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Twenty Years of Soil Management on a Vienna Silt Loam

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About the Author

"Unlike a mine, which is exhausted with time, the soil will last indefinitely if properly managed and cared for."

This statement by Professor Leo F. Puhr has been his watchword since 1927, when he was appointed assistant professor of soils at State College. Except for PhD. work at the University of Wisconsin, he has spent his life here, teaching, counseling students, and conducting soil research.

He has taught several courses since then including geology, general soils, soil classification and genesis, soil conservation, soil fertility and management, laboratory methods, agronomy seminar, and soil problems.

His research contributions have been as varied. His major work has been in the area of soil fertility, which includes studies on the effects of cropping on the rate of depletion of organic matter, nitrogen and phosphorus, and the use of fertilizer on South Dakota soils.

In 1941, he selected and layed out the extensive soil research plots, on the agronomy farm at Brookings and planned and developed experiments, designed to cover virtually every aspect of soil management.

He has worked on research to develop crop rotations that would maintain soil fertility **and** produce optimum yields, he has studied the influence of tillage methods on crop production, the value of crop residues for conserving nitrogen and organic matter, and the use of monoculture or continuous cropping in place of crop rotations.

Another of his major projects is the study of cyanide poisioning of livestock by sorghums and other crops.

In 1951, Dr. Puhr was appointed for three years as collaborator to the Bureau of Soil and Fertilizer Laboratory of the USDA's Agricultural Research Administration in Washington, D. C.

He is a Fellow of the American Association for the Advancement of Science, a member of the American Society of Agronomy and of the Soil Science Society of America, and Alpha Zeta, an agricultural honorary.

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Summary

Effect of Fertilizers on Grain Yields

During the 20 years of this experiment, soil fertility levels progressively declined with continuous cropping when no fertility maintenance practices were used. Consequently, the need for fertility improvement practices has increased with each successive year. Small grains have given more consistent responses to fertilizer treatments than corn. With the continued decline in fertility, response to fertilizer by corn is expected to be more consistent in the future.

The application of 40 lbs. of nitrogen per acre to corn and the application of 20 to 30 lbs. of nitrogen per acre to small grains will produce maximum yields of crops in most years.

The application of 20 lbs. of

phosphate (P_2O_5) per acre per year will provide adequate available phosphorus for grain crops.

Effect of Crop Residue Management and Tillage Practices

Subsurface tillage is a satisfactory tillage practice for providing protection to the soil and for conserving moisture, especially for the corn crop.

The yields of corn, oats, and wheat on the subsurfaced plots compared very favorably with the yields obtained on the plowed plots.

The use of fertilizer and manure with subsurface tillage is essential for securing optimum or satisfactory crop yields.

Crop residues should be conserved and returned to the soil, because they are valuable from the standpoint of nitrogen and organic matter maintenance. Plowing, with residues returned, has produced more corn, oats, and wheat than where the residues were removed.

Effect of Depth of Plowing and Other Tillage Practices

The tillage practices, which include plowing at depths of 4, 7, and 10 inches, subsurfacing with a blade, one way or disk plowing and double disking, produced the following results:

(1) For corn, 7 inches was the optimum depth of plowing.

(2) Subsurface tillage produced highest yields of corn when soil moisture was limited.

(3) The depth of tillage had less influence on yields of wheat when adequate fertility was provided.

Effect of Legumes

Legumes, including alfalfa, red clover, and sweet clover, are valuable from the standpoint of adding or returning nitrogen to the soil. The problem of moisture depletion by these legumes seriously limits their use in areas with frequent summer droughts. Plowing earlier in the season has helped to overcome this problem.

The use of legumes for fixation of nitrogen only is generally not profitable. Under special conditions such as protecting a soil from erosion, the retirement of land from production and the payment for this practice may make the use of legumes as a source of nitrogen only, economically profitable.

Continuous Cropping, or Monoculture

Continuous cropping with the same crop was successfully practiced for 20 years. The most significant soil changes were the loss of total nitrogen and the depletion of available soil phosphorus.

To secure optimum crop yields under continuous cropping requires the use of fertilizer to maintain an adequate fertility level in the soil. In a corn-oats-wheat rotation the return of crop residues was effective in reducing rates of nitrogen losses.

Twenty Years of Soil Management on a Vienna Silt Loam

by Dr. Leo F. Puhr, *Professor of Agronomy**

Soil management is a challenging problem for every farm owner and operator in South Dakota. The principal basis of profitable and stable crop production is skilled soil management. Climate sometimes imposes limitations on crop yields, but good management can often reduce the seriousness of these restrictions. It is estimated that in South Dakota farmers return annually to the soil only about 11% of the nitrogen and 18% of the phosphorus which are removed by crops each year. This continued depletion reduces the capacity of the soil to produce crops. The farmer can no longer depend upon the original fertility of the virgin soil to supply the crops with adequate nutrients for maximum production.

Organic Matter Shortage

The maintenance of soil organic matter is a major problem in soil management. About 40% of the original soil organic matter was lost during the first 50 to 75 years of cultivation. Organic matter is especially important because it vitally affects the physical properties of the soil and serves as a storehouse for essential plant nutrients.

A major phase of soil management is the application of the most efficient methods of water conservation.

Reasons Behind Research

The purpose of the research reported in this publication is to develop information on soil management which can be used in the solution of these problems. This research involves the following areas of soil management:

(1) Effect of fertilizers on grain yields.

(2) Effect of crop residue management and tillage practices on crop yields.

(3) Effect of depth of plowing and other tillage practices on yields of crops.

(4) Effect of sweet clover rotations on crop yields.

(5) Determination of the economy of growing alfalfa as a crop, as well as a source of nitrogen, in

*The author wishes to express his appreciation to Dr. Fred F. Shubeck, associate professor of agronomy, for his assistance in preparing the manuscript.

comparison with a non-legume rotation, where nitrogen fertilizer is applied.

(6) Comparitive evaluation of legumes and nitrogen fertilizer, as sources of nitrogen in crop production.

(7) The use of continuous cropping, or monoculture for the production of field crops, and the effect of this practice on crop yields.

(8) The effect of continous cropping and crop rotations on the total nitrogen and available phosphorus in the surface soil.

These soil management experiments were conducted on the Agronomy Farm, located at Brookings, South Dakota, from 1942 to 1961 inclusive. The soil type of the Agronomy Farm is Vienna Silt loam, one of the extensive soil types in Eastern South Dakota. The design of all experiments was a randomized block, replicated three times.

A long period is required to properly measure the influence of these practices on crop yields and on the soil itself because of the variations in climate from year to year. The rainfall factor is especially important because it exerts a controlling influence on crop production.

EFFECTS OF FERTILIZERS ON CROP YIELDS

The object of these trials was to determine the effects of fertilizer on yields of crops when the three elements, nitrogen, phosphorus, and potassium, were applied singly and in combination. The fertilizers and rates per acre used on each crop each year are as follows: 20 lbs. of nitrogen applied as ammonium nitrate, 20 lbs. of phosphorus pentoxide (P_2O_5) applied as treble superphosphate, and 30 lbs. of potassium oxide (K_2O) applied as muriate of potash.

Corn, Oats, Wheat

All fertilizer was applied in the spring by broadcasting and disking into the soil. The cropping system used on the fertilizer plots is now corn and oats. Previous to 1958, the rotation was corn, oats, and wheat. The fertilizer experiments were started in 1942 and have been carried on continuously since that date. The results of the fertilizer trials on corn, oats, and wheat are presented in tables 1, 2, and 3. The results of 20 years of fertilizer applications on corn are presented in table 1.

Climate imposed a ceiling on corn yields more frequently than on small grain. In 2 of the first 10 years of the experiments there was a definite increase in corn yields due to fertilizer treatment. In five out of the last ten years there was an increase in corn yields due to fertilizer application.

In the favorable corn growing years, the corn yields obtained on the unfertilized control plots are now somewhat lower than those obtained on the control plots in the earlier part of the experiment. This indicates a progressive decline in soil fertility in a corn-small grain rotation where no attempt was made to restore fertility.

Table 1. Effect of Fertilizer on Yields of Corn (1942-61) in a Corn-Oats-Wheat Rotation. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre							
Year	None	N	P	K	NP	NK	PK	NPK
1942	52.8	49.7	50.1	54.2	57.7	57.1	60.9	61.0
1943	38.0	33.8	39.1	36.8	31.9	31.5	38.4	28.0
1944	68.8	74.7	71.4	76.8	72.5	74.3	80.1	74.1
1945	49.1	49.2	50.2	45.5	49.6	49.3	51.5	50.1
1946	41.5	44.3	45.3	49.5	49.9	48.3	51.7	48.9
1947	36.9	39.2	37.3	38.6	40.8	36.9	40.5	39.9
1948	64.4	62.8	66.7	68.2	65.7	68.7	68.3	65.3
1949	10.4	16.3	13.6	22.0	28.2	23.0	21.1	8.5
1950	51.0	52.5	55.6	55.4	58.1	55.2	56.1	53.0
1951	34.5	36.3	37.8	31.0	40.5	34.5	39.1	41.6
1952	63.3	72.1	69.5	73.5	76.9	76.3	69.0	70.6
1953	64.2	72.3	67.0	64.1	79.9	73.3	72.7	67.8
1954	52.2	51.8	51.0	55.1	55.8	54.7	53.4	48.8
1955	39.6	39.2	40.5	41.9	42.9	40.7	41.3	29.8
1956	59.4	56.4	56.1	56.3	68.0	54.3	46.4	48.1
1957	44.6	39.5	42.7	42.5	40.6	45.8	40.6	36.6
1958	25.8	17.8	24.6	27.3	17.2	18.4	21.6	11.3
1959	40.1	26.6	30.5	40.5	33.2	28.7	32.1	21.7
1960	58.0	66.5	60.9	63.9	68.7	66.5	57.8	62.3
1961	54.8	71.5	58.7	58.5	69.3	70.0	59.0	70.5
20 yr. avg.	47.5	48.6	48.4	50.1	52.4	50.4	50.1	46.9
Last 5 yrs. avg.	44.7	44.4	43.5	46.5	45.8	45.9	42.2	40.5

N = 20 lbs. of N per acre in the form of ammonium nitrate.
P = 20 lbs. of P_2O_5 per acre in the form of treble superphosphate.
K = 30 lbs. of K_2O per acre in the form of muriate of potash.

Nitrogen Needs

The nitrogen releasing capacity of this soil and similar soils is still sufficient to produce enough available nitrogen to meet the needs of the corn crop in years of average or below average rainfall. The nitrogen release and subsequent removal from soil planted to corn is considerably greater than release and removal when planted to small grain (table 16). Since more nitrogen is released and made available under corn than under small grain, the responses of corn to nitrogen have been limited in the past.

In the future, as the soil nitrogen levels decline, the need for fertilizer nitrogen on corn will increase.

Phosphorus alone was not very beneficial in increasing yields. In the good corn years of 1953, 1956, and 1960, the combination of nitrogen and phosphorus gave the largest yield increases.

Table 2. Effect of Fertilizer on Yields of Oats (1942-1962) in a Corn-Oats-Wheat Rotation. Agronomy Farm, Brookings, South Dakota

				Yield in Bushels Per Acre				
Year	None	N	P	K	NP	NK	PK	NPK
1942	45.3	40.4	42.1	43.7	36.7	38.6	45.6	46.6
1943	100.2	90.5	88.2	92.1	97.5	95.3	97.3	89.4
1944	75.5	63.7	69.8	65.5	64.1	74.2	60.4	70.7
1945	88.4	88.4	98.7	82.0	95.7	97.2	90.8	98.9
1946	67.6	68.6	66.6	65.9	69.7	64.5	72.2	66.3
1947	80.1	93.9	75.0	86.6	95.5	91.8	89.9	86.9
1948	59.0	64.4	69.0	56.9	81.6	69.7	61.8	70.6
1949	43.9	53.9	43.7	41.0	58.3	52.5	43.6	51.7
1950	55.3	62.5	63.3	59.8	70.2	60.0	59.8	65.5
1951	50.2	78.1	65.6	52.1	79.1	81.0	64.2	82.9
1952	49.9	55.4	39.3	49.2	58.1	65.2	42.7	59.8
1953	38.1	68.1	43.8	41.0	65.8	59.6	40.6	73.4
1954	38.1	58.1	38.7	34.3	66.5	53.2	40.0	51.6
1955	53.7	48.0	54.2	49.9	62.3	53.6	47.8	54.9
1956	42.0	43.4	41.5	37.6	64.7	44.5	50.4	41.5
1957	39.8	65.3	39.1	39.4	77.8	60.1	38.9	70.7
1958	45.9	49.1	44.5	44.1	64.1	42.8	48.2	54.7
1959	35.7	24.8	32.8	28.9	31.2	30.7	32.4	20.6
1960	49.3	76.3	59.7	44.4	79.0	73.2	51.0	75.8
1961	30.7	60.4	33.6	31.4	61.3	54.1	32.0	61.6
20 yr. avg.	54.4	62.7	55.5	52.3	69.0	60.4	55.5	64.7
Last 5 yrs. avg.	40.3	55.2	41.9	37.6	62.7	52.2	40.5	56.7

N = 20 lbs. of N per acre per year.
P = 20 lbs. of P_2O_5 per acre per year.
K = 30 lbs. of K_2O per acre per year.

In table 2, the results of 20 years of fertilizer trials on oats are presented.

There was a substantial increase in yield of oats from a combination of nitrogen and phosphorus fertilizer applications in 8 out of 9 years (1953-1961 inclusive). There was no response in 1959 because of adverse weather conditions.

Soil Fertility Lowered

The check, or control plots now yield 15 to 20 bushels less than in the initial 10 years of the experiment. In 1943, the check or control plots yielded 100 bushels of oats per acre, while in 1961, a good oats year, the yield on the check plots was 30.7 bushels of oats per acre. This reflects a progressive decline of soil fertility brought about by the removal of nutrients or fertility by continuous crop production. Therefore, the restoration and maintenance of soil fertility becomes more imperative with each successive crop year.

The average oats yield for the last five years of the experiment (1957-1961) was as follows: unfertilized plots, 40.3 bu. per acre; plots receiving nitrogen application, 55.2 bu. per acre; plots receiving nitrogen plus phosphorus application, 62.7 bu. per acre.

In table 3, the wheat yields are listed for the years 1942 through 1957. Wheat was taken out of the rotation in 1958.

The 16 year average (1942-1957) of the plots receiving the nitrogen plus phosphorus treatment was 4.9 bushels more than the average of the plots receiving no fertilizer. In some years plant diseases reduced the response to fertilizer treatment.

EFFECTS OF CROP RESIDUE MANAGEMENT AND TILLAGE PRACTICE ON CROP YIELDS

These experiments measure the effect of tillage methods, fertilizers, and crop residues on crop yields, in a corn-oats-wheat rotation. A total of eight different treatments were used. The two basic tillage practices were subsurface tillage about 6 inches deep, with a single blade (six treatments), and moldboard plowing (two treatments).

The six subsurface tillage treatments were:

Table 3. Effect of Fertilizer on Yields of Wheat (1942-1957) in a Corn-Oats-Wheat Rotation. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre							
Year	None	N	P	K	NP	NK	PK	NPK
1942	23.2	22.8	25.4	22.4	24.5	25.4	23.7	24.4
1943	21.4	22.4	20.3	20.2	21.5	20.4	21.3	19.8
1944	16.4	12.6	15.6	19.1	16.9	15.7	17.1	13.2
1945	35.3	38.3	37.4	39.7	41.6	38.4	37.1	41.4
1946	20.6	27.0	19.8	18.5	31.2	28.8	20.8	26.6
1947	18.1	17.8	18.1	14.5	24.9	20.7	17.2	22.9
1948	14.4	24.6	18.5	20.4	32.4	23.7	21.6	24.4
1949	12.2	14.4	13.8	13.2	17.5	15.5	15.9	18.1
1950	21.3	21.8	24.1	23.6	27.3	22.5	23.4	24.9
1951	24.7	31.2	21.4	18.4	27.6	30.7	22.6	38.2
1952	13.6	17.1	15.3	15.7	22.5	19.0	18.5	19.6
1953	10.4	12.7	9.8	11.4	16.0	14.3	10.1	14.3
1954	12.1	9.2	14.2	12.0	14.9	12.0	16.4	13.2
1955	23.7	18.8	21.5	21.4	24.7	22.5	20.9	25.4
1956	14.6	8.3	11.6	14.3	10.4	8.3	10.3	6.8
1957	23.4	29.2	26.2	24.5	30.2	28.5	27.2	35.7
Avg.	19.1	20.5	19.6	19.3	24.0	21.7	20.3	23.1
Last 5 yrs. avg.	16.8	15.6	16.7	16.7	19.2	17.1	17.0	19.1

N = 20 lbs. of N per acre per year.
P = 20 lbs. of P_2O_5 per acre per year.
K = 30 lbs. of K_2O per acre per year.

1. Subsurface, crop residues returned.
2. Subsurface, crop residues removed.
3. Subsurface, crop residues returned, and manure applied.
4. Subsurface, crop residues returned, and nitrogen applied.
5. Subsurface, crop residues returned, and phosphorus applied.
6. Subsurface, crop residues returned, nitrogen, and phosphorus.

The two plowing treatments consisted of (1) plowing 7 inches deep with residues returned, and (2) plowing 7 inches deep without residues returned.

The cropping sequence in this experiment was corn-oats-wheat. The plowing and subsurfacing for corn were done in the fall, followed by a tandem disking prior to planting in the spring. The residues which were mixed into the surface soil remained near the surface.

Because oats followed the intertilled corn crop, neither of the two basic fall tillage treatments mentioned above was used for the seedbed preparation for oats. The oats seedbed was prepared by tandem disking the corn stubble in the spring.

The plowing and subsurfacing for the wheat were also done in the fall with tandem disking prior to planting in the spring. With this preparation the residues were mixed with the surface soil, but remained near the surface.

Manure was applied at the rate of 10 tons per acre once every three years on the wheat stubble where the manure treatment is indicated in the tillage treatments listed above.

Fertilized in Spring

Fertilizer was applied by broadcasting and disking in the spring, on those plots receiving commercial fertilizer. Twenty pounds of nitrogen and 20 pounds of P_2O_5 were applied per acre. In 1960, the rate of nitrogen application was changed to 40 pounds per acre. On those plots where residues were returned, all of the harvested straw and the stalks were either left or returned to the plots. On those plots where residues were removed, all of the harvested straw and the stalks were removed each year.

The effect of the various treatments on crop yields for the individual years, together with the average yields for the 20 year period (1942-1961) are given in tables 4, 5, and 6. The effects of tillage, residue management, and fertilizers on yield of corn are shown in table 4.

Subsurface Best with Low Moisture

Subsurface tillage produced the highest yields of corn in the years when moisture was limited. This was especially true in 1958 and 1959.

On the subsurface tilled plots where the residues were returned, the corn yields were higher than where the residues were removed. This was most noticeable in the drier years such as 1957, 1958, and 1959.

Table 4. Effect of Tillage, Residue, and Fertilizer on Yields of Corn (1942-1961) in a Corn-Oats-Wheat Rotation. Agronomy Farm, Brookings, South Dakota

Year	Yield in Bushels Per Acre							
	Subsurface Tillage Residue Returned	Subsurface Tillage Residue Removed	Subsurface Tillage Residue Returned + N	Subsurface Tillage Residue Returned + P	Subsurface Tillage Residue Returned + NP	Subsurface Tillage Residue Returned + Manure	Plow Residue Returned	Plow Residue Removed
1942	60.1	60.2	54.5	56.7	55.7	60.2	55.9	59.3
1943	35.0	33.5	32.2	35.6	23.7	34.5	36.4	34.6
1944	72.8	72.6	70.2	72.7	74.7	73.3	76.2	76.3
1945	46.4	45.1	39.2	39.4	39.1	39.7	55.4	53.1
1946	31.7	33.5	30.4	26.5	28.8	33.9	43.7	43.7
1947	36.9	38.9	38.3	38.3	37.8	38.2	43.1	40.2
1948	71.9	62.6	76.8	73.6	72.6	66.8	71.6	69.4
1949	37.3	33.1	36.5	39.0	39.7	42.1	18.9	15.5
1950	28.9	31.5	32.2	30.8	31.2	28.0	26.4	31.4
1951	27.3	30.2	24.9	30.0	26.9	33.4	30.5	29.5
1952	61.1	65.8	62.2	63.5	61.6	67.8	72.2	65.6
1953	43.7	46.9	44.5	44.7	51.4	54.7	64.6	59.3
1954	53.0	51.6	56.5	55.4	58.6	61.1	59.3	50.6
1955	48.7	46.9	47.2	52.3	47.7	45.0	39.9	42.0
1956	64.4	60.9	66.9	65.2	71.0	83.0	66.0	60.8
1957	54.7	47.2	55.4	53.5	57.6	63.7	57.4	49.8
1958	44.3	38.4	40.9	46.2	43.4	42.1	22.1	24.5
1959	54.7	47.8	47.6	56.8	50.1	54.4	36.2	34.6
1960	63.3	59.0	68.0	64.0	68.1	72.4	71.0	64.6
1961	61.6	60.7	72.6	71.1	76.1	76.3	75.4	66.3
20 yr. avg.	49.9	48.3	49.9	50.8	50.8	53.6	51.1	48.6

N = 20 lbs. of N per acre per year, 1942-1959.
40 lbs. of N per acre per year, 1960-1961.
P = 20 lbs. of P_2O_5 per acre per year.

The yield of corn was increased by the application of each of the following treatments to the subsurface tillage plots with crop residues returned:

(1) Manure
(2) Nitrogen
(3) Phosphorus
(4) Nitrogen plus phosphorus

This increased yield was particularly evident in the more favorable corn years.

The return of crop residues with plowing as a tillage practice, produced greater yields of corn than plowing with residues removed. This increase in yield was a reflection of the fertility returned in the crop residues and of improved physical properties of the soil.

The effect of tillage, residue management, and fertilizers on the yield of oats is shown in table 5. The effects of tillage treatments on yield of oats were not so pronounced as those found with corn. This is because the oats followed a cultivated corn crop, and because the seedbed for all oats plots of this experiment was uniformly prepared by tandem disking of the corn ground in the spring.

Crop Residues Increased Oats

On the plots which were plowed for the previous crops, the return of crop residues was responsible for a sizeable increase in average oats yields. Where no fertilizer was applied, but where residues were returned, plowing for corn and wheat resulted in a higher average oats yield than subsurface tillage.

In the plots which were subsurface tilled for corn and wheat, there was a striking increase in oats yield, where nitrogen or nitrogen plus phosphorus or manure was applied.

The effects of tillage, residues, and fertilizer on yield of wheat are presented in table 6. The results with wheat are quite similar to those obtained for oats (table 5).

When the seedbed was plowed, the return of crop residues increased the yield of wheat. When the seedbed was subsurface tilled, the effect on wheat yield due to return of residues was not appreciable. However, the residue gave protection to the soil against wind and water erosion.

In the subsurface tilled plots, nitrogen plus phosphate or manure gave the most satisfactory yield increases.

EFFECTS OF DEPTH OF PLOWING AND OTHER TILLAGE PRACTICES ON CROP YIELDS

The purpose of this experiment was to determine the effects of tillage practices on the yields of crops, in a corn-oats-wheat rotation.

The tillage practices in the experiment were:

1. Plowing at 4 inches.
2. Plowing at 7 inches.
3. Plowing at 10 inches.
4. Subsurfacing with a blade 6 inches deep.
5. One-way or disc plowing.
6. Double disking.

Each crop was grown every year for twenty years under all six tillage practices.

Table 5. Residual Effect of Tillage, Residue, and Fertilizer on Yields of Oats (1942-1961) in a Corn-Oats-Wheat Rotation. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre							
Year	Subsurface Tillage Residue Returned	Subsurface Tillage Residue Removed	Subsurface Tillage Residue Returned + N	Subsurface Tillage Residue Returned + P	Subsurface Tillage Residue Returned + NP	Subsurface Tillage Residue Returned + Manure	Plow Residue Returned	Plow Residue Removed
1942	44.5	50.5	43.7	46.8	37.0	44.9	43.6	45.4
1943	103.3	109.6	103.2	100.5	93.8	106.6	97.4	93.9
1944	56.7	57.6	62.8	54.2	62.6	58.4	70.8	69.7
1945	82.3	86.9	97.9	82.6	97.4	87.5	97.3	91.5
1946	70.1	62.3	58.5	65.2	53.5	61.1	68.5	63.1
1947	68.1	69.9	83.5	75.4	89.0	82.0	68.1	65.7
1948	61.7	54.7	72.1	74.2	67.7	61.9	71.4	54.3
1949	52.4	53.8	65.5	56.0	66.9	63.4	55.9	41.6
1950	54.7	56.7	65.4	57.9	71.1	67.5	58.7	52.9
1951	47.7	49.4	68.6	50.2	69.4	64.3	60.8	63.1
1952	54.7	55.8	44.0	49.4	62.5	56.1	48.0	52.5
1953	56.6	42.2	64.5	50.8	69.0	61.5	45.5	40.4
1954	36.6	37.1	49.1	38.2	52.7	59.9	42.4	34.2
1955	49.8	50.2	50.1	56.2	55.7	53.7	56.7	48.2
1956	38.6	31.4	39.3	45.4	43.6	51.7	38.2	30.6
1957	46.8	42.5	64.9	46.2	73.1	69.0	50.1	39.8
1958	52.0	47.4	58.7	48.4	58.4	55.9	57.1	45.3
1959	37.4	32.8	29.2	40.3	26.8	34.4	32.1	29.5
1960	41.6	38.1	67.1	38.0	74.7	63.6	50.5	47.5
1961	30.3	36.0	54.6	30.7	54.4	43.5	43.3	39.0
20 yr. avg.	54.3	53.2	62.1	55.3	63.9	62.3	57.8	52.4

*The differential tillage treatments were performed for the preceeding corn crop.
N = 20 lbs. of N per acre per year, 1942-1959.
40 lbs. of N per acre per year, 1960-1961.
P = 20 lbs. of P_2O_5 per acre per year.

Table 6. Effect of Tillage, Residue, and Fertilizer on Yields of Wheat (1942-1961) in a Corn-Oats-Wheat Rotation. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre							
Year	Subsurface Tillage Residue Returned	Subsurface Tillage Residue Removed	Subsurface Tillage Residue Returned + N	Subsurface Tillage Residue Returned + P	Subsurface Tillage Residue Returned + NP	Subsurface Tillage Residue Returned + Manure	Plow Residue Returned	Plow Residue Removed
1942	22.2	24.1	24.5	24.0	24.4	23.7	23.4	22.0
1943	23.1	23.5	24.5	24.0	26.5	22.2	25.4	23.2
1944	14.8	13.3	16.6	15.4	15.9	16.3	18.3	17.5
1945	27.1	26.3	30.7	29.9	35.4	28.9	35.0	33.0
1946	20.9	22.0	26.9	18.7	27.3	25.7	22.1	21.6
1947	18.9	15.6	20.1	20.9	23.0	21.3	20.0	20.5
1948	19.8	20.2	31.4	26.4	35.3	28.9	17.9	15.5
1949	12.8	13.5	14.2	14.7	17.7	16.7	13.0	9.6
1950	20.6	21.0	28.4	21.9	29.8	26.0	23.8	21.2
1951	12.7	11.5	20.4	13.3	22.8	18.6	17.6	14.0
1952	9.1	11.0	12.1	11.6	14.5	14.6	13.5	13.2
1953	8.7	7.3	12.5	8.9	14.8	12.2	11.8	7.1
1954	5.3	4.3	6.7	6.3	7.6	7.6	6.1	4.9
1955	20.9	19.1	20.4	21.5	24.4	25.3	18.4	17.1
1956	11.3	9.6	11.1	13.7	13.0	15.3	10.6	8.7
1957	17.4	16.4	24.3	22.1	30.4	27.1	20.8	20.5
1958	20.5	20.9	24.8	22.2	26.4	25.9	20.6	17.7
1959	16.2	16.0	15.5	16.2	14.6	16.0	18.1	14.7
1960	18.9	17.5	28.5	18.0	30.1	25.9	29.5	23.4
1961	14.7	16.1	25.2	13.3	22.9	19.1	20.4	18.6
20 yr. avg.	16.8	16.5	20.9	18.2	22.8	20.9	19.3	17.2

N = 20 lbs. of N per acre per year, 1942-1959.
40 lbs. of N per acre per year, 1960-1961.
P = 20 lbs. of P_2O_5 per acre per year.

Effects When Residue Not Returned

In this trial the crop residues from the small grain crops were not returned to the soil except for the binder stubble, but all of the corn stalks were left on those plots planted to corn. Previous to 1957, no fertilizer was applied. In order to reduce the limiting effect of soil fertility for crop production, 20 pounds of nitrogen and 20 pounds of P_2O_5 per acre were applied each year to all plots, from 1957 through 1959. In order to compensate for the gradual lowering of soil fertility, the rate of nitrogen application was increased to 40 pounds per acre each year, beginning in 1960.

For corn and wheat, the six tillage practices listed in tables 7, 8, and 9 were performed in the fall on the oats and wheat stubble. No fall tillage was done on the corn stalk ground. In the spring, the seedbed for oats which followed corn was prepared by double disking. The corn and wheat plots were uniformly prepared for planting by tandem disking prior to planting the crop in the spring.

7-Inch Plowing Excels

The 20 year average shows the highest yield of corn when the plots were plowed 7 inches deep, as shown in table 7. In years when soil moisture was a limiting factor, corn yields were the highest

Table 7. Effect of Depth Plowing and Other Tillage Practices on Yields of Corn (1942-1961). Agronomy Farm, Brookings, South Dakota

		Yield in Bushels Per Acre				
Year	Plow 4"	Plow 7"	Plow 10"	Subsurface	One Way	Double Disk
1942	42.2	51.6	49.6	44.0	40.5	40.5
1943	31.7	32.5	33.0	30.3	31.8	35.5
1944	73.3	74.1	64.2	75.8	68.2	72.4
1945	52.0	53.3	53.2	40.2	49.1	35.1
1946	43.3	46.3	48.7	37.7	43.4	32.0
1947	38.7	40.5	36.5	37.0	38.8	35.8
1948	73.0	72.0	70.2	69.7	71.3	64.0
1949	11.5	14.7	13.4	31.4	20.2	25.2
1950	54.7	55.1	53.6	49.3	51.9	49.1
1951	27.7	27.0	25.3	17.8	25.0	19.5
1952	64.7	64.5	63.1	59.6	57.2	54.2
1953	59.6	63.5	62.8	48.0	52.0	49.2
1954	54.9	53.5	53.7	47.1	47.7	43.3
1955	41.8	46.4	38.0	48.4	40.9	42.8
1956	51.2	57.4	52.2	54.4	50.8	49.2
1957	52.1	52.4	47.7	52.5	49.9	46.3
1958	19.3	22.8	19.5	40.6	26.2	28.7
1959	27.6	35.1	30.5	47.7	29.1	34.5
1960	65.8	72.8	71.6	63.0	61.6	59.8
1961	78.5	80.5	81.0	74.0	69.6	67.5
20 yr. avg.	48.2	50.8	48.4	48.4	46.3	44.2

All plots received the following fertilizer:
- 20 lbs. of N per acre per year, 1957-1959.
- 40 lbs. of N per acre per year, 1960-1961.
- 20 lbs. of P_2O_5 per acre per year, 1957-1961.

on the subsurface tilled plots. This was especially noticeable in 1958 and 1959. When soil moisture was more adequate, as in 1960 and 1961, plowing produced the highest yield of corn.

Double disking the small grain stubble for seedbed preparation resulted in the lowest average corn yield of any of the tillage practices. This land has not been plowed for 20 years.

The residual effects of depth of plowing and other tillage practices on yields of oats are presented in table 8.

Because the seedbed for oats, which followed the corn, was prepared by uniformly double disking the corn ground, the previous tillage practices on corn and wheat did not have a pronounced effect on yield of oats.

After 1956, when fertility was improved by use of nitrogen and phosophorus fertilizers, there were no appreciable differences in yields of oats due to tillage practices.

Table 9 lists the wheat yields obtained with different depths of plowing and different tillage practices.

The higher yields after 1956 are due to a combination of fertilizer applications, disease resistant varieties and favorable weather.

In years of limited soil moisture as in 1959, the highest yields of

Table 8. Residual Effects of Depth of Plowing and Other Tillage Practices for Corn on Yields of Subsequent Oats (1942-61). Agronomy Farm, Brookings, South Dakota

			Yield in Bushels Per Acre			
Year	Plow 4"	Plow 7"	Plow 10"	Subsurface	One Way	Double Disk
1942	40.4	36.4	31.0	43.7	39.9	35.6
1943	99.6	96.4	92.4	91.4	97.6	89.5
1944	70.6	70.3	68.1	54.4	58.1	49.2
1945	96.6	103.2	105.0	85.1	73.6	74.6
1946	68.2	59.7	67.3	58.7	64.9	67.8
1947	86.0	78.1	79.1	82.2	77.5	78.3
1948	53.5	50.3	66.2	49.8	58.3	57.8
1949	50.4	43.0	54.3	45.4	51.3	46.9
1950	61.0	57.1	62.4	56.9	59.5	57.5
1951	55.0	46.4	60.8	42.7	43.7	46.2
1952	51.5	43.7	48.4	44.2	44.5	44.8
1953	44.3	34.0	45.9	46.8	41.3	40.5
1954	40.5	39.4	44.4	34.0	30.5	30.6
1955	58.0	55.8	56.5	51.5	52.3	52.5
1956	35.3	34.6	42.4	35.6	34.1	40.2
1957	57.8	65.2	64.4	61.2	57.4	63.5
1958	58.9	53.3	60.6	47.2	50.3	49.2
1959	27.9	27.2	29.1	35.5	30.7	31.9
1960	73.1	75.8	71.6	68.9	71.3	71.2
1961	66.8	60.1	73.0	60.4	64.0	64.1
20 yr. avg.	59.8	56.5	61.2	54.8	55.0	54.6

All plots received the following fertilizer:
20 lbs. of N per acre per year, 1957-1959.
40 lbs. of N per acre per year, 1960-1961.
20 lbs. of P_2O_5 per acre per year.

Table 9. Effect of Depth of Plowing and Other Tillage Practices on Yields of Wheat (1942-61). Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre					
Year	Plow 4"	Plow 7"	Plow 10"	Subsurface	One Way	Double Disk
1942	24.6	24.1	25.5	25.2	24.3	25.8
1943	19.9	21.2	25.5	21.5	20.1	17.5
1944	17.5	17.1	18.0	11.0	10.1	12.5
1945	34.2	34.5	37.1	29.3	33.2	25.0
1946	18.9	16.6	19.9	15.6	15.6	15.8
1947	20.4	19.2	20.8	14.8	16.4	14.9
1948	18.6	18.9	18.2	20.0	19.6	19.5
1949	12.7	12.6	12.5	13.5	13.0	11.5
1950	20.8	20.8	21.5	19.8	23.1	19.0
1951	19.3	15.9	21.1	12.6	16.0	13.3
1952	11.7	11.0	11.4	9.5	10.1	6.7
1953	10.2	9.2	10.3	6.0	7.8	6.7
1954	8.7	6.9	7.4	7.9	6.4	6.0
1955	18.0	18.5	18.4	19.0	16.7	16.5
1956	11.4	15.5	14.3	14.8	10.0	9.9
1957	27.3	26.2	27.8	29.4	24.7	24.2
1958	22.5	25.5	23.8	25.9	21.1	20.3
1959	10.8	12.6	9.6	17.2	12.1	13.1
1960	29.2	30.0	30.7	32.4	28.3	29.2
1961	28.1	30.2	24.8	28.5	26.8	25.1
20 yr. avg.	19.2	19.3	19.9	18.7	17.8	16.6

All plots received the following fertilizer:
20 lbs. of N per acre per year, 1957-1959.
40 lbs. of N per acre per year, 1960-1961.
20 lbs. of P_2O_5 per acre per year, 1957-1961.

wheat were obtained by subsurface tillage.

In 1960, the yields of wheat were about the same for all tillage practices. The higher rate of nitrogen application on these plots started in 1960 may have been responsible for leveling out yields in that year.

High Fertilty—Less Tillage

The depth of tillage had less influence on yields of wheat when adequate fertility was provided. It appears that when the fertility of the soil is at an optimum level, it is not necessary to till the soil as much as when the fertility is inadequate. With optimum fertility, good wheat yields were obtained by merely double disking the stubble in the fall and in the spring prior to planting the wheat.

There were only minor differences in wheat yield due to depth of plowing when adequate fertility was provided.

Subsurface tillage appeared to be the most effective way to protect the soil from erosion and to conserve soil moisture.

EFFECTS OF SWEET CLOVER ROTATIONS ON CROP YIELDS

The purpose of this experiment was to determine the effects of sweet clover on the yields of crops in a corn-wheat-clover rotation. Another objective of this experiment was to determine the optimum time for plowing under sweet clover for soil improvement purposes and for conserving soil moisture.

The sweet clover was seeded with the wheat crop, and the following year it was plowed under for green manure. Two methods were followed in plowing under the sweet clover:

(1) Plowing under in June and disking once in the summer.

(2) Mowing in June, allowing regrowth until August and then plowing under.

The reason for plowing the sweet clover in June was to accomplish a partial fallow which would permit the accumulation of subsoil moisture. For each method of plowing under the sweet clover, there were both phosphorus fertilized and unfertilized plots. The rate of P_2O_5 was 60 lbs. every three years, or once in the rotation.

Sweet Clover Effect on Yields

The influences of the different methods of handling sweet clover on the yields of corn and wheat are shown in tables 10 and 11. The average corn yield (1944-1961) from the plots where the preceeding sweet clover was mowed in June and plowed on August 1 was about the same as in the corn plots where the preceeding sweet clover was plowed on June 15. This period (1944-1961) was characterized by generally high corn yields and favorable rainfall. Phosphorus applications on the sweet clover did not appreciably increase the corn yields.

Wheat was the second crop after the legumes, consequently, less residual effect on the yield of wheat would be expected from the differ-

Table 10. Effect of Different Methods of Managing Sweet Clover in Rotation on Yields of Corn. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre			
Year	Sweet Clover Plowed June 15	Sweet Clover Plowed June 15 With P Fertilizer	Sweet Clover Mowed in June Plowed Aug. 1	Sweet Clover Mowed in June Plowed Aug. 1 With P Fertilizer
1944	72.3	72.0	75.9	79.7
1945	44.7	49.1	49.9	48.2
1946	44.7	47.2	47.4	48.9
1947	35.4	41.8	41.2	42.2
1948	69.6	70.2	73.1	74.6
1949	26.2	25.6	32.4	24.3
1950	56.7	53.0	55.1	54.8
1951	27.6	27.6	30.0	35.1
1952	64.8	66.8	68.7	72.6
1953	65.4	69.7	73.1	75.7
1954	55.9	56.8	60.7	56.8
1955	35.9	34.7	31.0	32.1
1956	61.6	64.0	70.5	64.6
1957	49.9	53.2	59.2	59.7
1958	41.4	40.7	13.7	11.2
1959	46.8	44.6	34.4	28.3
1960	70.3	70.0	70.7	68.9
1961	81.6	83.9	84.3	84.8
18 yr. avg.	52.8	53.9	54.0	53.5

Table 11. Effect of Different Methods of Managing Sweet Clover in Rotation on Yields of Wheat. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre			
Year	Sweet Clover Plowed June 15	Sweet Clover Plowed June 15 With P Fertilizer	Sweet Clover Mowed in June Plowed Aug. 1	Sweet Clover Mowed in June Plowed Aug. 1 With P Fertilizer
1944	17.9	18.0	18.5	17.5
1945	37.2	42.4	40.3	38.0
1946	29.1	31.8	32.2	30.1
1947	21.8	23.2	22.8	24.8
1948	28.0	28.4	30.1	33.3
1949	20.8	24.3	20.3	21.0
1950	24.7	25.0	28.5	26.2
1951	31.5	34.2	31.9	33.7
1952	18.3	24.6	19.5	24.1
1953	15.9	16.3	16.6	18.4
1954	12.3	14.3	14.7	13.5
1955	26.1	25.6	25.0	28.9
1956	17.1	18.2	22.7	21.9
1957	26.8	32.5	31.0	29.1
1958	28.6	32.4	28.5	30.5
1959	13.2	13.0	10.1	11.0
1960	33.6	33.1	33.6	33.9
1961	31.2	30.5	30.2	33.3
18 yr. avg.	24.1	26.0	25.4	26.1

ent methods of handling the sweet clover. Phosphate applied to the sweet clover slightly increased the yield of wheat. The yields of wheat in the sweet clover rotation are quite similar to those in the corn-oats-wheat rotation discussed previously (table 3) where nitrogen was obtained from commercial fertilizer in place of a legume.

In 1957, the corn-wheat-sweet clover experiment was expanded to include 4 additional rotations:

(1) Corn-wheat-red clover plus 60 lbs. of P_2O_5.

(2) Corn-wheat-oats with sweet clover catch crop plus 20 lbs. of P_2O_5/acre/year on each crop.

(3) Corn-wheat-oats plus 30 lbs. of nitrogen and 20 lbs. of P_2O_5/acre/year on each crop.

(4) Corn-wheat-oats (no fertilizer and no legume).

Red Clover Effect on Yields

In rotation 1 the red clover was planted with the wheat. The next year the first hay crop was mowed but not removed. The second crop was plowed under in August without mowing, together with the first crop. No red clover hay was removed, in order that this rotation could be compared to the sweet clover rotation where the sweet clover was plowed in August and all of the clover crop returned. A total of 60 lbs. of P_2O_5 was applied once in each cycle of the rotation on the red clover in the spring.

In rotation 2, sweet clover was planted with both the wheat and the oats and plowed under each fall of the year it was planted. On those plots receiving phosphorus in this rotation, 20 lbs. of P_2O_5 were applied on each crop each year making a total of 60 lbs. in each cycle of the rotation.

In rotation 3, the source of nitrogen was commercial fertilizer rather than legumes. In 1960, the rate of commercial nitrogen was increased to 40 lbs. per acre per year.

Rotation 4 is considered a check or control rotation because no nitrogen or phosphorus was applied and no legumes were planted.

Rotations Summarized

Table 12 summarizes the yield results of these four rotations from 1957-1961, together with the sweet clover catch crop rotation for the same period. The yield of corn was greater when the sweet clover was mowed in June than when the sweet clover was mowed in June and plowed in August. This was especially noticeable in the dry years of 1958 and 1959 (see rainfall record, table 21). In years of above average rainfall as 1960 and 1961, the differences due to time of plowing were not so apparent. In future years the yield of the check or control plot would be expected to decrease as the original fertility declines.

The yield of wheat was increased in all of the legume rotations, and by the use of nitrogen and phosphorus fertilizer when compared with the check or control rotation. Especially large increases of wheat were obtained in 1961 by the use of nitrogen and phosphorus fertilizer.

The yield of oats in the corn-wheat-oats rotation was only slightly increased by the sweet clover catch crop plus phosphorus treatment. The catch crop was sweet clover planted in the spring with wheat and oats and plowed under in the fall.

The oats yield in the corn-wheat-oats rotation was increased by the addition of nitrogen and phosphorus fertilizer.

COMPARISON OF CROP PRODUCTION IN ALFALFA AND NON-LEGUME ROTATIONS

In this study, a comparison was made between a legume rotation of

Figure 1. Effect of fertilizer on wheat growth and appearance in 1961. Left: no fertilizer; right: 40-20-0. The wheat was grown in a corn-wheat-oats cropping system (table 12).

Table 12. Effect of Sweet Clover, Red Clover, and Nitrogen, and Phosphorus Fertilizer on the Yield of Corn, Wheat, and Oats. Agronomy Farm, Brookings, South Dakota.

Year	Sweet Clover Plowed in June	Sweet Clover Plowed in June and Phosphorus	Sweet Clover Plowed in August	Sweet Clover Plowed in August and Phosphorus	Red Clover and Phosphorus Plowed in August	Corn-Wheat-Oats and Sweet Clover Catch Crop + P	Corn-Wheat-Oats + 30#N + 20# P *	Corn-Wheat-Oats - No Fertilizer or Legume
	Yield in Bushels Per Acre							
1. CORN								
1957	49.9	53.2	59.2	59.7	56.6	56.8	59.8	56.8
1958	41.4	40.7	13.7	11.2	11.2	13.2	18.9	23.5
1959	46.8	44.6	34.4	28.3	36.1	38.6	41.0	43.1
1960	70.3	70.0	70.7	68.9	68.2	71.6	60.8	72.7
1961	81.6	83.9	84.3	84.8	85.1	76.0	87.1	78.0
5 yr. avg.	58.0	58.5	52.5	50.6	51.4	51.2	53.5	54.8
2. WHEAT								
1957	26.8	32.5	31.0	29.1	28.1	27.1	31.9	27.1
1958	28.6	32.4	28.5	30.5	28.6	25.6	29.4	24.1
1959	13.2	13.0	10.1	11.0	9.9	14.5	14.5	15.4
1960	33.6	33.1	33.6	33.9	34.7	32.4	29.0	27.3
1961	31.2	30.5	30.2	33.3	25.5	20.3	32.1	18.1
5 yr. avg.	26.7	28.3	26.7	27.6	25.4	24.0	27.4	22.4
3. OATS								
1957						61.2	73.8	48.8
1958						50.3	45.5	53.1
1959						22.3	13.5	30.6
1960						68.4	82.2	53.9
1961						51.1	71.8	54.6
5 yr. avg.						50.7	57.4	48.2

*The nitrogen rate was changed to 40 lbs. of N/acre/year in 1960.
60 lbs. of P_2O_5 per acre were applied once in a rotation.

corn-flax-alfalfa-alfalfa and a non-legume rotation of corn-flax-corn-oats with and without nitrogen fertilizer.

In the legume rotation the alfalfa remained for two full crop years after planting with the flax. Two crops of hay were harvested each year. After remaining two full crop years, the alfalfa was plowed up. Eighty pounds of P_2O_5 were applied once in four years on the first alfalfa year.

There were 3 non-legume rotations, all with the same cropping sequence of corn-flax-corn-oats. One of these rotations received no nitrogen, the second rotation received 20 lbs. of nitrogen per acre per year on each crop and the third received 40 lbs. of nitrogen per acre per year on each crop. The second and third rotations received 20 lbs. of P_2O_5 per acre each year on each crop. The rotation which received no commercial nitrogen received no P_2O_5. This was the check or control rotation. These rotations have at this time made only one complete cycle.

All of the crop residues were returned to the soil except the flax straw.

Corn Yield Higher in Non-Legume Rotation

The yields of corn in the alfalfa rotation are listed in table 13. In the check or control rotation where no legume or commercial nitrogen was used, the yields of corn were higher almost every year (1956-1961) than in the alfalfa rotation. The depletion of soil moisture by the alfalfa caused these yield reductions, especially in years when mid-summer rainfall was short.

There was one notable exception however, in 1961, when the corn in the alfalfa rotation out-yielded the check or control rotation. The rainfall in 1961 was about 4 inches above normal.

In 1961, on the plots where 40 lbs. of nitrogen were applied, the yield of corn was about the same as the yield of corn in the legume-rotation where it followed 2 years of alfalfa.

Where 20 lbs. of nitrogen per acre was applied, the 5 year average corn yields were about 4 bushels less than where 40 pounds of nitrogen were applied. In a good corn year (1961), 20 lbs. of nitrogen gave an increase of about 9 bushels over the check or control plots; 40 lbs. of nitrogen gave an increase of about 19 bushels of corn per acre over the check or control plots.

The 6 year averages for oats indicate a substantial increase in yield over the check or control plots for both the 20 and 40 lb. application rates. On this location, 20 lbs. of nitrogen applied every year on all crops gave close to optimum yields of oats in most years.

The yields of flax in these rotations were increased by nitrogen treatments in years with favorable growing conditions. Frequently, yields were adversely affected by weather and plant diseases.

The alfalfa yields for the corn-flax - alfalfa - alfalfa rotation are shown in table 13. The value of the alfalfa as a crop can be compared with the production of corn and oats in these rotations. Some other values and advantages of alfalfa are:

Table 13. Effect of Alfalfa in Rotation and Nitrogen Fertilizer on Yield of Corn, Oats, and Flax (1956-61). Agronomy Farm, Brookings, South Dakota.

Year	Corn bu/A	Flax bu/A	1st Year Alfalfa or Corn lb/A	1st Year Alfalfa or Corn bu/A	2nd Year Alfalfa or Oats lb/A	2nd Year Alfalfa or Oats bu/A
CORN-FLAX-ALF.-ALF.						
1956	67.0	6.1	4566		5338	
1957	34.4	9.8	4629		5014	
1958	12.9	10.1	2042		3180	
1959	33.6	9.5	59		1389	
1960	71.1	18.6	3338		3608	
1961	86.8	11.0	4974		5706	
Avg.	50.9	10.9	3268		4039	
CORN-FLAX-CORN-OATS + 20#N						
1956	--	--	--	--	--	--
1957	54.1	9.7		55.2		61.7
1958	25.1	14.4		32.2		53.6
1959	40.9	16.7		31.6		45.3
1960	73.5	17.4		69.2		80.2
1961	75.8	11.3		79.3		65.4
Avg.	53.9	13.9		53.5		61.2
CORN-FLAX-CORN-OATS + 40#N						
1956	68.6	5.4		65.5		23.9
1957	52.7	9.5		51.5		66.8
1958	23.0	12.1		26.8		61.3
1959	43.5	15.6		34.1		42.7
1960	75.4	18.6		71.9		71.6
1961	85.3	12.0		84.2		76.8
Avg.	58.1	12.2		55.7		57.2
CORN-FLAX-CORN-OATS						
1956	69.0	6.1		65.7		26.0
1957	49.7	9.2		54.5		45.6
1958	36.4	12.5		31.6		50.8
1959	45.2	13.7		39.1		40.7
1960	76.5	14.7		71.4		76.0
1961	66.4	8.6		70.2		38.6
Avg.	57.2	10.8		55.4		46.3

(1) Addition of nitrogen to the soil.

(2) Improvement in physical properties of the soil.

(3) Erosion control.

It is difficult to assign values to these factors, but their importance is recognized.

COMPARISON OF LEGUMES AS A SOURCE OF NITROGEN

The objectives of this study were:

(1) To determine the economy of growing legumes as a source of nitrogen for crops.

(2) To determine the optimum rate of nitrogen fertilizer application for corn, oats, flax, and wheat.

(3) To determine the influence of soil treatment on the quality of the crop as measured by protein content.

The basic rotations were corn-oats-flax-legume, and corn-oats-flax-wheat. The legumes used were alfalfa, red clover, and sweet clover. The legume was planted with the flax and held over for one additional year in all of the legume rotations. There were three legume rotations with either alfalfa, red clover, or sweet clover as the legumes The first cutting of hay was mowed, allowed to lay and was then plowed under with the second crop in August or September.

Return Maximum Nitrogen

This rotation was designed to return to the soil the maximum amount of nitrogen produced by one full year's growth of legume. In this way a determination could be made of the effect of legume nitrogen on the yield of crops, in comparison with the application of fertilizer nitrogen. These legume rotations received 80 lbs. per acre of P_2O_5 as treble superphosphate in four years, applied on the established legume stand.

The non-legume rotations had the same cropping sequence except that wheat replaced the legume. There were four non-legume rotations, and each received a different rate of commercial nitrogen. The rates of application were 0, 20, 40, and 60 lbs. of nitrogen per acre per year on each crop. These rotations received 20 lbs. of P_2O_5 per acre per year, except the check or control rotation which received no nitrogen or phosphate. The rate of phosphate application, 80 lbs. of P_2O_5 per acre per rotation, was the same as in the legume rotation, except that the phosphate was applied at the rate of 20 lbs. per acre in each of the four years of the rotation. All of the non-legume crop residues were returned to the soil except the flax straw.

The results of these rotations are presented in table 14. No yields are given for corn and oats in 1957 in the red clover rotations, because they were started in 1958, and the land was planted to flax. These rotations have gone through one cycle of four years. The second cycle of rotations was started in 1961.

Corn After Legume Lowered Yields

In the legume rotations, the yields of corn following the legume were decreased markedly in the unfavorable years when compared with those in the non-legume rotation. In the favorable corn year of 1961 there was a decided increase in corn yield attributable to the legumes in the rotation. This increase was about 17 bushels per acre, which was the same as the increase for 40 lbs. of nitrogen (table 14). The legumes—alfalfa, red clover, and sweet clover—were of equal value in increasing yields of corn in 1961. In unfavorable years, commercial nitrogen did not increase the yield of corn. In the favorable year of 1961 there was a consistent increase of corn yield, with increasing rates of nitrogen application.

Oats Increased with Adequate Rain

The oats crop was increased by nitrogen fertilizer in years of favorable rainfall. Additional yield increases for rates of nitrogen greater than 20 lbs. per acre were usually small. In the legume rotation, oats

Table 14. Effect of Nitrogen Fertilizer and Legumes on Yields of Crops (1957-1961). Agronomy Farm, Brookings, South Dakota.

	Yield in Bushels Per Acre						
	Corn-Oats -Flax-Wheat, No Fertilizer or Legume	Corn-Oats -Flax-Wheat + 20#N	Corn-Oats -Flax-Wheat + 40#N	Corn-Oats -Flax-Wheat + 60#N	Corn-Oats -Flax-Red Clover	Corn-Oats -Flax-Sweet Clover	Corn-Oats -Flax-Alfalfa
CORN							
1957	51.6	51.4	51.1	53.2	--	62.6	--
1958	24.0	16.5	14.8	14.3	5.9	8.4	7.2
1959	35.0	26.5	18.0	19.7	15.4	19.1	22.6
1960	66.5	69.2	69.1	68.9	61.2	61.7	62.6
1961	67.2	75.0	84.4	87.5	84.3	84.7	84.1
Avg.	48.9	47.7	47.5	48.7	41.7	47.3	44.1
OATS							
1957	52.4	69.1	74.9	77.0	--	67.0	--
1958	51.6	53.1	65.6	72.9	71.7	55.8	54.9
1959	42.6	38.9	37.7	37.4	37.8	29.8	33.6
1960	75.4	82.1	78.8	69.1	82.3	73.6	89.6
1961	43.1	72.9	76.0	71.3	50.2	53.5	46.6
Avg.	53.0	63.2	66.6	65.5	60.5	55.9	56.2
FLAX							
1957	9.6	11.2	11.7	11.0	--	10.1	--
1958	11.5	11.4	13.7	13.6	11.2	9.9	10.5
1959	13.2	13.2	13.6	14.7	12.7	12.6	11.7
1960	18.1	15.7	16.0	14.9	13.7	13.0	13.4
1961	11.5	13.9	16.5	19.5	11.0	9.5	10.7
Avg.	12.8	13.1	14.3	14.7	12.2	11.0	11.6
WHEAT							
1957	26.1	30.5	30.9	32.1			
1958	17.1	19.7	17.9	18.8			
1959	11.6	12.3	8.2	11.3			
1960	28.8	34.6	28.5	31.8			
1961	23.9	33.0	31.5	30.4			
Avg.	21.5	26.0	23.4	24.9			

Figure 2. Response of oats to fertilizer (40-20-0) in a corn-oats-flax-wheat rotation (table 14).

Figure 3. Response of flax to nitrogen fertilizer in a corn-oats-flax-wheat rotation as compared to flax growth in a corn-oats-flax-red clover rotation (table 14).

was the second crop after the legumes. The legume rotations increased the yield of oats but were not as effective in increasing these yields as the application of 20 lbs. of commercial nitrogen each year.

In the years 1958 and 1959, the production of dry matter or hay was much reduced by drought; consequently, the amount of nitrogen fixed by the legumes was restricted.

In a good flax year, 1961, the yields of flax were strikingly increased with increased rates of nitrogen application. In other years, the yields of flax were variable, largely because of adverse weather conditions. In the legume rotations, flax was the third crop after the legumes. The effects of legumes on flax has been limited because of the short duration of the experiment.

In the case of wheat, 20 lbs. of nitrogen per acre gave the highest yield, as shown in table 14. This 4.5 bushel average wheat yield increase was obtained with a fertilizer investment of $4.80 per acre.

Legumes Expensive For N

It is apparent from the data in table 15 that it is not economically profitable to grow legumes only as a source of nitrogen. The current acreage reduction program for crops which offers payment for taking land out of production, may make the growing of legumes as a source of nitrogen an economically sound practice.

The production of wheat in the non-legume rotation greatly enhances the net return from this rotation. However, not many farmers, especially in this area, would have a wheat base of sufficient acreage to permit one fourth of their crop land to be planted to wheat. Therefore, a lower value crop may have to be substituted for wheat, which would reduce the income from the rotation.

In 1961, the net value of all crops in the non-legume rotation exceeded the net value of the crops in the legume rotation. The cost of nitrogen was calculated at $.14 per lb., phosphorus at $.10 per lb. These figures include the cost of application. The cost of growing the legume was calculated on the basis of $11.00 per acre land rental; seed and mowing, $4.00 per acre, and phosphate fertilizer, $8.00 for the rotation, or $2.00 per acre per year.

In 1961, the response to fertilizer treatment was profitable with all crops, as shown in table 14 or 15.

Table 15. Net Returns Per Acre on Nitrogen and Legume Rotations. Agronomy Farm, Brookings, South Dakota.

Rotation *	Corn	Oats	Flax	Wheat	Total Value	Fertilizer Cost or Legume Cost	Net Return (Four-yr. rotation)
			value/acre				
			1960 CROPS				
C-O-F-W	$66.50	$45.24	$54.30	$57.60	$223.64	$ --	$223.64
C-O-F-W + 20 lbs.N	69.20	49.26	47.10	69.20	234.76	19.20	215.56
C-O-F-W + 40 lbs.N	69.10	47.28	48.00	57.00	221.38	30.40	190.98
C-O-F-W + 60 lbs.N	68.90	41.46	44.70	63.60	218.66	41.60	177.06
C-O-F-Alf	62.60	53.76	40.20		156.56	23.00	133.56
C-O-F-Sw. Clover	61.70	44.16	39.00		144.86	23.00	121.86
C-O-F-Red Clover	61.20	49.38	41.10		151.68	23.00	128.68
			1961 CROPS				
C-O-F-W	67.20	25.86	34.50	47.80	175.36	--	175.36
C-O-F-W + 20 lbs.N	75.00	43.74	41.70	66.00	226.44	19.20	207.24
C-O-F-W + 40 lbs.N	84.40	45.60	49.50	63.00	243.50	30.40	213.10
C-O-F-W + 60 lbs.N	87.50	42.78	58.50	60.80	249.58	41.60	207.98
C-O-F-Alf	84.10	27.96	32.10		144.16	23.00	121.16
C-O-F-Sw. Clover	84.70	32.10	28.50		145.30	23.00	122.30
C-O-F-Red Clover	84.30	30.12	33.00		147.42	23.00	124.42

*C = corn, O = oats, F = flax, W = wheat.
Crops calculated in Table 15 are valued at $1.00/bu. for corn, $.60/bu. for oats, $3.00/bu. for flax, and $2.00/bu. for wheat.

In 1960, the response to fertilizer treatment was limited because considerable residual fertility was carried over from 1959, a dry year, and rainfall restricted the yield of corn. Because of the short duration of this experiment (5 years) and the occurance of two drought years, the conclusion should be regarded as tentative.

Yield Effects Emphasized

The value of legumes for livestock feed was not given consideration in this study, nor were other benefits of legumes, including organic matter maintenance, soil erosion control, as well as weed control and the value of diversification of crops. The approximate yield of alfalfa hay in 1961 was 2½ tons per acre in the alfalfa rotation. The value of this hay for livestock feed would be approximately $18.00 per ton.

That the application of nitrogen fertilizer and the use of legumes will increase the protein content of crops is shown in table 16. The protein content of corn was increased by both legumes and nitrogen fertilizer. Nitrogen fertilizer effectively increased protein content on oats and wheat. Forty pounds of nitrogen per acre produced about the maximum content of protein for corn, oats, and wheat. The application of 20 lbs. of nitrogen per acre per year is utilized largely for increasing the yield of corn, oats, and wheat. The application of 40 lbs. of nitrogen is required for an increase of both yield and protein content of the grain. A considerable portion of the 40 lbs. of nitrogen application is used for increasing the protein content of the crop. The yield of these crops is shown in table 14.

CONTINUOUS CROPPING OR MONO-CULTURE

The purpose of this experiment, which was begun in 1942, was to determine if continuous cropping with the same crop could be successfully practiced. Another purpose was to determine the effect on fertility when the same crop was grown on the same soil year after year continuously. In this manner the rate of fertility depletion by the various crops could be measured. None of the crops received any commercial fertilizer or manure. The corn stalk residues were left on the plots. With

Table 16. The Effect of Nitrogen Fertilizer and Legumes on the Protein Content of Crops in 1961. Agronomy Farm, Brookings, South Dakota

Soil Treatment	Crude Protein Corn %	Oats %	Wheat %
C-O-F-W *	8.64	13.51	12.29
C-O-F-W + 20 lbs. N	8.98	14.12	14.65
C-O-F-W + 40 lbs. N	10.46	16.11	16.04
C-O-F-W + 60 lbs. N	11.41	16.98	16.89
C-O-F-Alf	10.95	13.35	
C-O-F-Red Cl	10.63	13.32	
C-O-F-Sw. Cl	10.59	14.21	

*C = corn, O = oats, F = flax, W = wheat, N = nitrogen.

small grains, the harvested portion of the straw was not returned but the standing stubble was left on the plots.

Original Plots Subdivided

In 1959, the plots were divided into halves. One half was fertilized and the other half was continued as before without fertilizer. For corn, 60 lbs. of nitrogen and 40 lbs. of P_2O_5 were applied per acre; for small grain 40 lbs. of nitrogen and 40 lbs. of P_2O_5 were applied per acre.

Over a period of 20 years, continuous corn produced more pounds of grain than any of the other crops in the experiment (table 17). After 2 years of low crop yields in 1958 and 1959, there was an upsurge in yield in 1960. This was due to the very small removal of fertility by the crops in 1958 and 1959, which were drought years.

After the plots were divided in 1959, the fertilized half yielded considerably more grain than the unfertilized half (table 18). By applying fertilizer to one half of the plots in 1959, the yields of corn, barley, rye, and oats were increased until they were equal to or higher than those obtained at the beginning of the experiment 20 years before.

Weeds, especially wild oats, have become a serious problem in the continuous barley, oats and wheat, but not in the continuous rye.

EFFECTS OF CROPPING ON DEPLETION OF SOIL NITROGEN

The most significant effect of continuous cropping on the surface soil was the large loss of nitrogen, as shown in table 19.

The continuous row crops, corn and sorghum, reduced the total soil nitrogen in the surface 6 inches by approximately 25% in a period of 18 years.

The nitrogen losses from continuous oats, continuous barley, continuous wheat, and continuous rye were considerably less than the nitrogen losses from the intertilled crops.

In the corn-oats-wheat rotation, the return of crop residues was effective in reducing the rates of nitrogen losses. The nitrogen loss was 6.5% less over an 18 year period when crop residues were returned. The return of the residues caused a saving of 320 lbs. of nitrogen per acre during this period.

To replace the nitrogen removed from the soil in 18 years by this corn-oats-wheat rotation where the residues were removed, would cost $116.60 per acre. With the same rotation and residues returned it would cost $81.40 to return the nitrogen. This was based on the present price of $.11 per pound of nitrogen in commercial fertilizer.

EFFECTS OF CROPPING ON AVAILABLE PHOSPHORUS CONTENT OF SURFACE SOILS

Crop production caused a progressive decline in available soil phosphorus, as shown in table 20. After 18 years of continuous cropping the available phosphorus in the surface soil was seriously reduced by both the row crops and the small grain. Available phosphorus was determined by the Bray weak acid method.

In the corn-wheat-clover rotation, the available phosphorus in the surface soil was maintained approximately at the original level by an annual application of 20 lbs. of P_2O_5 per acre.

Table 17. Effect of Continuous Cropping on Yields of Unfertilized Grain (1942-1961). Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre				
Year	Cont. Wheat	Cont. Oats	Cont. Rye	Cont. Barley	Cont. Corn
1942	19.2	32.8	44.4	40.2	56.5
1943	19.8	65.9	33.9	38.2	38.7
1944	15.0	54.8	19.3	17.8	65.5
1945	37.5	83.5	43.7	50.9	44.2
1946	18.4	39.8	18.6	35.1	41.9
1947	18.8	75.3	18.9	40.5	40.9
1948	23.0	46.9	26.2	49.0	59.8
1949	12.8	28.9	18.8	24.1	29.2
1950	18.3	49.7	33.1	36.8	45.5
1951	17.8	53.2	20.9	32.9	25.8
1952	14.6	52.6	30.9	31.1	52.1
1953	10.8	45.0	20.7	32.2	56.0
1954	11.5	44.9	31.8	31.5	46.6
1955	22.0	53.7	22.3	37.2	36.9
1956	11.5	24.8	None	23.3	61.8
1957	22.9	50.1	34.0	34.4	36.2
1958	22.2	46.7	18.2	24.3	31.8
1959	9.3	26.1	12.2	15.0	35.4
1960	29.8	51.1	32.6	47.4	54.2
1961	16.0	52.0	28.0	26.7	55.1
20 yr. avg.	18.6	48.9	26.8	33.4	45.7

Figure 4. Comparison of continuous rye, fertilized and unfertilized. This crop has been grown annually on the same land since 1942 (tables 17-18).

Table 18. Effect of Fertilizer on Yields of Continuous Crops. Agronomy Farm, Brookings, South Dakota

	Yield in Bushels Per Acre									
	Cont. Wheat*		Cont. Oats*		Cont. Rye*		Cont. Barley*		Cont. Corn**	
Year	Ferti-lized	Unfer-tilized	Ferti-lized	Unfer-tilized	Ferti-lized	Unfer-tilized	Ferti-lized	Unfer-tilized	Ferti-lized	Unfer-tilized
1959	6.4	9.3	22.3	26.1	17.1	12.2	15.4	15.0	49.6	35.4
1960	30.1	29.8	78.0	51.1	47.6	32.6	55.7	47.4	62.7	54.2
1961	20.6	16.0	70.8	52.0	38.8	28.0	48.6	26.7	70.6	55.1
Avg.	19.0	18.4	57.0	43.1	34.5	24.3	39.9	29.7	61.0	48.2

*40 lbs. of N and 40 lbs. of P_2O_5 per acre for wheat, oats, rye, and barley.
**60 lbs. of N and 40 lbs. of P_2O_5 per acre for corn.

Table 19. Effect of Cropping on Depletion of Soil Nitrogen in the Surface Soil from 1941-1958. Agronomy Farm, Brookings, South Dakota

Treatment *	Pounds of Nitrogen Per Acre in Surface Soil 1941	1958	Loss of N in lbs./acre	% of loss 1941-1958
Continuous Corn	4780	3660	1120	23.4
Continuous Sorghum	4720	3460	1260	26.6
Continuous Rye	4920	4580	340	6.9
Continuous Oats	4800	4020	780	16.2
Continuous Barley	4820	4080	740	15.3
Continuous Wheat	4700	3720	980	20.8
Corn-oats-wheat rotation crop residues returned	4780	4040	740	15.4
Corn-oats-wheat rotation crop residues not ret'd	4820	3760	1060	21.9

*The harvested straw was not returned to the continuous small grain plots. The sorghum crop was harvested for forage. The corn stover was not removed from the continuous corn plots. No nitrogen fertilizer or manure was applied to any of the plots.

Table 20. Effect of Cropping on the Available Phosphorus Content of the Surface Soil from 1941-1958. Agronomy Farm, Brookings, South Dakota

Treatment	Available Phosphorus in lbs./acre in Surface Soil 1941	1958
Continuous Corn	107	33
Continuous Sorghum	122	28
Continuous Rye	100	19
Continuous Oats	117	32
Continuous Barley	110	32
Continuous Wheat	97	27
Corn-oat-wheat rotation	115	55
Corn-wheat-clover rotation	125	43
Corn-wheat-clover + 20 lbs. P_2O_5/acre/year	120	102
Corn-oat-wheat + 20 lbs. P_2O_5/acre/year	110	135

Table 21. Precipitation Record for Brookings, South Dakota, 1942-1961

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Inches
	Inches of Precipitation												
1942	.02	.10	2.36	1.69	7.78	4.88	3.02	.78	2.96	.42	.14	.17	24.32
1943	.76	.61	1.07	.57	1.99	6.02	3.70	6.10	1.43	3.15	.89	T	26.29
1944	1.05	.72	.66	2.04	6.46	4.34	3.32	6.81	1.36	.40	1.47	.02	28.65
1945	.34	.89	.81	1.48	3.19	5.64	2.49	2.06	2.21	.45	.75	1.31	21.62
1946	.08	.62	2.32	.81	2.22	7.09	2.13	.52	7.30	4.53	.97	.25	28.84
1947	.40	.15	.86	3.39	1.22	4.80	.73	1.12	3.27	1.72	2.40	.33	20.39
1948	.01	1.16	.21	1.79	2.06	4.72	3.43	2.43	.63	1.55	.56	.02	18.57
1949	.51	T	1.43	.41	2.28	2.82	2.04	1.07	2.90	1.69	1.02	.71	16.88
1950	.28	.12	1.47	1.63	4.99	1.42	3.13	.98	--	2.71	.46	.31	--
1951	.25	.59	1.79	1.46	3.35	4.96	2.27	8.29	1.68	1.31	.28	1.37	27.60
1952	1.44	.62	.62	1.37	1.91	4.46	2.21	3.25	.94	0.00	.07	.16	17.05 E
1953	.46	1.40	1.14	3.51	3.58	6.40	3.24	3.85	.28	.79	1.16	.93	26.74
1954	.06	.60	1.63	1.21	2.66	3.28	.57	2.08	3.35	1.51	.10	.15	17.20
1955	.16	.53	.14	2.88	.95	3.02	1.33	4.47	.79	.14	.18	.79	15.38
1956	.27	.17	.70	1.22	2.74	4.06	6.03	3.77	.40	1.21	.72	.19	21.48
1957	.06	.38	.35	1.11	4.52	4.00	.97	1.90	1.35	1.21	1.07	.47	17.39
1958	.05	.60	.27	1.99	.10	3.45	3.01	.87	1.91	.13	.97	.10	13.45
1959	.23	.36	T	.32	6.81	2.43	1.60	3.06	2.10	2.59	.60	.62	20.72
1960	.32	.04	.87	3.00	3.26	4.73	1.49	6.98	2.64	.55	.88	1.22	25.98
1961	.12	.23	.54	.97	6.00	4.64	2.03	5.52	2.02	1.63	.20	.18	24.08

E - amount is wholly or partially estimated.
-- means no record.
T - precipitation less than .01 inches.