retained at seeding time, depending on the amount produced. A very small amount was retained with one-way-disk plowing, and the plow produced a black fallow condition.

Weeds, plant diseases, and insects.—More weeds were normally present on the plots receiving subsurface tillage, but these were not a problem of consequence. No disease or insect problems were encountered.

TABLE 14.—*Experimental data from Moccasin, Mont., under alternate winter wheat and fallow, 1949–53*

Year	Annual precipitation	Winter-wheat yield[1] when plots were—		Trash on surface at seeding time when plots were—		Protein content when plots were—	
		Mulched	One-wayed	Mulched	One-wayed	Mulched	One-wayed
	Inches	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Percent*	*Percent*
1948–49	12.87	25.40	25.27	3,312	110	12.1	12.7
1949–50	16.29	20.57	22.97	1,862	0	10.9	11.5
1950–51	12.63	14.17	13.86	2,891	203	13.8	14.5
1951–52	9.76	21.63	22.62	842	0	12.6	13.0
1952–53	15.35	24.46	25.13	1,183	100	10.5	11.3
Average	13.38	21.21	21.97	1,783	69	12.0	12.6

[1] Each yield figure is the average from triplicate plots.

ADDITIONAL INFORMATION FOR TABLE 14

Plot characteristics.—The soil is a dark clay loam with gravelly limestone subsoil. The slope is approximately 1 percent, although it may vary from ½ to 1½ percent.

Type of equipment and sequence used in performing tillage.—The Noble blade sweep machine was used after harvest, followed by Noble blade weeder sweeps and the Dunham packer during the summer. The one-way disk plow was used continually on unmulched plots.

TABLE 15.—*Experimental data from Lincoln, Nebr., under corn-oats-wheat rotation, 1939-54*

Year	Crop-year precipitation (July-June)	P-E index	Winter-wheat yield [1] when plots were—		Straw produced when plots were—		Winter-wheat yield [2] when plots were—		Straw produced when plots were—	
			Mulched	Plowed	Mulched	Plowed	Subtilled	Plowed	Subtilled	Plowed
	Inches		*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*
1938-39	24.58	42.99	22.3	17.2	1,122	1,190	...	...	...	...
1939-40	17.79	34.90	27.6	30.3	2,942	2,937	...	...	...	...
1940-41	27.44	55.21	16.9	20.5	2,945	3,360	...	...	...	...
1941-42	28.34	57.71	40.2	42.2	3,220	3,692	...	...	...	...
1942-43	25.55	44.95	35.6	43.5	3,160	3,880	...	...	...	...
1943-44	32.21	64.74	17.9	17.2	1,865	2,175	24.0	25.9	3,025	3,485
1944-45	31.59	61.55	39.7	40.3	4,650	4,689	...	...	...	...
1945-46	22.25	40.93	34.2	34.0	3,545	3,571	49.2	50.5	6,050	6,275
1946-47	35.63	66.55	32.0	40.4	3,346	4,615	32.2	28.5	5,457	6,058
1947-48	23.57	55.81	25.7	25.8	1,825	1,735	45.8	47.7	3,410	3,670
1948-49	37.60	82.22	27.5	26.4	3,085	2,955	30.4	32.6	4,320	4,790
1949-50	25.84	50.43	20.6	25.3	1,648	2,143	46.6	44.3	4,417	4,270
1950-51	43.84	88.09	19.8	19.9	2,206	2,398	...	...	...	...
1951-52	32.02	63.28	24.3	15.7	1,381	1,482	46.4	46.5	5,882	5,854
1952-53	23.61	50.33	9.6	14.0	844	1,363	20.6	25.3	2,471	2,849
1953-54	21.68	45.36	18.5	18.0	3,385	3,507	27.5	31.1	3,426	3,769
Average	28.33	56.56	25.15	26.9	2,573	2,856	35.8	36.9	4,276	4,558

[1] Yields are averaged from triplicate plots in a rotation of corn, oats, wheat.

[2] Yields are averaged from 4 plots in a rotation of sweetclover (2 years), wheat, corn, oats.

TABLE 15A.—*Runoff and soil erosion from land during a 3-year rotation of corn, oats, wheat, Lincoln, Nebr.*[1]

Crop	Months crop was on land	Runoff when plots were—		Erosion when plots were—	
		Mulched	Plowed	Mulched	Plowed
	Number	*Inches*	*Inches*	*Tons per acre*	*Tons per acre*
Corn	12	0.81	2.04	1.99	9.26
Oats	6	.68	1.79	.99	5.76
Wheat	18	.60	1.68	.79	3.10
Total		2.09	5.51	3.77	18.12
Average		.70	1.84	1.26	6.04

[1] Average results for the 6-year period, July 1940–June 1946.

ADDITIONAL INFORMATION FOR TABLES 15 AND 15A

Plot characteristics.—Plots were 21 by 35 feet and were located on a Sharpsburg silty clay loam soil, on a slope of approximately 8 percent.

Type of equipment and sequence used in performing stubble-mulch tillage.—Plowing operations were with a two-way plow parallel to the direction of the land slope. Blade type implements were used for subtillage; these were either 24-inch sweeps or 5-foot, single-sweep Noble tillers. After the tiller operation, a treader or skew-treader was used on both plowed and subtilled land, to condition it for seeding. Preparation of the seedbed for wheat was started immediately after oats harvest.

Yellow-blossom sweetclover was seeded on limed land that had been prepared by subtilling and then compacting with a treader. The sweetclover was seeded at the rate of 12 pounds per acre with a seeder attached to a treader. Two methods were used in seeding the sweetclover: (1) Oats were seeded first as a "nurse" crop; (2) the sweetclover was seeded alone. The nurse crop of oats tended to keep the weeds down, but at the same time, it reduced the yield of sweet clover. When seeded alone, the sweetclover made more growth the first year but sometimes became weedy. Growth of the clover the second year was about the same for the two methods. The sweetclover was either mowed in the late-bloom stage or harvested for seed. Immediately after these operations, the land was tilled in preparation for seeding wheat. Half the plots were plowed and the other half were subtilled. Subtillage was followed immediately by a treading operation. The sweetclover straw on the subtilled plots interfered with planting. It was determined that this condition results in an uneven stand, and that it may lower yields.

Amounts of residue retained on surface of experimental plots.—Under subsurface tillage methods, from 25 to 40 percent of the residues produced were retained on the surface at the time of seeding wheat.

Weeds, plant diseases, and insects.—Growth of cheatgrass occurred with subsurface tillage, but reasonable control was obtained by using the skew-treader. Weevil infestations were present in the 2-year sweetclover-wheat rotation but were not attributable to the cultural variables under study.

TABLE 16.—*Experimental data from North Platte, Nebr., under continuous winter wheat and alternate winter wheat on fallow, 1950–53*

Year	Crop-year precipitation (August–June)	Yield from continuous winter wheat						Yield from alternate winter wheat on fallow					
		Without nitrogen when plots were—			With 30 pounds nitrogen per acre, when plots were—			Without nitrogen, when plots were—			With 30 pounds nitrogen per acre, when plots were—		
		Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Inches	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*
1949–50	14.53	18.5	14.6	14.7	15.7	13.2	16.4	35.7	38.4	38.9	37.6	40.5	43.2
1950–51	25.67	21.7	22.3	18.9	26.9	20.6	18.7	17.9	18.7	17.5	18.3	18.5	17.9
1951–52	13.48	23.2	23.2	22.7	25.3	27.1	25.6	29.7	28.3	32.4	29.0	27.0	29.5
1952–53	11.65	3.7	2.3	4.1	2.3	.0	1.3	23.3	15.1	17.4	21.0	10.1	14.2
Average	16.33	16.8	15.6	15.1	17.6	15.2	15.5	26.6	25.1	26.6	26.5	24.0	26.2

Year	Protein content of continuous winter wheat						Protein content of winter wheat on fallow					
	Without nitrogen, when plots were—			With 30 pounds nitrogen per acre, when plots were—			Without nitrogen when plots were—			With 30 pounds nitrogen per acre, when plots were—		
	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1949–50	12.0	13.1	12.3	12.6	13.1	12.4	11.2	12.4	12.5	12.8	13.9	13.3
1950–51	11.1	10.6	10.7	11.2	11.0	11.5	12.6	12.5	12.2	13.0	13.0	13.1
1951–52	9.9	10.4	10.2	10.9	11.4	11.2	12.2	14.2	13.5	14.4	15.8	19.8
1952–53	14.9	15.1	15.4	.0	.0	.0	13.8	13.9	13.7	14.8	15.0	14.7
Average	[1] 11.0	[1] 11.4	[1] 11.1	[1] 11.6	[1] 11.8	[1] 11.7	12.4	13.2	13.0	13.8	14.4	14.2

[1] Protein averages for continuous wheat are for 3-year period (1950–52) only, for comparison between check plots (no nitrogen) and plots receiving nitrogen treatment.

Additional Information for Table 16

Explanation of the study.—This was an investigation of methods of residue management with and without nitrogen fertilizer in the production of winter wheat. One part of the study was in a continuous-wheat cropping system; the other, an alternate wheat-fallow cropping system.

Plot characteristics.—Plots were 1/10 acre in size. A split-plot experimental design was used with 3 replications on Holdrege very fine sandy loam. Continuous winter wheat was on land with a slope of slightly less than 1 percent. Alternate wheat with fallow (on stubble-mulched plots) was on land with a slope of 2 to 2.5 percent. Each residue-treatment plot was split; one-half of each received no nitrogen, while the other half received 30 pounds of available nitrogen per acre.

Type of equipment used in performing tillage.—In the continuous-wheat cropping system, the differential residue-management tillage operations occurred in late July or early August, after the wheat crop had been combine harvested. The nitrogen application was made after stubble burning and prior to the tillage operation. The plots were rod-weeded or lightly disked, to control weeds if late summer rains occurred or volunteer wheat growth began. Plowing was to a depth of 4 to 6 inches. The rod-weeding of plowed plots was often difficult because of buried residues wrapping on the rod. A Noble 75-degree-angle, 6-foot, single-sweep subtiller with a single-radius, 6-inch blade was used for subtilling at a depth of about 4 to 5 inches. A rolling coulter was used ahead of the standard. A John Deere one-way disk, with 22-inch disks spaced 8 inches apart, was used to one-way the plots to a depth of about 3 to 4 inches. The same tillage operations were made on the alternate wheat-fallow-system stubble plots at the same time with the equipment just described, and no subsequent tillage operations occurred until the following spring.

Amount of residue retained on surface of experimental plots.—The stubble after continuous wheat was not particularly heavy, varying from 0.5 to 0.75 ton per acre. In the alternate wheat-fallow system, the stubble provided about 1.25 to 1.75 tons of residue per acre. After a season of fallow, the subtilled and one-way-disked plots had some crop residue on the surface but not enough to hamper seeding operations.

Weeds, plant diseases, and insects.—Difficulty was experienced with weed growth in the continuous-wheat cropping system. The broad-leaved weeds were controlled with 2,4-D weed spray. The control of downy bromegrass in the subtilled plots was only fair, but it was rather complete in plots tilled by other methods. In years when late-summer rains germinated the downy bromegrass, it was quite successfully destroyed by rod weeding or light disking prior to wheat-seeding time. These wheat crops were relatively free of downy bromegrass. In years during which no precipitation of consequence occurred after subtilling operations in late summer and wheat seeding in September, the downy bromegrass germinated and emerged with the wheat after sufficient precipitation. No weed trouble occurred in the alternate wheat-fallow system.

TABLE 17.—*Experimental data from Mandan, N. Dak., under alternate spring wheat and fallow, 1932–53*

Year	Crop-year precipitation (May–September)	Yield[1] from spring wheat on fallow when plots were—		Straw produced when plots were—	
		Mulched	Plowed	Mulched	Plowed
	Inches	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*
1931–32	10.70	20.0	20.7	2,100	2,260
1932–33	6.67	4.5	4.7	2,080	720
1933–34	5.68				
1934–35	13.28	13.5	11.7	1,790	2,050
1935–36	.95				
1936–37	10.15	10.8	7.5	1,800	1,750
1937–38	9.40	17.2	16.7	1,670	1,850
1938–39	9.01	16.5	16.3	3,060	3,170
1939–40	10.12	20.7	21.0	2,010	1,990
1940–41	10.34	33.0	35.0	3,370	3,100
1941–42	10.99	28.8	22.5	2,520	2,450
1942–43	12.05	25.2	25.5	2,240	2,120
1943–44	10.56	34.0	38.5	2,710	2,940
1944–45	6.28	25.0	28.7	1,950	2,030
1945–46	7.48	3.0	3.8	870	1,070
1946–47	13.56	14.5	19.7	1,430	1,720
1947–48	8.61	22.0	22.8	1,930	2,380
1948–49	10.62	8.3	15.2		
1949–50	9.25	13.8	13.3		
1950–51	9.63	2.3	15.2		
1951–52	6.62	22.2	23.7		
1952–53	13.25	24.7	22.5		
Average	9.33	16.3	17.5	1,935	1,927

[1] Wheat-yield figures are from single plots.

ADDITIONAL INFORMATION FOR TABLE 17

Plot characteristics.—Plots were 1/10 acre in size. The soil at this location is a Cheyenne fine sandy loam on land slopes of 1 to 3 percent.

Type of equipment and sequence used in performing tillage.—Stubble-mulch tillage was carried out with a narrow shovel duckfoot cultivator at a depth of 3 to 4 inches. A rod-weeder with tiller-bar attachment was used for secondary cultivation and weed control. Moldboard plowing was to a depth of 6 inches. Both operations were started in May following the year the crop was grown.

Amount of residue retained on surface of experimental plots.—From 4 to 8 tillage operations were performed on summer fallow. Little residue was retained on the surface in years in which a large number of cultivations were required to control weeds.

Weeds, plant diseases, and insects.—Weeds tended to be more prevalent on duckfoot-cultivated land than on plowed fallow. No differences were observed in diseases and insect pests.

TABLE 18.—*Experimental data from Cherokee, Okla., under continuous winter wheat, 1942–51*

Year	Crop-year precipitation (July–June)	P-E index	Yield [1] of continuous winter wheat when plots were—		Straw produced when plots were—		Soil-moisture determinations [2]						Runoff (contour farming) when plots were—	
							After harvest when plots were—		After seeding when plots were—		At beginning of spring growth when plots were—			
			Mulched	Plowed	Mulched	Plowed	Mulched	Plowed	Mulched	Plowed	Mulched	Plowed	Mulched	Plowed
	Inches		*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Inches*	*Inches*
1941–42	30.03	52.95	16.4	15.2	3,440	3,160	11.80	13.25	13.82	13.57	13.64	13.29	4.277	3.806
1942–43	20.28	34.38	7.6	10.0	1,380	2,020	10.80	10.67	13.57	13.36	11.34	11.41	1.125	.837
1943–44	20.40	42.74	15.8	21.6	2,920	3,720	8.62	8.80	8.47	8.36	12.23	13.06	2.512	2.745
1944–45	34.35	57.64	16.0	26.4	3,300	3,880	6.41	5.69	13.87	13.50	13.26	14.86	5.142	5.895
1945–46	23.70	35.57	18.5	27.4	1,940	2,620	9.27	8.61	13.20	12.41	12.60	12.21	2.838	3.558
1946–47	24.61	46.43	12.6	22.8	2,180	3,360	8.84	8.54	13.29	14.23	13.34	13.94	1.852	.841
1947–48	17.88	37.64	12.3	16.8	1,480	1,780	9.12	9.87	9.38	8.36	13.20	13.07	1.660	1.762
1948–49	42.10	83.40	13.2	10.1	2,180	2,120	6.90	6.85	14.68	14.26	12.96	14.07	10.618	12.023
1949–50	18.23	26.86	16.5	21.3	1,560	2,360	10.80	10.84	11.84	11.57	9.88	9.95	.456	.836
1950–51	38.50	61.55	15.0	22.0	1,560	2,120	7.66	8.12	12.03	11.87	11.91	11.89	8.734	10.533
Average	27.01	47.92	14.4	19.4	2,328	2,720	9.02	9.12	12.41	12.15	12.43	12.77	3.921	4.284

[1] Each yield figure is the average from triplicate plots.
[2] Moisture in 3-foot depth of soil.

ADDITIONAL INFORMATION FOR TABLE 18

Plot characteristics.—Plots were 2 to 3 acres in area and were equipped with rate-measuring flumes to gage runoff. The soil at this location is Grant silt loam, on 2- to 3-percent slopes.

Type of equipment and sequence used in performing tillage.—Sweeps and tillers used in this experiment during the crop years 1942–51 were the plow "lay" sweeps and the Raydex sweeps. The plow "lay" sweeps were used during the first tillage after harvest, while the subsequent cultivations were performed with the Raydex sweeps. The wheat was seeded with a semideep-furrow, disk type drill with 10-inch spacings.

Amount of residue retained on surface of experimental plots.—With subsurface tillage, it was estimated that approximately 65 percent of the residue produced was retained on the surface.

Weeds, plant diseases, and insects.—Cheatgrass was a serious problem on the subsurface-tilled plots. Weed infestation was 5.6 times as great on continuously mulched areas as on plowed land. In years of high September rainfall, the weeds germinated and were killed prior to wheat seeding. Heavy weed infestations occurred subsequent to years of low September rainfall; this was because their germination was delayed until after wheat seeding.

On mulched areas, foot rot of wheat was a problem. There was an average of 8.8 times as many whiteheads in wheat grown on subtilled land as in that grown on plowed land. Some straw-worm damage was observed on mulched land in 1943.

Soil properties.—There was a tendency for small-sized water-stable particles to accumulate on the surface of subtilled plots. Measurements of water-stable particles in spring 1953 showed a subtilled surface to have 72.7 percent of water-stable aggregates of the size range $<0.42>0.02$ mm. compared with 65.2 percent on the surface of a plowed plot. According to dry-aggregate determinations made at the same time, the surface of subtilled plots contained 60.1 percent dry clods <0.84 mm. in size compared with 51.2 percent for plowed plots. Thus, in the absence of cover, the surface of subtilled plots tended to contain more material of sizes easily eroded than did plowed plots.

TABLE 18A.—*Average yields obtained in nitrogen experiment on continuous winter wheat, Cherokee, Okla., 1945–50* [1]

Rate of nitrogen applied (pounds per acre)	Grain yield when plots were—		Straw yield when plots were—	
	Mulched	Plowed	Mulched	Plowed
	Bushels per acre	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*
None	15.4	16.2	2,100	2,020
4	16.2	16.9	2,180	1,960
8	17.9	17.4	2,240	2,360
12	18.0	17.4	2,540	2,400
16	17.7	16.9	2,390	2,400
24	19.1	19.0	2,600	2,520

[1] Experiment conducted on new plots each year (not the plots described in explanation following table 18).

TABLE 19.—*Experimental data from Stillwater, Okla. (Perkins Farm), under a rotation of winter wheat, oats, sweetclover, 1941–52*

Year	Crop-year precipitation (July–June)	Winter wheat yield [1] when plots were—			Winter wheat straw produced when plots were—			Soil-moisture determination in 3-foot soil depth (October only) when plots were—		
		Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed	Mulched	Plowed	One-wayed
	Inches	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	*Percent*	*Percent*	*Percent*
1940–41	38.1	8.5	6.2	6.9	1,503	1,277	1,429	13.1	13.6	12.4
1941–42	50.3	19.1	18.1	16.2	2,105	1,867	1,724	15.9	16.0	16.0
1942–43	37.8	12.6	8.9	10.6	1,489	1,055	1,303	16.6	17.2	16.5
1943–44	33.3	32.9	34.8	33.0	2,487	2,792	2,409	....	....	....
1944–45	34.7	16.7	16.4	17.1	2,584	2,951	2,886	....	....	....
1945–46	36.9	21.0	19.0	18.1	2,088	1,929	1,768	....	....	....
1946–47	27.9	36.3	37.6	35.6	3,426	3,625	3,318	....	....	....
1947–48	29.1	22.2	22.0	23.3	1,740	1,658	1,683	....	....	....
1948–49	35.0	34.1	37.4	34.1	2,793	2,990	2,830	....	....	....
1949–50	24.4	23.5	24.0	23.0	1,982	1,953	1,856	....	....	....
1950–51	34.7	13.0	7.5	11.1	1,901	1,561	1,441	....	....	....
1951–52	35.2	22.2	27.2	23.2	1,775	2,188	1,610	....	....	....
Average	33.95	21.8	21.6	21.0	2,156	2,154	2,021	....	....	....

[1] Wheat-yield figures are the average of 6 replications from 3 crops of wheat grown in a 5-year rotation, including oats and sweetclover.

Additional Information for Table 19

Plot characteristics.—Plots averaged 20 by 70 feet in size. Land slope was approximately 2½ percent. The soil was a Norge loam.

Type of equipment and sequence used in performing tillage.—The tillage implements used were a two-way moldboard plow, a basin lister with 8-inch shovels spaced 21 inches apart, and a one-way disk with 26-inch blades. During the first 2 years, a 42-inch Pence blade was used for subsurface tillage. Beginning with the third year, these blades were replaced by 30-inch Dempster sweeps.

Amount of residue retained on surface of the soil after wheat seeding.—The residue retained on the surface of the soil was measured during early years of the experiment by using a line-transect procedure. In 1942 the percentage of cover on the surface of the ground on plots tilled with the Dempster sweep was 15.6 percent at time of planting. The percentage of cover on the surface of the plowed plots was 0.8 percent. This amount of cover controlled erosion between terraces.

Weeds, plant diseases, and insects.—No difficulty was experienced with weeds, plant diseases, or insects.

Soil-nutrient determinations.—Determinations of easily soluble phosphorus and exchangeable potassium after 7 years demonstrated the tendency of subtilled land to be more productive in the 0- to 3-inch layer. The difference was not so evident in the moldboard-plowed soil. The average variation in exchangeable potassium in the 2 layers of soil collected from the plowed plots was only 5 parts per million (p. p. m.), whereas the exchangeable potassium in the surface 3 inches of soil from the plots subtilled with sweeps was 48 p. p. m. higher than in the 3- to 6-inch layer. The difference in available phosphorus was only 2 p. p. m. higher in the 0- to 3-inch layer on the plowed plots, but it was 7 p. p. m. higher on plots where the residue was left on the surface of the land, as compared with samples collected from the 3- to 6-inch layer on these plots.

TABLE 20.—*Experimental data from Pendleton, Oreg., under winter wheat, 1941–53*

Year	Crop-year precipitation (July–June)	P-E index	Yield [1] from continuous winter wheat when plots were—			Yield [1] from winter wheat on fallow when plots were—						Yield [1] from winter wheat on fallow, on leased property (Hill and King Farms, near Helix, Oreg.) when plots were—					
			Mulched	Plowed	One-wayed	Mulched		Plowed		One-wayed		Mulched		Plowed		One-wayed	
						Non-fertilized	Fertilized [2]	Non-fertilized	Fertilized [2]	Non-fertilized	Fertilized [2]	Non-fertilized	Fertilized [2]	Non-fertilized	Fertilized [3]	Non-fertilized	Fertilized [3]
	Inches		*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*
1940–41	19.54	42.22	24.3	26.7	25.7	...	...	...	...	...	...	...	...	...	...	...	...
1941–42	20.46	46.59	35.0	35.0	37.3	...	...	...	...	...	...	...	...	...	...	...	...
1942–43	20.70	55.26	41.3	59.5	38.2	...	...	...	...	...	...	...	...	...	...	...	...
1943–44	12.49	27.98	26.2	34.0	25.5	32.4	33.2	39.4	39.4	33.6	33.2	...	...	...	...	...	...
1944–45	15.65	36.88	11.9	19.8	10.7	21.4	21.6	21.4	20.3	23.3	23.7	...	...	...	...	...	...
1945–46	17.84	44.44	32.8	37.2	19.0	22.8	21.0	32.7	35.1	22.0	23.3	...	...	...	...	...	...
1946–47	16.27	37.22	41.0	48.7	40.2	43.9	40.0	46.0	47.0	43.7	42.4	...	...	...	...	...	...
1947–48	22.76	57.20	23.8	23.3	12.5	...	...	...	...	...	...	...	...	...	...	...	...
1948–49	14.95	45.29	39.3	42.3	37.2	32.5	33.4	42.0	42.1	37.3	38.1	...	...	...	...	...	...
1949–50	16.43	45.22	38.8	39.8	45.0	...	...	...	...	...	...	26.9	27.5	24.9	28.6	25.2	25.2
1950–51	18.62	48.91	24.2	25.7	31.3	28.2	34.2	36.4	49.3	33.7	42.2	...	...	...	...	...	...
1951–52	15.85	39.82	30.2	37.5	40.2	...	...	...	...	...	...	32.2	39.1	35.5	41.6	33.3	38.5
1952–53	16.68	41.63	33.9	39.2	29.3	32.0	39.4	34.6	40.6	33.5	39.5	19.7	27.8	22.5	31.1	19.6	27.5
Average	17.56	43.74	31.0	36.1	30.2	29.9	31.7	35.2	38.7	31.7	34.1	26.3	31.5	27.6	33.8	26.0	30.4

[1] Each yield figure is the average of 3 replications.
[2] Prior to 1951, 10 pounds of nitrogen were added at wheat-seeding time. Starting in 1951, nitrogen applications were at the rate of 30 pounds per acre.
[3] 20 pounds of nitrogen were added at wheat-seeding time.

TABLE 20A.—*Winter-wheat yields with various rates of nitrogen fertilizer applied at plowing time, on mulched and clean-fallowed plots, Pendleton, Oreg., 1951–52*

Year	Pounds per acre of fertilizer used, and preparation of plot									
	None (check plots)		33		66		99		132	
	Mulched	Plowed	Mulched	Plowed	Mulched	Plowed	Mulched	Plowed	Mulched	Plowed
	Bushels per acre	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*
1951	33.2	40.3	48.4	52.9	57.7	56.5	56.9	60.6	59.7	55.7
1952	42.0	39.6	55.3	50.9	62.0	53.5	62.1	58.4	64.5	59.8
Average for 1951–52	37.6	40.0	51.9	51.9	59.9	55.0	59.5	59.9	62.1	57.8

TABLE 20B.—*Soil-moisture data from Pendleton, Oreg., under winter wheat and fallow*

Year	Amount of moisture in 5-foot depth of soil			
	Unit	In mulched plots	In plowed plots	In one-wayed plots
1940 [1]	Percent	21.80	19.50	21.20
1951 [2]	Inches	12.66	10.32	
1952 [2]	do.	10.87	7.54	

[1] Determination in fall following summer fallow.
[2] Determination in April, at beginning of growing season following summer fallow.

Additional Information for Tables 20, 20A, and 20B

Plot characteristics.—Plots were 0.1 acre in size, on Walla Walla silt loam. Average slope is 2.7 percent, running at a slight angle but lengthwise of the plots. The extreme slopes are 2 to 3.5 percent. (These characteristics not applicable to plots on Hill and King Farms.)

Type of equipment and sequence used in performing tillage.—Under wheat-fallow system, the first operation with the sweep machine was made during late March or early April. The rod-weeder with tiller-bar attachment was used for secondary operation. Where stubble was extremely heavy, the skew-treader was used before rod weeding. The rod-weeder was used for subsequent cultivation.

Amount of residue retained on surface of soil after wheat seeding.—By subsurface tillage, it has been possible to retain a large proportion of the residue produced on the surface.

Weeds, plant diseases, and insects.—Cheatgrass was a problem in some years where the sweep machines were used. It was found that a skew-treader tends to control and kill cheatgrass.

TABLE 21.—*Experimental data from Newell, So. Dak., under alternate spring wheat and fallow and continuous spring wheat, 1932–53*

Year	Crop-year precipitation (September–August)	Spring-wheat yield [1] in alternate wheat-fallow system: Grain yield when plots were— Mulched	Grain yield when plots were— Plowed	Straw yield when plots were— Mulched	Straw yield when plots were— Plowed	Spring-wheat yield [1] on duckfooted and fall-plowed grain stubble in continuous wheat: Grain yield when plots were— Duckfooted	Grain yield when plots were— Plowed	Straw yield when plots were— Duckfooted	Straw yield when plots were— Plowed	Protein content [1] of continuous spring wheat when plots were— Mulched	Protein content when plots were— Plowed
	Inches	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Percent*	*Percent*
1931–32	19.28	17.7	19.3	3,440	3,840	...	...	...	...	...	...
1932–33	19.68	21.0	18.8	2,240	2,070	...	...	...	...	...	...
1933–34	13.08	18.3	17.7	2,350	2,290	...	...	...	...	...	...
1934–35	14.71	11.0	9.7	2,090	2,520	...	...	...	...	...	...
1935–36	9.77	.7	1.0	330	520	...	...	...	...	...	...
1936–37	16.72	11.3	10.8	1,820	1,750	...	...	...	...	...	...
1937–38	11.79	13.5	13.6	1,615	1,635	...	...	...	...	...	...
1938–39	10.29	...	...	...	...	...	...	...	...	...	...
1939–40	15.45	(2)	(2)	(2)	(2)	...	...	...	...	...	...
1940–41	21.17	26.0	23.5	4,015	3,865	...	...	...	...	...	...
1941–42	19.42	38.3	38.3	4,400	4,175	...	...	...	...	...	...
1942–43	13.23	32.5	31.3	3,125	3,100	...	...	...	...	...	...
1943–44	17.49	33.5	35.0	3,590	3,050	...	...	...	...	...	...
1944–45	13.99	21.9	20.8	2,610	2,180	...	...	...	...	...	...
1945–46	23.36	37.2	36.1	3,145	2,835	...	...	...	...	...	...
1946–47	19.55	29.8	38.4	2,840	2,595	...	...	...	...	...	...
1947–48	17.50	35.6	37.5	2,765	2,875	...	...	...	...	...	...
1948–49	11.65	15.7	14.5	1,610	1,735	...	...	...	...	...	...
1949–50	14.61	19.0	21.8	1,160	1,440	10.2	11.3	590	820	...	...
1950–51	14.25	24.5	21.5	2,880	2,110	18.0	3.2	1,670	640	13.0	15.4
1951–52	13.24	15.0	12.8	1,373	970	2.9	2.7	353	465	14.7	16.0
1952–53	15.93	20.4	20.1	2,207	1,859	17.5	15.6	1,231	2,189	10.6	14.5
Average	15.73	20.1	19.7	2,300	2,155	12.2	8.2	961	1,029	12.8	15.3

[1] Each yield or protein figure is the average of 2 plots.
[2] Crop completely destroyed by hail.

ADDITIONAL INFORMATION FOR TABLE 21

Plot characteristics.—Plots were 0.1 acre in size, located on Pierre clay with land slope of 1 to 2 percent.

Type of equipment and sequence used in performing tillage.—Under alternate wheat-fallow system, grain stubble was duckfooted in the spring when weeds were well started, and thereafter as necessary to control weeds. Depth of cultivation was limited by the condition of soil and capacity of the field cultivator, and it varied from 3 to 5 inches. Plowing was performed during the last half of May, if possible, but *seasonal* conditions necessitated considerable variation in time of plowing. The plowed land was left rough and was duckfooted when necessary during the remainder of the season, to control weeds. Plowed fallow required an average of 2 cultivations with the duckfoot cultivator for the season, while duckfoot fallow required a total of 4 cultivations per season. Under continuous wheat, tillage operations were started immediately after harvest.

Weeds, plant diseases, and insects.—Greater amounts of annual weed grasses appeared on duckfoot-cultivated plots than on plowed plots, and additional cultivations were required to control them.

Soil properties.—Determinations of organic matter were made on mulched and plowed fallow plots in 1953. The rate of decline of organic matter appeared to have been checked by subsurface-tillage methods. The percentage of organic matter in a 12-inch soil depth averaged 1.04 and 0.92 for mulched and plowed plots, respectively.

Table 22.—*Experimental data from Amarillo, Tex., under continuous winter wheat and a wheat-fallow system, 1943–53*

Year	Crop-year precipitation (July–June)	P-E index	Wheat yield [1] from continuous wheat when plots were—		Wheat yield [1] from wheat-fallow system when plots were—		Straw produced under continuous wheat when plots were—		Straw produced under wheat-fallow system when plots were—	
			Mulched	One-wayed	Mulched	One-wayed	Mulched	One-wayed	Mulched	One-wayed
	Inches		*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*
1942–43	17.30	24.11	7.1	6.0	14.6	11.9	1,512	1,451	2,462	2,270
1943–44	21.21	23.70	26.4	24.5	28.4	28.4	2,091	2,705	3,152	3,135
1944–45	15.66	17.97	6.9	6.3	20.4	16.7	439	601	1,038	922
1945–46	13.50	17.19	6.0	2.6	13.9	8.5	1,040	700	1,676	1,474
1946–47	20.82	29.65	34.3	28.4	30.8	33.1	3,560	3,664	...	...
1947–48	13.64	23.82	6.2	4.6	15.7	13.9	...	...	...	...
1948–49	27.04	46.82	19.4	21.5	38.4	36.0	3,236	3,793	6,339	5,962
1949–50	16.14	21.81	.0	.0	.0	.0	...	...	...	...
1950–51	25.32	34.12	8.6	7.4	13.0	9.1	866	810	1,260	1,113
1951–52	15.05	21.16	5.4	4.1	17.4	16.0	784	647	1,951	1,792
1952–53	8.98	13.00	.6	.5	2.8	1.9	...	...	...	...
Average	17.70	24.85	11.0	9.6	18.3	16.0	1,691	1,796	2,235	2,083

[1] Until 1948, each yield figure is the average from 4 replicated plots. Subsequent data are the averages from duplicate plots.

Table 22A.—*Soil-moisture determinations*[1] *at Amarillo, Tex., under continuous winter wheat and a wheat-fallow system, in various years*

Date of determination	Moisture under continuous wheat when plots were—		Moisture under wheat-fallow system when plots were—	
	Mulched	One-wayed	Mulched	One-wayed
	Inches	*Inches*	*Inches*	*Inches*
October 1943	0.90	0.70	3.90	3.90
November 1944	2.90	6.10	2.20	5.50
October 1948	1.40	2.50	.70	5.70
March 1949	2.00	2.50	3.90	3.70
May 1949	2.80	1.80	4.30	1.50
July 1949	.40	.40	1.70	.60
October 1949	2.40	4.50	3.40	4.70
February 1950	1.50	3.00	1.10	3.10
March 1950	.90	2.20	1.60	2.20
May 1950	.60	1.80	1.10	2.30
June 1950	1.90	3.50	3.30	3.70
October 1950	3.30	3.30	5.10	5.30

[1] Available moisture to 4-foot depth.

Table 22B.—*Permeability data obtained during fallow at Amarillo, Tex., by using a rainfall applicator, fall of 1951*

Condition of surface[1]	Moisture condition of soil	Amount of—		
		Water	Runoff	Infiltration
		Inches	*Inches*	*Inches*
Stubble mulch on delayed fallow	Dry	2.43	0.21	2.22
	Wet	2.45	1.28	1.17
Stubble mulch on early fallow	Dry	2.24	.23	2.01
	Wet	2.44	.60	1.84
One-wayed fallow without mulch	Dry	2.34	1.30	1.04
	Wet	2.29	1.63	.66

[1] Pullman silty clay loam with 1- to 3-percent slopes.

Additional Information for Tables 22, 22A, and 22B

Plot characteristics.—Plots were 80 by 200 feet, or about 0.37 acre in area, on Pullman silty clay loam. Slopes were 0 to 1 percent. (These characteristics do not apply to plots used for study of permeability data.)

Type of equipment and sequence used in performing tillage.—On continuously cropped wheat plots, the practice 1942–48 was to use 30-inch sweeps after wheat harvest. An additional cultivation was given with sweeps prior to seeding. Beginning in 1944, the first operation with sweeps was at a depth of approximately 4 inches. Subsequently, 2 shallow operations were performed before seeding.

On alternate wheat and fallow, the first cultivation with sweeps was performed from April through July of the fallow year, depending on weed or volunteer-wheat growth. From 2 to 3 additional shallow operations with sweeps were performed prior to wheat seeding in the fall.

Use of the sweep machine alone was satisfactory for weed control and seedbed preparation.

Amount of residue retained on surface of experimental plots.—The amount of residue retained after a year of fallow following the 1949 wheat crop was 56 percent for sweep cultivation and 12 percent for one-way-disk methods.

Weeds, plant diseases, and insects.—No plant disease or insect damage attributable to stubble-mulch tillage was observed. A higher proportion of stinkgrass was observed in the weed population in stubble-mulched plots during a prolonged wet spell in 1950. No difficulty was experienced in killing grassy weeds with a sweep machine operated at a depth of 1½ inches.

Soil properties.—Mulch tillage is checking the rate of decline of organic matter in a 0- to 3-inch soil depth. In 1949, the content of organic matter in the surface soil under continuous wheat was 2.20 percent as compared with 2.11 percent where the one-way disk plow was used. Under wheat-fallow, comparable figures were 2.07 and 1.96 percent, respectively. Wind-tunnel studies of erodibility and dry-aggregate studies of soil structure were made on selected plots.

Protein content of grain.—In 1949 comparisons of protein content of wheat under stubble-mulch and one-way cultural systems were made. Wheat following fallow had 13.4 percent compared with 16.5 percent for stubble mulching and one-waying, respectively. Under continuous wheat, comparable values were 12.9 and 15.8 percent, respectively.

TABLE 23.—*Experimental data from Pullman, Wash., under a wheat-fallow system, with different rates of straw applied, 1943–52*

Year	Crop-year precipitation (July–June)	P–E index	Yield [1] [2] of winter wheat from plots with straw applied at the rate of—						Amount of runoff [3] from plots with straw applied at the rate of—						Amount of soil lost [3] from plots with straw applied at the rate of—					
			2 tons per acre for—		1 ton per acre for—		(None for check plots)		2 tons per acre for—		1 ton per acre for—		(None for check plots)		2 tons per acre for—		1 ton per acre for—		(None for check plots)	
			Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots	Mulched plots	Plowed plots
	Inches		*Bu. per acre*	*Bu. per acre*	*Bu. per acre*	*Bu. per acre*	*Bu. per acre*	*Bu. per acre*	*In.*	*In.*	*Ir.*	*In.*	*In.*	*In.*	*Tons per acre*	*Tons per acre*	*Tons per acre*	*Tons per acre*	*Tons per acre*	*Tons per acre*
1942–43	22.95	77.21	31.7	29.2	33.9	33.9	33.1	35.4	1.37	2.01	1.30	2.17	1.88	2.51	1.3	8.4	0.7	9.0	6.0	11.7
1943–44	14.05	41.17	36.7	42.0	42.0	42.9	43.2	45.8	.01	.00	.00	.02	.01	.01	.0	.0	.0	.0	.0	.0
1944–45	16.32	49.24	29.3	35.7	29.8	32.7	32.0	32.5	.00	.00	.05	.01	.02	.16	.0	.0	.0	.1	.0	3.1
1945–46	22.59	76.18	24.5	31.2	26.0	34.9	30.1	36.9	.47	3.74	1.90	3.93	4.26	4.13	1.3	54.6	13.4	57.5	44.2	65.0
1946–47	18.71	56.39	25.7	33.9	24.3	30.3	28.3	36.0	.02	.24	.04	.30	.14	.81	.0	.3	.3	.6	.4	2.7
1947–48	31.05	94.79	24.9	25.3	23.9	30.8	25.5	29.0	.96	4.63	2.61	4.69	3.61	5.09	3.4	40.8	18.3	54.2	36.5	66.4
1948–49	18.86	70.55	32.3	44.7	33.6	45.0	40.8	40.0	.07	.14	.09	.15	.10	.06	.1	.4	.1	.3	.2	.3
1949–50	24.38	82.19	25.7	33.0	27.9	31.4	30.2	36.0	2.80	3.99	3.57	3.48	4.52	4.91	1.6	13.3	3.1	9.9	10.2	18.1
1950–51	22.60	71.58	28.0	31.4	25.8	33.3	30.3	32.6	.22	.15	.29	.32	.29	1.24	.2	.5	.3	1.3	.5	4.6
1951–52	23.76	77.34	21.5	25.9	22.1	30.9	23.2	30.2	.02	.28	.02	.35	.34	.38	.1	3.9	.1	6.8	3.6	7.4
Average	21.53	69.66	28.0	33.2	28.9	34.6	31.7	35.5	0.59	1.52	0.99	1.54	1.52	1.93	0.8	12.22	3.63	13.97	10.16	17.93

[1] Each yield figure is the average from duplicate plots.
[2] L. S. D. (least significant difference) at 5-percent level, 1.3 bushels per acre.
[3] Runoff and erosion data are for November through March, the period regarded as the "erosion year."

Additional Information for Table 23

Plot characteristics.—Plots were 12 by 90 feet and ran parallel with a 25-percent land slope. The soil at this location is Palouse silt loam.

Type of equipment and sequence used in performing tillage.—Cultural operations were performed during summer fallow season as follows: Initial tillage was performed during the period May 1–15, depending on the weather. Implements were operated perpendicular to the contour (lengthwise of the plots) at a depth of about 6 inches. Within 1 or 2 days, after initial tillage, a spike-tooth harrow was operated on the plowed land and a rotary hoe (treader) on the subsurface-tilled land, parallel with the initial tillage operation. Land was thereafter rod-weeded when necessary for weed control. Two or three weedings were required each season; these were performed on the contour across all plots, at a depth of about 3 inches. Wheat was seeded on the contour during the period October 1–20, depending on moisture conditions. In dry seasons, seeding was delayed until about mid-October, the seed being planted in dry soil. Wheat did not make sufficient growth prior to the erosion season to have any appreciable effect on runoff or soil losses.

The equipment used consisted of: *Subsurface tiller*—a pull type machine equipped with three 30-inch sweeps, rolling coulters, and power lift; *moldboard plow*—a 3-bottom, 18-inch tractor plow part of the time, and at other times, a single-bottom plow attachment on wheel tractor; *treader*—an 8-foot section of Dunham rotary hoe, operated so that the teeth dug into the soil; *rod weeder*—a 12-foot unit equipped with high-clearance shanks and power lift; *grain drill*—a John Deere 10-foot press-wheel drill with double-disk furrow openers.

Amount of residue retained on surface after wheat seeding.—Straw was added or removed from all plots to secure specified amounts each year before cultural practices were initiated. A considerable amount of straw was retained on the surface of subtilled plots at seeding time, whereas only traces were present on the surfaces of plowed plots.

Weeds, plant diseases, and insects.—Cheatgrass was the most common weed encountered, especially during the last 5 years of the experiment when 2, 4–D was used. Weeds probably caused part of the yield reductions secured on subsurface-tilled land. No plant diseases or insect problems appeared to be associated with methods of fallow.

TABLE 24.—*Experimental data from Sheridan, Wyo., under spring and winter wheat grown in a wheat-fallow system, 1943–51*

Year	Spring-wheat yield [1] when plots were—		Winter-wheat yield [1] when plots were—	
	Mulched	Plowed	Mulched	Plowed
	Bushels per acre	*Bushels per acre*	*Bushels per acre*	*Bushels per acre*
1942–43	19.3	19.9	19.8	...
1943–44	.8	1.3	...	...
1944–45	20.8	24.9	...	...
1945–46	18.2	19.9	...	...
1946–47	17.6	21.5	...	23.7
1947–48	30.1	23.4	23.1	24.6
1948–49	20.9	18.2	21.9	24.7
1949–50	22.6	25.3	20.8	22.3
1950–51	12.2	14.7	13.1	12.2
Average	21.5	20.4	19.7	21.0

[1] Each yield figure is the average obtained from 3 plots.

ADDITIONAL INFORMATION FOR TABLE 24

Plot characteristics.—Plots were 1/55 acre (6 by 132 feet) in size. Two of the fields used in this study have soils classed as silty clay loam and are on a slope of about 2 percent; the other two fields have soils classed as fine sandy loam and are on a slope of 4 to 5 percent.

Cropping system.—This consisted of fallow, grain-variety trials, subtillage experiment, then corn. These treatments were located on the various fields at random. Thus, as this cropping system went through the 4-year period, any one treatment had only a random chance of occurring on the plot it occupied 4 years earlier.

Type of equipment and sequence used in performing tillage.—For plowing, a moldboard plow was used. After fall plowing, the ground was left rough through winter and harrowed smooth prior to spring seeding. Spring plowing was followed by disking, and sometimes harrowing, then seeding. When a duckfoot cultivator with 8- to 10-inch sweeps was used, no other tillage was involved. The duckfoot was used once or twice in the fall and once or twice in the spring prior to seeding. When a lister was used, fall-listed ground was left rough through winter and harrowed down in spring; spring-listed ground was disked after listing, then seeded. When a subsurface tiller was used, it consisted of a Chase sweep implement with 18-inch sweeps; this was used in the same manner as the duckfoot. When a basin lister was used, the listing was done in the spring and followed by the use of the disk prior to seeding. When the double disk was used, it consisted of a standard 12- to 14-inch tandem disk; this was employed in 2 treatments—one in the fall and one in the spring.

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