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The use of sweetclover or other legumes as green manure for supplying nitrogen to crops that follow has been generally unsuccessful under dryland farming (1, 3, 6). Where moisture limits crop production, including a green manure crop in a small grain-fallow cropping system increases the moisture-deficiency hazard. If, however, careful management or a more favorable climatic environment sufficiently reduces this risk, green manuring becomes an economical method of adding nitrogen for the cash crop.

Sweetclover is currently used as a green-manure crop in some dryland areas of the Intermountain states. Two climatic conditions combined with special management permit this practice. One climatic condition is typical of higher elevations where a spring-grain-fallow system is used. Annual rainfall exceeds 14 inches and the growing season is short and dry. The sweetclover is allowed to reach a height of 24 inches the spring of the fallow year before being plowed down. When plowed at this stage of growth, only the soil moisture in the upper part of the use zone is depleted. Winter precipitation recharges this zone prior to the time spring grain is drilled.

Under the other climatic condition, typical of lower elevations, annual rainfall is less than 14 inches and the spring growing season starts relatively early. The sweetclover is plowed down while there is still surface moisture or sufficiently early so that surface moisture will be replenished before winter wheat is drilled. Under this climatic condition, time rather than stage of growth determines when the sweetclover is plowed down. Often the clover does not exceed 6 to 8 inches in height when plowed. Since the nitrogen content is relatively high at this immature growth stage, considerable nitrogen is added to the soil (7).

Under both climatic conditions, 3 to 8 pounds of biennial sweetclover per acre are seeded with spring grain. The sweetclover competes with the spring grain only to the extent of becoming established during the seeding year and has not depressed the grain yields (7).

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The sweetclover green-manure crop is usually plowed under with a moldboard plow. This method stems from long-established custom and common belief that unless the residue is incorporated into the soil the derived fertility benefits will be minimized. Complete coverage of the green material with the moldboard leaves the soil unprotected and susceptible to wind and water erosion. According to a Nebraska study (5), nitrate production was not appreciably lower after subtilling than after plowing. That study indicated that subtilling was preferable under dryland conditions because the delay in decomposition extended the nitrification period so that it more nearly coincided with crop use.

In view of the erosion-control value of stubble-mulch tillage (8, 9), an experiment was conducted from 1951 to 1956 at the high-altitude dryland station near Tetonia, Idaho, to evaluate certain tillage treatments for surface utilization of sweetclover. The primary objectives of the experiment were to determine how best to obtain an adequate sweetclover kill, to operate the tillage implements through the residue, and to maintain the residue throughout the fallow period. Nitrates, soil moisture, yield and protein content of the wheat that followed sweetclover were measured for interpretative purposes.

At the Tetonia station the annual precipitation of 13 inches is distributed quite uniformly over the year. Spring frosts occasionally cause some damage to spring and winter grains produced in a fallow rotation. These crops seldom respond to nitrogen fertilzer. Because of the relatively low rainfall and late spring, this location is not favorably suited for use of sweetclover in a winter wheat-fallow rotation. The experimental soil has been tentatively classified as Tetonia silt loam and falls within the Chestnut Great Soil group.

Experimental Methods

Except for 1954, when alfalfa was used, biennial Madrid sweetclover was planted alone in the spring on land that had been fall plowed after the grain crop was harvested. This method of establishment differs from the customary practice of using a grain companion crop. It was experimentally justified on the basis of decreasing the possibility of stand failure. The quantity of sweetclover or alfalfa growth just prior to initial spring tillage was measured by taking ten square-yard quadrates of the plot area as a whole. Residue was sampled in the late fall of 1951, 1952, and 1953 by taking three square-yard quadrates per plot.

The experiment on utilization of sweetclover consisted of six initial tillage treatments—moldboard plowing, sweep tillage, one-way disking, tandem disking prior to sweep tillage, sweep tillage followed by tandem disking, and sweet clover clipped prior to sweep tillage. The moldboard, one-way disk, and sweep implements were operated at a depth of 5 inches and the tandem disk at about 2 to 3 inches. Subsequent tillage to control weeds or to complete the sweetclover kill was limited to either 1 or 2 rod weedings during the summer-fallow period.

The plot treatments were replicated four times and arranged in a randomized block design. Three treatments are shown in figure 1. Plot width was maintained at 30 feet throughout the 6-year period, but length varied from 100 to 150 feet depending upon the availability of land.

In the fall of 1952 one-half of each plot was rotary hoed to distribute the residue to facilitate drilling winter wheat with a 7-inch single disk drill. In other years when the seedbed was too dry to establish winter wheat, the plot area, when on sloping land, was rotary subsoiled to increase intake of moisture from melting snow for the benefit of the following spring wheat crop.

The effect of the initial tillage treatment on sweetclover kill was estimated by making live plant counts just prior to the first rod weeding.

Soil for nitrate analysis was sampled in the spring and fall to a depth of 1 foot at 3 systematic locations and composited. Nitrates were determined by the phenoldisulphonic acid method (4).

Soil moisture was sampled on each plot of one replication the fall after tillage and in the spring just prior to spring wheat drilling, through the fall of 1953. Thereafter, only the moldboard, one-way disk, and sweep plots were sampled. Three locations per plot were sampled by 1-foot depth increments to a depth of 6 feet. Samples were not collected in the fall of 1952. Moisture percentage was converted on a volume basis to inches of moisture. Available moisture is considered as the quantity of moisture retained at $\frac{1}{3}$ atmosphere of tension minus the quantity retained at 15 atmospheres.

Wheat yields following sweetclover were computed from two combine swath samples taken parallel with plot length. Nitrogen content of the wheat was determined according to the standard procedure (2). Protein content of wheat is expressed as percent nitrogen times the conversion factor 5.7.

Results and Discussion

Sweetclover Kill

The degree of kill associated with the six initial treatments varied widely between years (table 1). This was primarily due to differences in moisture content in the plow layer when the tillage was performed. In 1951, 1953, and 1954, the soils were completely dry down to tillage depth, but in 1952 and 1955 some available moisture still remained in the tillage layer. The moldboard plow was generally most effective in killing the sweetclover. There was less year-to-year variation in the number of sweetclover plants surviving after moldboard plowing than after any of the other treatments. The sweetclover kill was more consistent in this case because the moldboard kills by both root severance and by plant burial whereas the other treatments must rely almost entirely upon root severance. The sweep treatments all resulted in good kills when the tillage layer was dry and were superior in this respect to the moldboard. Sweep blades 3 or 7 feet wide worked equally well, provided the blades overlapped at least 8 inches.

Sweep tillage alone was generally as effective in killing the

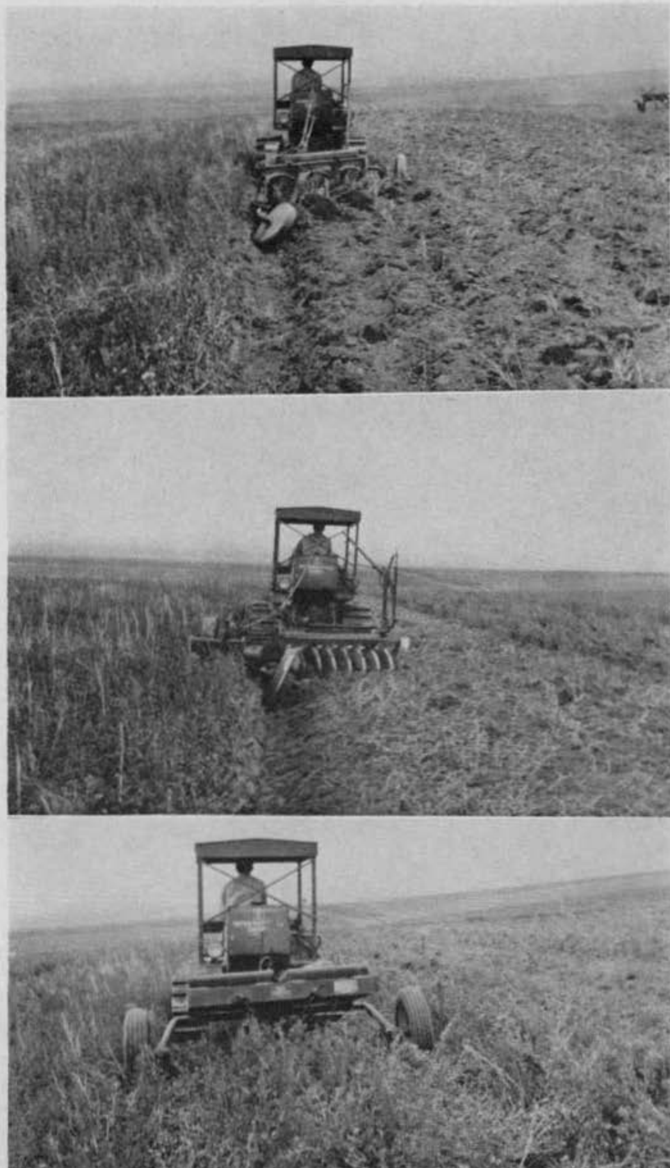

FIGURE 1—From top to bottom, the moldboard, one-way disk, and sweep tilling a 1½-ton sweetclover green manure crop.

sweetclover as clipping before sweep tillage or disking before or after sweep tillage. The poorest kill was obtained from the one-way disk because of its inability to sever all roots.

Preliminary trials with the offset disk and 12-inch duckfoot cultivator demonstrated that these implements are incapable of effecting a satisfactory kill no matter what the soil moisture content and were excluded from the formal study.

TABLE 1—Number of sweetclover or alfalfa plants that survived the initial tillage operation.

Tillage Treatment	Year				
	1951	1952	1953	1954*	1955
	plants/ acre	plants/ acre	plants/ acre	plants/ acre	plants/ acre
Moldboard	100	1,400	500	T	2,700
One-way disk	1,000	30,600	1,500	T	12,900
Sweep	T**	9,000	T	T	5,800
Disk before sweep	T	6,300	600	T	2,900
Disk after sweep	T	3,900	T	T	5,600
Clip before sweep	T	10,200	T	T	3,300

* Alfalfa.
** Trace.

If the soil was dry to tillage depth when the sweep implement was used, it was necessary to either delay subsequent tillage with the tandem disk until the residue had dried to the extent of being brittle, or reduce the disk angle. The dry, loose soil and succulent sweetclover residue combination prevented normal operation of the tandem disk immediately after sweep tillage. If residue was in excess of 3,000 pounds per acre when initial tillage was performed, it was also necessary to wait until the residue was completely dry before rod weeding.

The alfalfa tilled in 1954 reached a height of only 6 to 8 inches when a severe frost retarded further growth. All initial tillage treatments resulted in an "apparent" kill. Regrowth from the crowns, in contrast to sweetclover, persisted throughout the summer fallow period independently of the initial tillage treatments.

Weed growth on summer fallow after initial tillage of sweetclover was negligible and less than on summer fallow after wheat.

Residue Maintenance

The kind of initial tillage, the number and kinds of subsequent tillage operations, and summer rainfall influenced the quantity of residue maintained on the surface. The residue data for 1951, 1952, and 1953 are given in table 2. Precipitation from initial tillage to the fall sampling date was 7.28, 2.79, and 1.47 inches for these respective years. There were 3,150; 3,660 and 900 pounds per acre of air-dry sweetclover at the time of initial tillage for the respective years. At the end of the summer fallow period 5.7, 63.1, and 64.4 percent of the initial amount of residue remained for the sweep-tillage treatment in those years. The relatively high summer rainfall of 1951, an extremely rare occurrence, was the dominant reason for rapid decomposition and reduced quantity of residue remaining on the surface at the end of the summer fallow period.

TABLE 2—Quantity and percent of original quantity of sweetclover maintained on the surface after summer fallow tillage operations.

	Subsequent Tillage and Year										
	1951*				1952				1953		
Initial tillage	Rodweeded and drilled		None		Rodweeded rotary hoed, and drilled		Rodweeded and rotary subsoiled		Rod-weeded		Average
	lbs/A	%	lbs/A	%	lbs/A	%	lbs/A	%	lbs/A	%	%
Moldboard	37	1.2	51	1.6	160	4.3	195	5.3	161	17.9	6.1
One-way disk	123	3.9	166	5.3	852	23.2	906	24.7	275	30.5	17.5
Sweep	149	4.7	180	5.7	1066	29.1	2313	63.1	580	64.4	33.4
Disk before sweep	196	6.2	402	12.7	550	15.0	1208	33.0	346	38.4	21.1
Disk after sweep	142	4.5	199	6.3	835	22.8	1417	38.7	314	34.9	21.4
Clip before sweep	320	10.1	581	18.4	1066	29.1	2239	61.1	510	56.7	35.1
LSD 5%					512	14.0	309	8.4	126	14.0	

* Samples were composited. Statistical analysis not possible.

Since the rainfall for the period represents two extremes, the average amount of sweetclover maintained on the surface can be expected to vary between 10 and 65 percent of the original quantity, provided the best tillage method is used. In descending order of effectiveness for maintaining the surface residues, the treatments fall into the following three categories: sweep tillage without disking, any tillage involving disking, and moldboarding. Any tillage after initial tillage caused some decrease in surface residue. This reduction varied greatly with the type of implement used. For example, in 1952 an average of 37.6 percent of the original residue was maintained on the portion of the plots that was rodweeded, and rotary subsoiled, and left to be planted to spring wheat, and only 20.6 percent for the portion that was rodweeded, rotary hoed, and drilled to winter wheat. The rotary hoe and drill covered a relatively large proportion of the surface residue as compared with the rotary subsoiler.

The maintenance of green-manure residue on the surface to protect the soil from erosion seems advantageous when the time period between initial tillage of the green manure and occupancy of the land by the succeeding crop is relatively long. Under summer-fallow dryland farming in the Intermountain States, this period varies from about 3 months to a year depending upon whether the succeeding crop is winter or spring grain. Fortunately, however, temperatures limit decomposition to approximately 4 months and these months are normally dry. Since any undue mixing of residue and soil increases the possibility of decomposition, minimum tillage is not only desirable but almost imperative. For this reason the possibility of maintaining immature leguminous residues on the surface is probably limited to semi-arid and dry-subhumid climates with dry summers.

TABLE 3—Nitrate nitrogen in the surface foot of soil the fall and spring following summer fallow tillage.

	1951-52		1952-53		1953-54		1954-55		1955-56		Average	
Treatment	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A	lbs N/A
Moldboard	58	7	56	68	6	25	30	28	19	11	34	28
One-way disk	45	5	35	47	11	25	22	26	16	10	26	23
Sweep	46	6	21	30	13	19	19	27	15	15	23	19
Average	50	6	37	48	10	23	24	27	17	12	27	23

Nitrate Nitrogen

Nitrate nitrogen in the surface foot of soil for moldboard, one-way disk, and sweep tillage is shown in table 3. For the entire period, nitrates were higher after the moldboard than after the one-way disk or sweep (P=0.05). Respective averages of fall and spring values for the moldboard, one-way disk, and sweep were 31, 24, and 21 pounds of nitrogen per acre in the surface foot. Nitrates following the one-way disk were not significantly higher than following the sweep. Clipping before, disking before, or disking after sweep tillage did not result in nitrate production significantly different from sweep tillage alone. The variation in nitrates between treatments for the different periods was significant (P=0.05).

Nitrates were high the fall of 1951 due to the prolonged wet period during August and the first part of September. By the following spring, however, they had been leached to lower depths by moisture from the melting snow. The fall average for the entire period was 27 pounds of nitrogen per acre compared to 23 pounds per acre for the spring sampling; this difference was significant (P=.05). The variation between period averages was sizeable and significant (P=.01). There was a small but significant negative correlation (r=—0.34, P=.05) between available moisture the spring of the crop year and nitrates, which indicates some degree of leaching below the surface foot. The season and treatment interaction was not significant.

Although surface foot samples cannot be expected to portray an accurate status of nitrate nitrogen within the root zone, it does serve as an index of the effect of residue placement on nitrification during the fallow season.

Soil Moisture

The three initial tillage treatments listed in table 4 did not differentially influence the amount of available soil moisture in a 6-foot soil depth at the start of the growing season. Placement of this relatively small quantity of residue was immaterial as far as moisture intake and storage were concerned. During this short time, the available soil moisture from one year to another varied as much as 32 percent less and 28 percent more than the mean for the period.

TABLE 4—Available moisture in 6-foot soil depth the spring of the crop year.

Treatment	Year					
	1952	1953	1954	1955	1956	Average
	in.	in.	in.	in.	in.	in.
Moldboard	6.62	3.74	3.63	5.93	6.10	5.21
One-way disk	7.41	3.58	4.35	5.43	6.30	5.41
Sweep	6.12	4.49	3.31	5.16	6.42	5.10
Average	6.72	3.94	3.76	5.51	6.27	5.24

Wheat Yield

The fall of 1951 was the only time it was possible during the 1951-56 period to establish a satisfactory stand of winter wheat after sweetclover. The summer of 1952 was extremely dry and winter wheat drilled that year failed to germinate on ordinary fallow. In 1953, 1954, and 1955, winter wheat was either not drilled or was drilled and failed to germinate because the sweetclover had used surface moisture that was not replenished by drilling time. Therefore, plots were reseeded to spring wheat.

There were no significant wheat yield differences that were attributable to the different treatments of sweetclover residue. The data of table 5 show a low yield level with rather minor variation between years with the exception of 1952.

Moisture was the dominant influence on wheat production. The correlation between yield and available soil moisture at the start of the growing season (about the middle of May), available soil moisture plus rainfall to the end of June, available soil moisture plus rainfall to the end of July, and available moisture plus rainfall to the end of August was 0.73, 0.81, 0.81, and 0.69, respectively. Considering the many other environmental factors which vary from season to season, the correlation coefficients are quite high. Stored soil moisture accounted for about 53 percent of the yield variation and soil moisture plus rain through July or August accounted for 66 percent. The relationship between available soil moisture plus rainfall through July is indicated in figure 2. The straight line of figure 2 was computed on the assumption that the relationship is linear for an individual year between moisture values of 4 to 10 inches.

TABLE 5—Yields of hard red spring wheat following initial summer fallow tillage treatments.

Treatment	1952*	1952*	1953	1954	1955	1956	Spring wheat average
	bu./ac.	bu./ac.	bu./ac.	bu./ac.	bu./ac.	bu./ac.	bu./ac.
Moldboard	23.8	26.8	13.4	11.6	15.8	16.1	16.7
One-way disk	23.1	28.1	13.8	13.6	15.9	16.0	17.5
Sweep	21.9	28.0	14.9	12.2	16.2	14.8	17.2
Disk before sweep	25.0	26.5	14.0	12.2	17.3	13.8	16.8
Disk after sweep	28.2	26.2	16.3	12.0	17.2	15.4	17.4
Clip before sweep	22.8	27.8	13.5	10.9	16.3	16.3	17.0
Yearly Average	24.1	27.2	14.3	12.1	16.4	15.4	17.1

*First column hard red winter wheat.

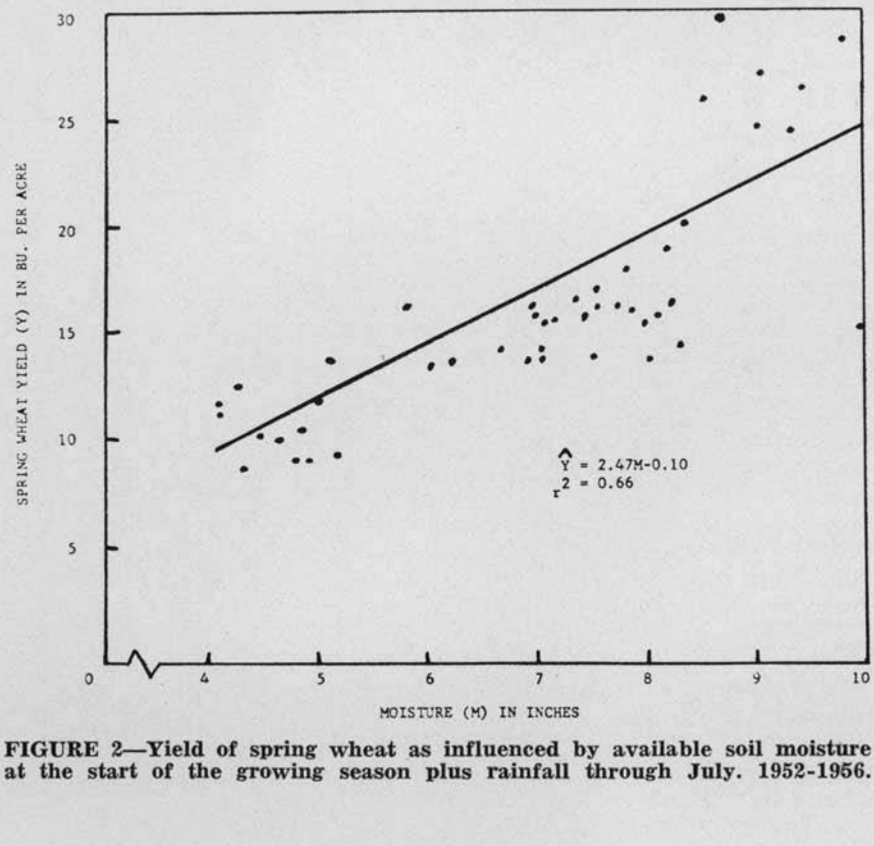

FIGURE 2—Yield of spring wheat as influenced by available soil moisture at the start of the growing season plus rainfall through July. 1952-1956.

Protein Content

The high grain protein values given in table 6 do not indicate any possibility that a nitrogen deficiency limited crop production.

Any differences in available nitrogen that may have been due to initial tillage treatments were not readily discernable in terms of nitrogen content of the wheat crop. In view of the high protein values shown in table 6, it is quite obvious that nitrogen was available in luxuriant quantities for every crop except possibly the 1952 spring wheat crop. That year, spring wheat had 2.2 percent lower protein content than the winter wheat but yielded 3.1 bushels per acre more than the winter wheat, thereby accounting for pracically all of the protein difference between the two crops. The spring wheat protein averages for the tillage treatments are not significantly different (P=.05) when the mean of one treatment is compared with the mean of any other treatment. The difference between the mean of the sweep plus the clip before sweep treatments, and the mean of the remaining treatments was significant (P=.01). Eighty percent of the treatment variability was due to this difference. This suggests that the two treatments which preserved the greatest quantity of residue on the surface were also the most effective in supplying nitrogen to the following wheat crop.

SUMMARY—

Several methods of initially tilling a sweetclover green manure crop under a dryland summer fallow system of farming were investigated.

TABLE 6—Grain protein content of hard red spring wheat as affected by tillage treatments.

Treatment	Year						Spring wheat avreage
	1952*		1953	1954	1955	1956	
	%	%	%	%	%	%	%
Moldboard	16.1	12.8	18.4	18.4	18.8	17.2	17.1
One-way disk	15.8	12.8	18.4	18.2	18.5	16.9	17.0
Sweep	16.1	14.6	18.2	17.5	19.4	17.2	17.4
Disk before sweep	15.6	12.8	18.2	18.1	18.2	16.9	16.8
Disk after sweep	14.8	12.3	18.9	18.4	18.4	16.7	16.9
Clip before sweep	15.4	15.1	18.9	18.5	19.4	16.7	17.7
Yearly average	15.6	13.4	18.5	18.2	18.8	16.9	

*First column hard red winter wheat.

The number of plants that survived the initial summer fallow tillage was consistently highest for the one-way disk treatment. When the soil was dry to tillage depth, sweep tillage resulted in the most complete kill. The moldboard was superior in this respect when the soil was moist within the tillage zone.

The amount of original residue maintained on the surface for two seasonal extremes ranged from about 10 to 65 percent, 5 to 30 percent, and 1 to 6 percent for the sweep, one-way disk, and moldboard treatments, respectively. Weeding operations with the rodweeder were not seriously destructive to surface residue.

Nitrates in the surface foot varied more by season and year than among initial tillage treatments. There was an indication, based on protein content of wheat, that nitrogen availability was positively correlated with the quantity of residue on the surface.

Differences in wheat yields attributable to the placement of sweetclover residues and methods of tillage were small.

The results reported apply to spring grain areas of high elevation with 14 or more inches of annual precipitation and to nitrogen-deficient winter wheat areas where sweetclover can be tilled before surface moisture is depleted.

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