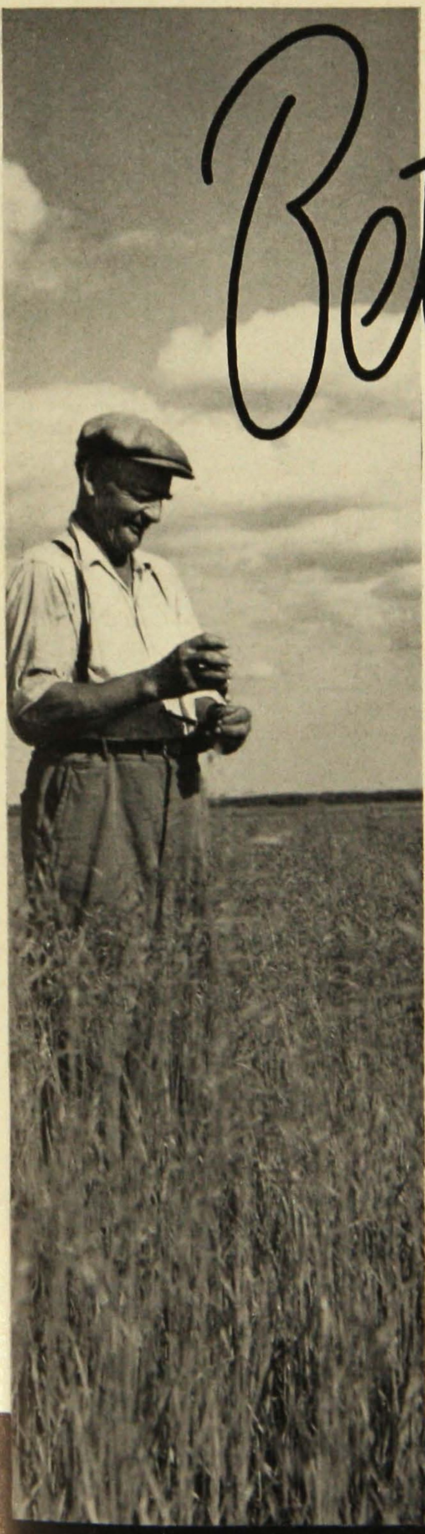
Extension Bulletin 256
April 1948



Better Soils

FOR BETTER LIVING

A REPORT OF THE MINNESOTA PHOSPHATE TEST-DEMONSTRATION PROGRAM

PAUL M. BURSON
•
R. S. HARRIS
•
C. O. ROST

UNIVERSITY OF MINNESOTA
Agricultural Extension Service
U. S. DEPARTMENT OF AGRICULTURE

A Program for Your Farm

The Minnesota phosphate test-demonstration described in this bulletin has shown that there are certain principles of soil fertility that can be applied on every Minnesota farm. Following these steps will point the way to better farming on your farm.

1. Determine proper landuse program based on soil type, slope, erosion, and crop production.
2. Retire all land not suitable for cultivation into permanent hay, pasture, or timber.
3. Establish and maintain on all tillable land a good crop rotation adapted to the soil type conditions.
4. Plan a pasture IMPROVEMENT program based on the use of phosphate and other needed fertilizers when starting a new pasture; on renovation and reseeding of old permanent pastures; and on use of rotation and supplementary pastures.
5. Establish a good pasture MANAGEMENT program.
6. On soils in the lime-deficient area in Minnesota apply lime according to soil test the season before planting the legume.
7. "Fertilize the crop rotation" by applying phosphate fertilizer or any mixed fertilizer on the small-grain crop seeded with a legume or a legume-grass mixture.
8. Apply PHOSPHATE FERTILIZER on the basis of at least 20 pounds of available P_2O_5 (100 pounds of 0-20-0 superphosphate or 50 pounds of 0-47-0) per acre for each year the legume or legume-grass mixture remains on the land, including the year seeded.
9. If the grain and/or legume crop remains on the land for only one year, apply at least 200 pounds of 0-20-0 or 100 pounds of 0-47-0 per acre.
10. Where POTASH is necessary, use a mixed fertilizer containing phosphate and potash (such as 0-20-10 or 0-20-20) at the rate recommended in 8.
11. Work fertilizer thoroughly into soil when preparing seedbed.
12. Supply the need for more nitrogen by plowing under the supply of organic matter from a good rotation. Inoculate all legumes. Return all crop residues to the soil and use better care in handling barnyard manures.
13. Seed legumes or legume-grass mixtures adaptable to your area and soil conditions.
14. Keep a farm record book so the farm organization can be studied to determine where improved farm-management practices and adjustments can be made.

Better Soils for Better Living

Paul M. Burson, R. S. Harris, and C. O. Rost

THE FERTILITY of the soil largely determines what and how much a farmer can produce as well as the market that can be established and maintained. High acre yields are necessary for profitable production of farm crops and of feed crops and pastures for livestock. Since most of the land suitable for cultivation is now being farmed, increases in the production of feed crops must, for the most part, come through increased yields.

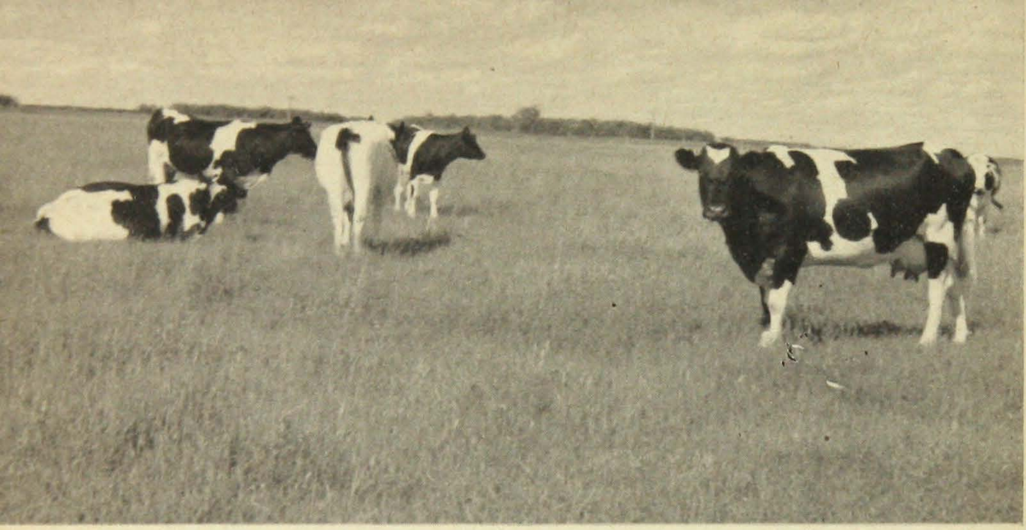
No type of farming, no matter how good, will maintain the fertility of the soil unless the principles of a sound soil-fertility and conservation program are applied. Such a program includes drainage, land clearing and cultivation, the application of limestone where needed, the use of good crop rotations, the maintenance of soil organic matter, the application of commercial fertilizer, especially phosphates, and the use of adaptable erosion control practices.

When corn and grain crops are sold, the farm loses three fourths of the phosphorus removed from the soil in the crops. The other one fourth remains in the crop residues. When crops are fed to livestock and sold as livestock products, the farm loses one fourth of the phosphorus contained in the crops fed. The other three fourths is recovered in the manure. Unless manure is handled and preserved carefully, even more phosphorus and other nutrients will be lost.

Phosphorus is often called the "Master Key" to agriculture. Low crop production is more often due to lack of phosphorus than of any other element. Phosphorus is found in every living cell and is essential to both plant and animal nutrition. In plants it is found in largest concentration in the seeds. In animals it makes up, along with calcium, the important element in the bones or skeleton.

Adequate amounts of available phosphorus in soils stimulate rapid plant

A well-planned cropping system is essential to good soil management.



Proper soil management meant better pastures for cooperators.

growth and development, hasten maturity, and improve the quality of crops. On the other hand, low availability of phosphorus in the soil means not only delayed maturity and poor plant growth but also a low phosphorus content of the plant. Thus animals fed on plants grown where little phosphorus is available in the soil grow poorly and develop deficiency diseases correctable only by supplying more phosphorus in the ration. However, in the long run the solution to the problem rests with the application of phosphate fertilizer to the soil.

A farm-sized phosphate test-demonstration program was started in Minnesota in 1940 and is to continue through 1949. The project is cooperative between the Tennessee Valley Authority and the Minnesota Agricultural Extension Service, and is known as the "Minnesota Phosphate Test-Demonstration Program." The Minnesota Agricultural Extension Service furnishes the supervision and recommends approved practices and methods; the Tennessee Valley Authority furnishes the high-analysis phosphate fertilizers for demonstration, together with certain funds that are matched by the State Extension Service for the employment of needed personnel.

The objectives of the phosphate test-demonstration program are to test the effect, value, and best methods of use of high-analysis phosphates. Minnesota is conducting phosphate tests on typical farms, under a program based on sound soil-fertility and soil-management practices. The test-demonstrations are designed to determine:

1. **The place of phosphate fertilizer in a balanced soil-fertility and conservation program.**
2. **The importance of phosphate fertilizers on legume stands and yields.**
3. **The residual effect of the phosphate applied on the small grain and legume crops at the time of seeding and on corn, small grains, and other crops which follow.**
4. **The place of phosphate fertilizer in pasture improvement.**
5. **The extent and importance of increased phosphorus content of hay and pasture crops.**
6. **The extent to which phosphorus deficiency in the livestock ration can be corrected through the use of high-analysis phosphate fertilizer on hay and pasture crops.**
7. **The net cash income and economic effect on the farm business when liberal use is made of high-analysis phosphate fertilizers.**

Farmers throughout Minnesota find application of phosphate profitable.

How the Minnesota Plan Works

THE MINNESOTA phosphate program was started in 1940 in 17 western Minnesota counties where the phosphate deficiency was known to be most acute. Becker, Murray, and Swift counties were added in 1942 and Steele County in 1945. The counties were selected by a committee of University staff members and were approved by the Tennessee Valley Authority.

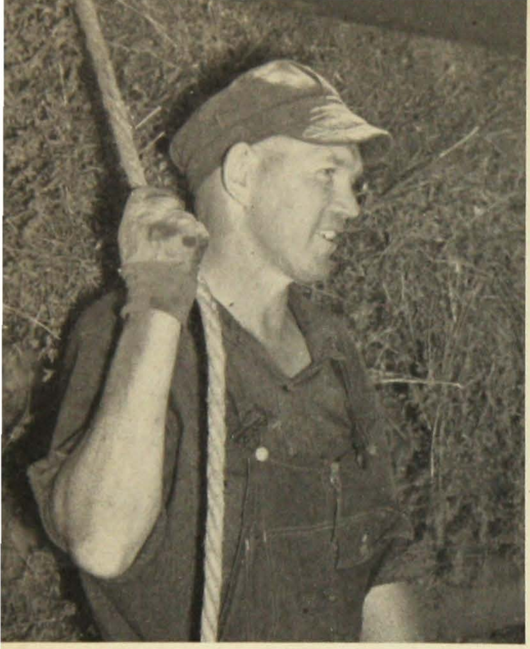
The program was set up on a five-year basis to include the entire farm. In 1944 the Tennessee Valley Authority and the Minnesota Agricultural Extension Service agreed to extend the project another five years completing a 10-year study in 1949. This report covers 1941 through 1945. An average of 173 farms participated during this time.

The County Plan

In each of the counties selected, the Extension Program-Planning Committee appointed a County Phosphate Test-Demonstration Committee. This committee, with the assistance of the county agricultural agent, organized and set up the demonstration program in the county. Meetings were held with farmers in different townships to determine if they were interested in having a phosphate test-demonstration farm in the township. If so, three men were selected to serve as a community phosphate test-demonstration committee. The chairman of the committee served as a member of the County Phosphate Test-Demonstration Association. The Community Committee then selected a suitable demonstration farm which was typical as to soil type conditions, size of farm, and type of farming for the area and arranged to carry on the five-year "farm-sized" test-demonstration program as a community service.

The Farm Plan

A five-year program of landuse for the entire farm was worked out with each demonstrator. The "farm-sized" demonstration plan included a farm map, a five-year land-use and crop-rotation program, a five-year phosphate-treatment program, and a five-year pasture-improvement program.



Philip Bredberg, Martin County, says, "Phosphate improves the stand of my legumes."

Nearly all the farmers in the program report phosphate fertilizer improved legume and legume-grass stands.

Each test-demonstrator agreed to apply the phosphate fertilizer furnished by the Tennessee Valley Authority for the cost of freight; to leave 20 per cent of each field untreated for comparison purposes; to permit the county agricultural agent, farmers, and others to visit his farm to observe and study results. He also agreed to pay an annual service fee of $10 to cover the cost of determining yields, keeping records, and making summaries and reports for the farm, and to keep a farm business record in an account book.

Each cooperator was furnished an analysis of each year's business operations, including a financial report, net worth and capital change, and a study of the farm organization and its management efficiency factors.

How Phosphate Was Used

The high-analysis phosphate fertilizer furnished by the Tennessee Valley Authority was calcium metaphosphate (0-63-0), containing 63 pounds of available phosphate (P_2O_5) per 100 pounds of material. From the beginning of the test-demonstration program in 1940 through 1946, 1,849 tons of high-analysis phosphate have been applied on 3,124 fields totaling 45,003 acres. The fertilizer was applied on the principle of fertilizing all crops in the different rotations.

All phosphate fertilizer for the rotation was broadcast or applied with a grain drill with fertilizer attachment on the small-grain crops at seeding time. It was worked thoroughly into the soil. The grain was seeded with a legume or a legume-grass mixture to be used later for hay or pasture. All legume seeds were inoculated before each seeding. No other fertilizer treatments were made during the rotation until it was time to seed the field down

Signs like this were posted on the farm of every cooperator taking part in the Minnesota phosphate demonstration program.

Adolph Finnern, Jackson County, says, "The large increases in my hay and pasture yields due to the phosphate program are essential to beef cattle production."

Every cooperator in the program reported that he will continue using phosphate after the program is completed.

again with a legume or a legume-grass mixture.

Twenty pounds of available phosphate (P_2O_5) was applied for each year the land remained in a legume or a legume-grass mixture. For example, a cooperator using a crop rotation including an alfalfa-brome grass mixture to remain on the land for three years, including the year seeded, applied 100 pounds per acre of calcium metaphosphate (0-63-0). This would be equivalent to 300 pounds per acre of 20 per cent superphosphate (0-20-0). If the alfalfa-brome grass mixture would remain on the land four years, 133 pounds per acre of calcium metaphosphate, or the equivalent of 400 pounds of 0-20-0, would be applied.

On each field fertilized, 80 per cent was phosphated and the rest was left untreated for the yield comparison.

Old permanent pastures that were fertilized, renovated, and legumes seeded, and newly seeded pastures remaining down longer than four years, received 166 pounds per acre of 0-63-0 which would be equivalent to 500 pounds per acre of 20 per cent superphosphate.

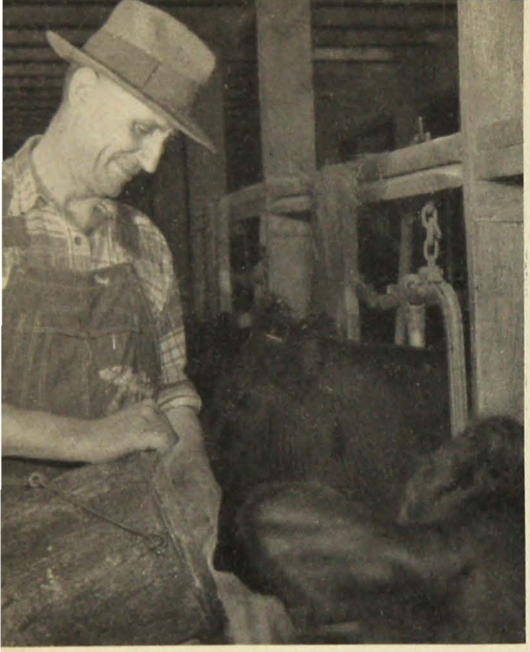
This method is known as "fertilizing the crop rotation."

How Yields Were Determined

All crop yields were determined by harvesting representative samples from each field on each of the untreated and phosphated areas each year. From 1940 through 1946, 9,816 samples were harvested from 4,698 fields to determine the differences in crop yields for all crops between the phosphated and untreated areas.

Six samples, one yard square, were harvested on each of the untreated and phosphated areas of small grains, flax and legume, and legume-grass mixtures

Willard Hanson, Mahnomen County, takes a sample of hay from a field treated with phosphate under the demonstration program.



H. I. Finstad, Pennington County, says, "Since I've been following the phosphate program my farm has been able to carry more livestock."

All farmers declared that they can now carry more livestock on their farms.

used for hay. On checked corn, following the legume or legume-grass mixtures in the rotation, five hills in five representative areas were harvested on the untreated and on the phosphated parts of the field. However, in the case of drilled corn 100-foot lengths were harvested on five representative areas on each treatment. Moisture samples of corn were taken to determine the effect of phosphate on maturity. Yields were calculated on the basis of 14.0 per cent moisture. All small grain and flax samples were sent to the Division of Soils, University Farm, where they were threshed and yields per acre calculated.

Hay yields were determined on the basis of air-dry hay comparable to typical farm conditions at the time the hay is normally put into the barn or stack.

Table 1. Use of Phosphate Fertilizer on Test-Demonstration Farms, 1940-1946

	1940	1941	1942	1943	1944	1945	1946	Total
Number of demonstration farms by years	210	205	192	178	166	125	124	....
Tons of phosphate applied	503	314	310	178	174	175	195	1,849
Use of phosphate fertilizer								
Number of fields treated	877	524	487	292	295	309	340	3,124
Number of acres treated	10,357	9,120	8,326	3,734	4,092	4,474	4,900	45,003
Number of fields sampled	603	600	828	846	734	483	604	4,698
Number of samples harvested	1,146	1,252	1,686	1,692	1,490	1,060	1,490	9,816

Gunder Christofferson, Mahnomen County, says, "Keeping farm business records as a result of the phosphate program has made me a better farmer."

After five years of record keeping, every cooperator indicated that he would continue to keep records even though not required.

Fertilizing Rotation Increases Yields

APPLICATION of phosphate fertilizer gave increases in yield of all crops in the rotation, and residual effects were incident for at least three or four years after the application of the fertilizer.

In this study the five-year average annual yield increases on small grains were highest on oats with an increase of 6.4 bushels per acre (table 2). Barley was increased 4.7 bushels per acre, wheat 2.6 bushels, and flax 1.3 bushels. These yield increases show the direct effect of the phosphate fertilizer treatments when made at the time the small grains and flax were planted with the legume or legume-grass seedings.

CROPS AFFECTED DIFFERENTLY

Legume and Hay Yields Increased

While the land remained in a legume or a legume-grass mixture, the phosphate fertilizer treatments increased the yield of alfalfa hay .83 ton per acre, alfalfa-brome grass mixture .98 ton per acre, and red clover .56 ton per acre. The phosphated alfalfa-brome grass mixture outyielded the phosphated alfalfa by .15 ton per acre, giving a total increase of .98 ton.

Corn Benefits

In the third or fourth year after the phosphate had been applied, depending on how long the legume or legume-grass mixture remained on the land, the fields were plowed and planted to corn. The corn on the phosphated areas averaged 6.5 bushels per acre over that on the untreated areas.

The principle of fertilizing the crop rotation is based on two facts. First, some of the phosphate still remains available in the soil to benefit the succeeding crops such as corn. Second, a good crop of a legume or a legume-grass mixture, plowed under, adds additional organic matter and available nitrogen.

W. B. Breckendorf, Martin County, says, "The phosphate program increased crop yields on my farm."

All cooperators reported that the program had increased yields on all crops in their rotations.

This is shown by the increases of 6.5 bushels of corn per acre three or four years after the application of the phosphate fertilizer. Therefore, one application of phosphate fertilizes all four types of crops (small grains, flax, legumes or legume-grass mixtures, and corn) in the rotation besides providing a higher level of organic matter and available nitrogen in the soil.

Straw Yields Better

Straw yields on all farms have been determined since 1943. Phosphate fertilizer gave an increase in the yield of straw for all small-grain and flax crops. The greatest average annual increases in yield of straw were with barley and oats while the least increase was with wheat. Phosphate fertilizer increased the yield of barley straw from .10 ton in 1943 to .18 ton in 1944. Oats straw was increased to .14 ton in 1944. The increase in flax straw ranged from .09 ton in 1944 to .13 ton in 1945, while wheat straw ranged from .05 ton in 1944 to .16 ton in 1943. (The complete summary of average straw-yield increase by counties is in table IV, appendix).

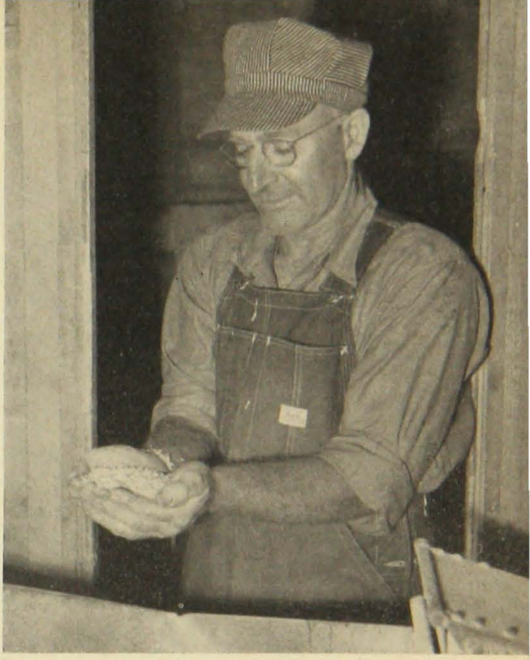
Bushel Weight Increased

The use of phosphate fertilizer, in addition to increasing yields of grains, hay, and straw, also increased the bushel weight of grain. The greatest average difference in weight per bushel in favor of phosphate was on barley, with an increase ranging from .3 pound in 1943 to 1.9 pounds in 1945. The increase for wheat ranged from .2 pound in 1944 to 1.1 pounds in 1943, while with oats the range was from .1 pound in 1942 to 1.0 pound in 1944. (The sum-

Miss Freida Hammers, technician in the University of Minnesota Soils laboratory, analyzes the phosphorus content of a hay sample.

Ed Kahlbaugh, Mahnomen County, says, "The phosphate program is the foundation of the future success of this country's agriculture."

Every cooperator plans to continue using phosphate. As the main reason, 52 per cent gave improved crop yields; 31 per cent, improved crop quality; 12 per cent, improved soil fertility; and 12 per cent, improved livestock health.



mary of increases in weight per bushel resulting from the use of phosphate fertilizer is given in table IV, appendix.)

INCREASE VARIES WITH SOILS

To determine the response of phosphate fertilizer on different soil types, the demonstration farms were grouped according to the major soil associations. These soil association groups include the Clarion-Webster, Barnes-Parnell, Fargo-Bearden, Taylor-McDougald, Ulen-Sioux, Wadena-Hubbard, and Kittson-Peat associations. Table I, appendix, gives a brief description of each soil association, the demonstration counties in each, and the five-year (1941-1945) average annual increases in crop yields from the use of phosphate fertilizer.

Small Grains and Flax

Increases from phosphate applied on oats ranged from 2.7 bushels per acre on the Fargo-Bearden soils to 13.8 bush-

Table 2. Five-Year Average Increase in Yields by Crops as Result of Phosphate Applications, 1941-1945*

Crop	No. of cuttings or fields sampled	Increases in yield per acre
Oats	517 fields	6.4 bu.
Barley	145 fields	4.7 bu.
Wheat	187 fields	2.6 bu.
Flax	125 fields	1.3 bu.
Red clover	18 cuttings	.56 ton
Alfalfa hay	610 cuttings	.83 ton†
Alfalfa-brome grass	64 cuttings	.98 ton†
Corn	298 fields	6.5 bu.

* The yields for 1940 are not included in the summary because all phosphate was applied late in the spring after planting, as a top-dressing, and was not thoroughly worked into the soil at the time of seeding.

† Hay yields were determined on the basis of first and second cuttings.

Edward M. Johnson, Marshall County, says, "A legume should always follow a small grain crop which has been phosphated and then turned under to benefit the cultivated crops."

Nearly every cooperator reported that results on his farm show that a crop rotation with a legume or a legume-grass mixture following small grains should always be used.

els per acre on the more sandy Wadena-Hubbard soils. Barley was increased from 1.9 bushels per acre on the Taylor-McDougald to 8.3 bushels per acre on the more sandy Wadena-Hubbard soils. The yield increases for wheat ranged from 1.5 bushels per acre on the Clarion-Webster association to 4.0 bushels per acre on the less productive Taylor-McDougald soils.

In the case of the yields of flax crops the increases ranged from .3 bushel per acre on the Kittson-Peat soil to 2.1 bushels per acre on the more productive prairie soils of the Barnes-Parnell association. These differences are apparently due to the better balance between the higher availability of nitrogen with the phosphate.

Alfalfa

Alfalfa hay was increased in yield from .65 ton per acre on the Ulen-Sioux to 1.35 tons per acre on the Fargo-Bearden soils. The alfalfa-brome grass mixture was increased in yield from .65 ton per acre on the Kittson-Peat soil to 1.30 tons per acre on the Clarion-Webster soil association.

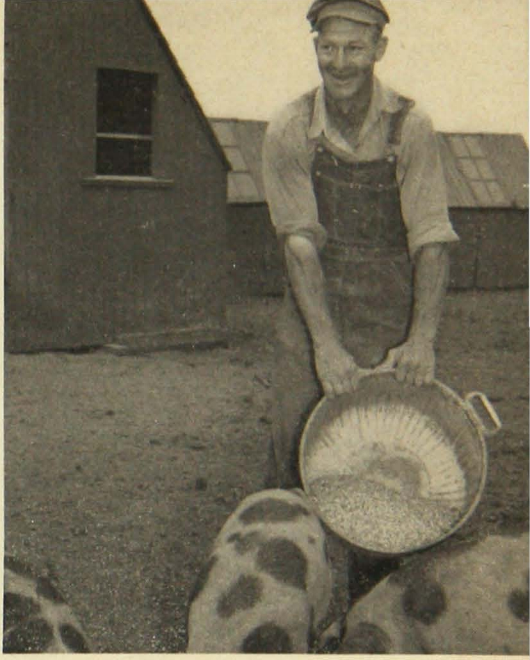
Table 3. Crop Yield Increases by Years as Result of Phosphate Application

Crop	1940	1941	1942	1943	1944	1945	1946
Barley, bu.	4.2	2.8	5.3	3.1	4.9	5.0	5.6
Oats, bu.	2.9	3.9	6.3	6.4	6.4	7.7	3.0
Wheat, bu.	1.7	2.4	3.3	3.2	2.1	3.3	3.0
Flax, bu.	.2	.8	.8	1.2	2.0	2.5	.9*
Alfalfa, tons	.23	.77	1.02	1.22	1.04	1.20	.88
Alfalfa-brome grass, tons	....	....	....	....	....	1.79	.79
Red clover, tons	....	.09	.60	.48	.73	1.54	.92
Sweet clover, tons	....	.26	.60	.79	.84	.39	.41
Corn, bu.	....	....	6.6	6.9	6.8	4.12	6.28

* Many fields injured by freeze in late spring.

E. R. Palleson, Nobles County, says, "Earlier corn maturity is very important to a hog raiser and phosphate does hasten corn maturity."

Four out of five cooperators found that small grains, flax, legume and legume-grass hays, and corn were hastened in maturity by use of phosphate.

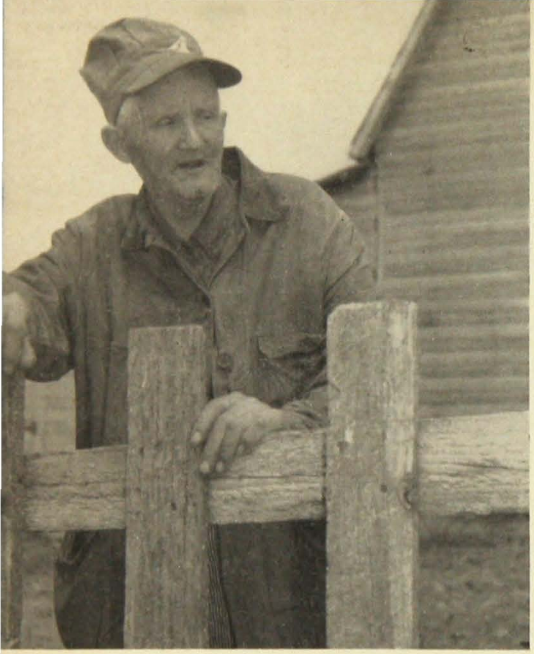


Corn

When the legume crops were plowed under and the fields were planted to corn to complete the rotation cycle, the increases in yield of corn per acre ranged from 4.9 bushels per acre on the Kittson-Peat soils to a high of 16.0 bushels per acre on the Taylor-McDougald soils, where the level of organic matter and available nitrogen originally was not high. For this reason the greatest increases in yield of corn were obtained on the Taylor-McDougald, Ulen-Sioux, and the Wadena-Hubbard associations. These three soil associations are generally lower in soil organic matter and available nitrogen than are the soils of other associations. Therefore, when additional amounts of organic matter were added to the soil in the form of a legume or a legume-grass mixture, resulting in greater amounts of available nitrogen, plus the residual effects of the phosphate fertilizer, the increase in yield of corn was greater than on the other soil associations where the level of soil organic matter and available nitrogen was originally much higher.

All Crops Benefit

These results show that on the major soil-type associations applications of phosphate fertilizer will give a response on all crops in the rotation, and the residual effects can be expected to show three or four years after application. Only when crops have a liberal supply of organic matter and available nitrogen can phosphate or any other commercial fertilizer give its maximum benefits. This is based on the fact that legumes and legume-grass mixtures readily respond to phosphate treatments, thus increasing the stand and growth of the legumes; this in turn adds more organic matter to the soil, resulting in a better balance of available nitrogen and phosphate for the succeeding crop.



Claus Hagge, Red Lake County, says, "I can't afford to quit using phosphate."

All the cooperators would continue to use phosphate even if the program were discontinued.

Good Crop Rotations Established

GOOD crop rotations were established and maintained on the phosphate test-demonstration farms. A good crop rotation is essential to any sound soil-fertility and conservation program. It is the basis of good land use and of maintaining the organic matter and available nitrogen content of the soil which provides for the most efficient returns from the use of any commercial fertilizer such as phosphate.

Legume Acreage Increased

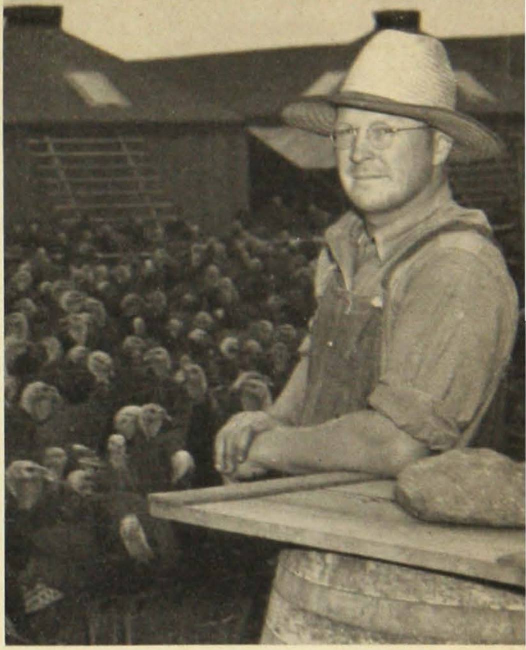
That good crop rotations provided a better balance between the residual phosphate, the soil organic matter, and the available nitrogen is shown by comparing the percentage of legumes or legume-grass mixtures in the cropping systems on the demonstration farms before the program was started in 1940 and after the program was well established.

In 1939 the demonstration farms averaged 33 per cent of all the tillable land on the farms in a legume or legume-grass mixture. This may appear high, but the legumes were not generally used in a regular crop-rotation system. Certain fields were seeded down to alfalfa, mixtures of brome grass and alfalfa, and other legume-grass mixtures and left as long as possible. The remainder of the tillable land was heavily cropped to corn, soybeans, flax, and small grains. However, after the program was established all tillable acres were rotated with legumes or a legume-grass mixture.

During the first year of the program (1940) the acreage of legumes or legume-grass mixtures was increased to 47 per cent. In 1941 the acreage increased to 53 per cent, and since then it has remained relatively constant. These figures indicate that legumes or legume-grass mixtures are now being used on about 18 per cent more of the tillable acres and are being used in rotation over all the tillable acres instead of a limited portion as before.

J. L. McKeever, Nobles County, says, "Turkeys profit from high-producing alfalfa pasture which the phosphating program gives me."

Farmers who now have a larger hay acreage carry more livestock on their farms. They use a part of the additional acreage to supplement their regular pastures during the summer.



Variations with Area

On the farms which lie northward from Becker County to the Canadian border an average of 40 per cent of the cropland was in legumes or legume-grass mixtures in 1939. After the program was established this was raised to 60 per cent, where it has since remained. On the farms which lie south from Stevens County to the Iowa line, cropland in a legume or legume-grass mixture increased from 26 per cent to 43 per cent, where it stands now.

Farms in northwestern Minnesota grow about 15 per cent more legume or legume-grass mixtures in the rotation than the farms in southwestern Minnesota, because sweet clover is seeded to a considerable extent in all small grains and is plowed under the following year as a green-manure crop. The percentage of alfalfa ran higher on farms in the southwestern than in the northwestern part of the state. The percentage of legume and legume-grass mixtures by counties is given in table 4.

Good Rotations Possible

The fact that the percentages of legumes or legume-grass mixtures have increased and are now consistent from year to year in the rotation shows that farmers can establish and maintain good crop rotations. The maintenance of good crop rotations on the demonstration farms is now showing a trend of more uniformity in crop yields and less year-to-year and field-to-field variations or variations between different soil conditions in the individual fields (table 3). This trend toward more uniformity in yields is due to the regular and continued supply of high-quality

Using a good crop rotation with legumes improves soil fertility. Plowing under legumes adds organic matter and nitrogen.

Table 4. Per Cent of Legumes and Legume-Grass Mixtures* Grown in Crop Rotations on Tillable Land

County	Per cent of legumes by years					
	1939	1940	1941	1942	1943	1944
Southwest Demonstration Farms						
Brown	22	38	50	50	47	51
Jackson	22	31	32	30	30	31
Kandiyohi	24	43	55	70	56	53
Martin	24	40	48	42	48	45
Nobles	40	47	39	48	52	41
Stevens	28	37	33	34	37	48
Watonwan	29	39	43	43	45	43
Yellow Medicine	15	33	41	41	32	45
Average	26	39	42	44	45	43
Northwest Demonstration Farms						
Kittson	45	56	67	44	44	49
Mahnomen	26	37	54	59	60	63
Marshall	44	64	71	77	75	80
Norman	34	47	55	51	44	37
Pennington	40	58	60	60	62	66
East Polk	43	56	59	73	61	70
West Polk	22	44	50	37	37	51
Red Lake	28	57	63	66	67	75
Roseau	54	75	86	76	62	59
Average	40	57	64	61	57	60
Average All Demonstration Farms	33	47	53	52	50	52

* Does not include soybeans and peas. Includes all tillable land seeded to legumes or legume-grass mixtures used for hay, pasture, or plowed under as a green manure crop.

organic matter and available nitrogen resulting from fertilizing the rotation.

In addition to reducing yield fluctuations, the use of a good crop rotation is the basic principle of reducing and preventing soil erosion on tillable land. The return of soil organic matter through the use of good crop rotation not only maintains and improves soil fertility but also improves soil structure, increases infiltration, conserves soil moisture, and reduces wind and water erosion to a minimum. The insurance of more uniformity in crop yields by providing for a better fertility balance in the soil and the reduction of soil erosion means greater stability of other enterprises on the farm.

Charles E. McCarthy, Watonwan County, says, "The phosphated hay goes one-third further and my stock appears to be in better condition."

About three-fourths of the cooperators noticed depraved appetites in their cattle (chewing wood, bones, etc.) but found that it disappeared after five years of the phosphate program.

Quality of Hay Improved

AN UNDERSTANDING of the chemical composition and the nutrients produced in hay and grain crops is important to all farmers, especially livestock feeders. This has long been recognized. The connection between the chemical composition and soil-fertility levels and the soil-management practices applied has been recognized more recently.

All feed crops do not have the same chemical composition or nutrient production nor does any one feed have the same composition under various growing conditions. In fact, the composition of plants as well as yields per acre varies with the soil type, the fertility of the soil, species, stage of growth, and seasonal conditions.

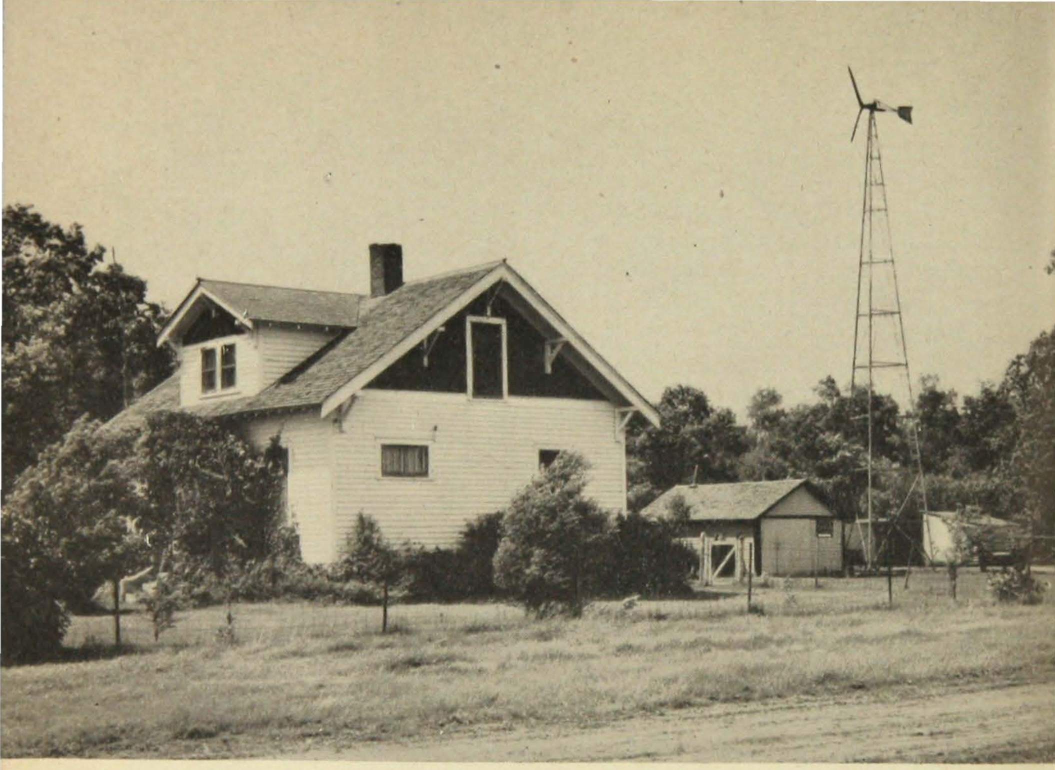
The data presented showing the phosphorus and protein increases in alfalfa hay on the five different soil associations give a clearer understanding of the application of good soil-fertility and management practices and the success in growing and feeding livestock.

BETTER ALFALFA HAY

From 1942 through 1945, samples of alfalfa hay were collected from each cutting in 69 representative fields in five different soil associations and were analyzed for protein, phosphorus, and calcium content. Year-by-year results are given in table II, appendix.

Protein Content

Fertilization with high-analysis phosphate definitely tended to increase the protein content of alfalfa hay. While the increase in some years was not marked or general on all soil associations, in the majority of cases the fertilized hay carried slightly higher percentages of protein. For example, there was no increase in protein on the four fields on the Barnes-Parnell soil association in 1942. Yet the four-year average for phosphate-treated land on that association showed an increase of 1.42 per cent of protein over the untreated



Improved soils make for better living on the farm. This is one of

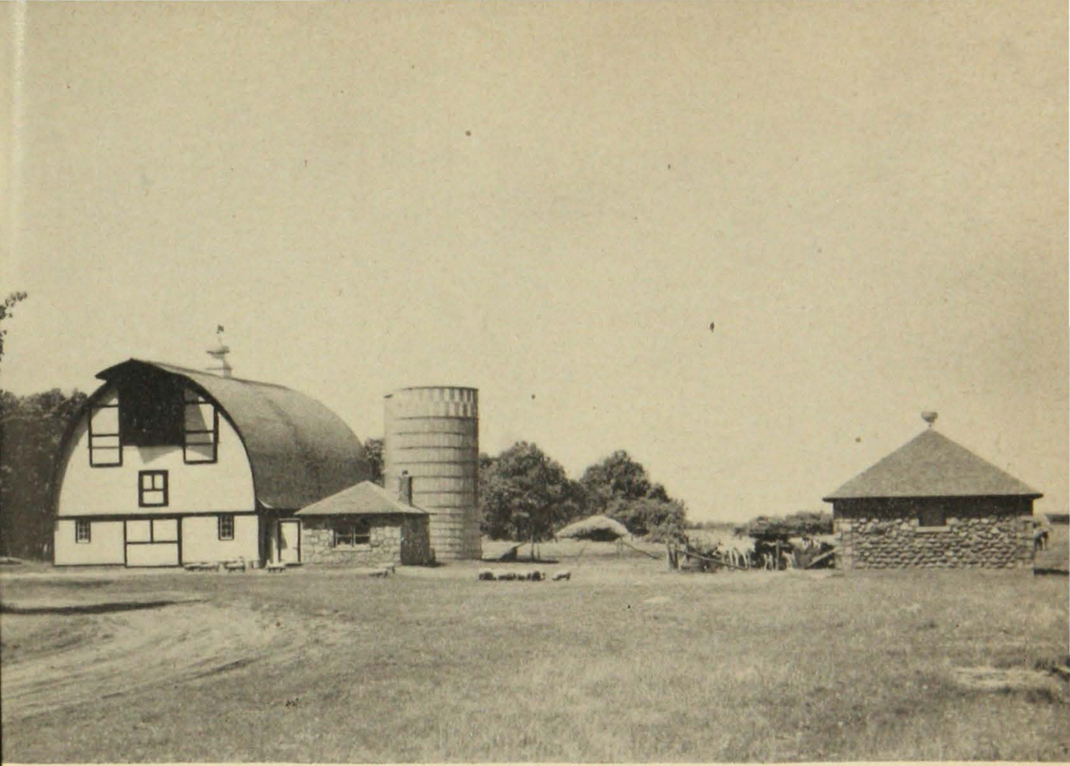
land. There was some increase in each association in protein due to phosphate fertilization, and the average increase for the 69 fields analyzed in the state was .75 per cent.

While the increase in percentage of protein is not large, it is of considerable importance when considered in connection with the increase in yield obtained on the fertilized land. For the fields analyzed the average yields were 2.13 tons and 3.14 tons per acre for the untreated and phosphated land, respectively. A calculation of the protein yield shows that an acre of untreated land averaged 828 pounds and a phosphated acre averaged 1,268 pounds of protein. If there had been no increase in the percentage of protein, a yield of 3.14 tons would have contained 1,221 pounds of protein, or 47 pounds less than the 1,268 pounds which it actually contained. Thus besides giving an increase in yield, the phosphate gave an additional 47 pounds per acre of protein through an increase in the percentage which the crop contained.

Phosphorus Content

Since the use of phosphate fertilizer very definitely increased the yield it might be expected that it would also increase the percentage of phosphorus in the hay. While this is not always the case, it was in most of the hays analyzed. The amount found in the phosphated alfalfa was on the average slightly more than 20 per cent higher than alfalfa grown on the unphosphated land.

The phosphorus content of the unfertilized alfalfa on the different soil associations was fairly uniform except for the Fargo-Bearden association. For the other associations it varied, on the average, between 0.24 and 0.26 per cent. On the Fargo-Bearden soils the average dropped to 0.18 per cent, which would indicate a low feeding value.



farmsteads on farms taking part in the phosphate fertilizer program.

After fertilization with phosphate the phosphorus content rose in all except two cases—two fields on Barnes-Parnell in 1944 showed no increase and one field on the Kittson soils in 1944 showed a slightly lower amount of phosphorus.

The higher percentage of phosphorus in forages and pasture crops is extremely important. It improves livestock health, it increases the feeding value of the hay or pasture crop, it increases the palatability of the feed as shown by preference of the cattle for phosphated hay and pasture, and it reduces or eliminates the need for mineral supplements. Furthermore, when such crops are fed to livestock it increases the amount of phosphorus returned to the land in manure. It also has a direct bearing on the problems of organic-matter maintenance and nitrogen supply. By returning high-

Table 5. Phosphate Fertilizer Increased the Production per Acre of Protein and Phosphorus in Alfalfa Hay on Five Soil Associations

Soil association	No. of fields	Protein			Phosphorus		
		Protein lbs. per acre		Lbs. increase per acre from	Phosphorus lbs. per acre		Lbs. increase per acre from
		Ck.	P	P	Ck.	P	P
Clarion-Webster	26	1,042.6	1,566.5	523.9	12.91	22.85	9.94
Barnes-Parnell	15	725.8	1,266.7	540.9	8.69	17.11	8.42
Kittson-Peat	14	704.8	1,077.5	372.7	8.69	15.72	7.03
Ulen-Sioux	7	663.1	1,049.3	386.2	8.89	16.13	7.24
Fargo-Bearden	7	669.7	1,321.6	651.9	6.51	16.24	9.73
Weighted Average	69	828.6	1,268.6	440.0	10.22	18.20	7.98

Growing corn and other crops on the contour helps save the soil.

phosphorus manures and crop residues, better stands of legumes and increased growth of all crops are obtained. These in turn directly affect soil organic matter and available soil nitrogen.

Calcium Content

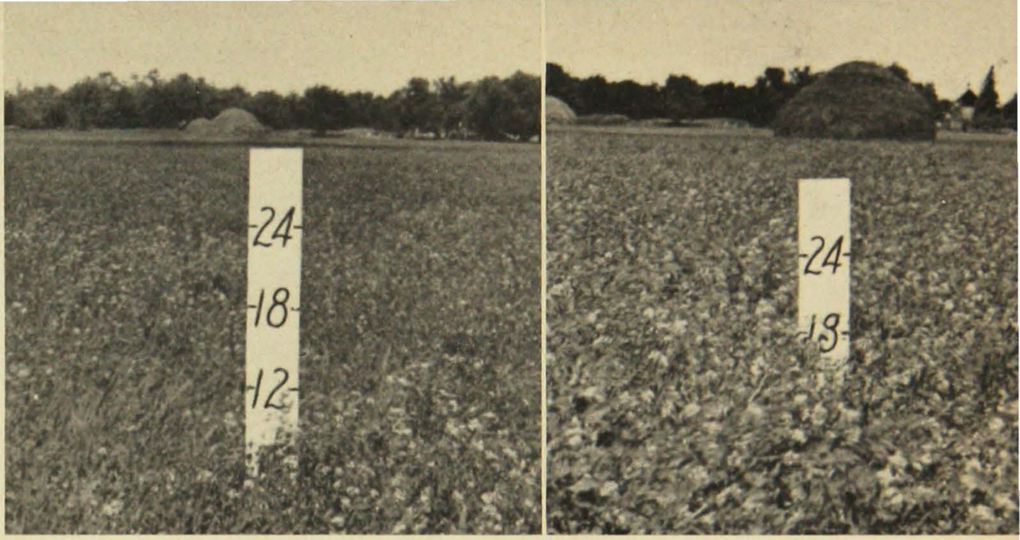
Fertilization with high-analysis phosphate did not appreciably affect the calcium content of the hay. There was no great difference in the lime content of the hay grown on untreated and phosphated land of the different soil associations. The fields upon which the alfalfa was grown are relatively well supplied with lime, so that differences in calcium content would not be expected. The average calcium content for the untreated and phosphated portions of the fields was almost exactly the same—1.63 and 1.64 per cent, respectively. Hay with a high content of calcium is to be preferred and should be actually worth more per ton than that produced on soils low or deficient in lime.

What Yield Increases Mean

On the basis of the laboratory analyses the increases in the production of protein and phosphorus in alfalfa hay from the use of phosphate were calculated. These increases by soil associations are shown in table 5. The range of the increase in protein per acre was from 372.7 pounds on the Kittson soils to 651.9 pounds on the Fargo-Bearden soil association. This increase, if calculated to 37 per cent protein feed, would be equivalent to 1,007 pounds of oil meal on the Kittson soils and 1,762 pounds of the same concentrate on the Fargo-Bearden soils. For all soil associations there was an average increase in protein of 440 pounds per acre which would be equivalent to the protein in 1,189 pounds of oil meal.

The increase in the production of phosphorus due to fertilization with high-analysis phosphate ranged from 7.03 pounds on the Kittson soils to 9.94 pounds on the Clarion-Webster soil association. This would be equivalent to 70 and 99 pounds respectively of 10 per cent bone meal. Cooperators have reported that following the initiation of the phosphate program their cattle have consumed decreasing amounts of mineral feed and in some cases have discontinued eating it.

Phosphated hay or pasture is also more palatable to livestock. This has been shown by their preference for both when given free choice. The data



Application of phosphate increases hay yields. One part of this field of alfalfa, red clover and brome was left unfertilized (left); 100 pounds of 0-63-0 per acre was applied on the other part. Both pictures were taken the same day.

for protein and phosphorus indicate that the feeding quality and the nutrients produced per acre can be improved and increased on soils that are given proper treatment and management.

Total Digestible Nutrients Increased

The six-year average (1940-1945) annual production of total digestible nutrients was computed on the main feed crops of alfalfa hay, oats, barley, wheat, and corn. The purpose was to determine the percentage increase of the total digestible nutrients produced on the phosphated areas as compared to the untreated areas of each of the seven soil associations. The total digestible nutrients of mixed hays, pasture crops, and small-grain mixtures were not determined because their composition is extremely variable. Wheat, while often a cash crop, is used to a considerable extent as a farm feed. Total digestible nutrients were calculated from certain established standards for each of the food crops.

The percentage increase in the production of total digestible nutrients per acre varied between crops and between soil associations, as shown in table 6.

Alfalfa ranged from 29.1 per cent increase of total digestible nutrients on

Table 6. Six-Year Average Total Digestible Nutrient Increase on the Phosphated Feed Crops by Soil Associations, 1940-1945

Soil association	Percentage increase of T.D.N. per acre					
	Alfalfa	Wheat	Oats	Barley	Corn	Crop average
Barnes-Parnell	37.0	16.3	10.7	11.3	19.0	18.9
Kittson-Peat	37.5	8.8	14.4	22.3	7.7	18.1
Ulen-Sioux	47.4	12.8	8.4	16.5	13.6	19.7
Clarion-Webster	31.7	11.4	12.2	10.1	6.6	14.4
Taylor-McDougald	40.0	16.4	23.7	6.9	20.0	21.4
Fargo-Bearden	56.2	16.1	6.9	17.7	9.1	21.1
Wadena-Hubbard	29.1	....	37.4	14.7	22.6	26.0
Average	39.8	13.6	16.2	14.2	14.1	19.9

the Wadena-Hubbard soils to 56.2 per cent on the Fargo-Bearden. Wheat increases ranged from 8.8 per cent on the Kittson-Peat soils to 16.4 per cent on the Taylor-McDougald. The widest spread in the percentage increase in the production of total digestible nutrients was on oats, with a range from 6.9 per cent on the Fargo-Bearden soils to 37.4 per cent on the sandier, less productive Wadena-Hubbard soils. Barley showed a similar trend, ranging from 6.9 per cent increase on the Taylor-McDougald soils to 22.3 per cent increase on the Kittson-Peat association.

Corn, which followed the legume crop in rotation, gave a five-year residual average annual increase in yield of 6.5 bushels per acre (table 2). The increase in the production of total digestible nutrients on the phosphated area for corn ranged from 6.6 per cent on the more productive Clarion-Webster soils to 22.6 per cent increase on the sandier, less productive Wadena-Hubbard soils. This again is based on the fact that legumes such as alfalfa and legume-grass mixtures readily respond to phosphate treatments, thus increasing the stand and growth of the legumes; this in turn adds more organic matter to the soil, resulting in better balance of available nitrogen and phosphate for the succeeding crop. These principles show that in soils that are well managed and that have a higher and a more uniform level of fertility there is an increase in the production of total digestible nutrients.

Effect of Phosphate in Your Area

The tables on the 12 pages that follow will give you an opportunity to check the effect of phosphating in your own area and under your own soil conditions. You can check annual crop yield increases; the effect of phosphates on the protein, phosphorus, and calcium content of alfalfa hay; and the annual increases in straw weights and weights per bushel of small grains.

Check these figures and see for yourself if phosphating will pay in your own community.

Table I. Five-Year Average Annual Yield Increases from Use of Phosphate Fertilizer by Soil Associations, 1941-1945

Soil association*	General soil characteristics	Counties	Oats, bu. per acre	Barley, bu. per acre	Wheat, bu. per acre	Flax, bu. per acre	Alfalfa, tons per acre	Alfalfa-brome, tons per acre	Red clover, tons per acre	Corn, bu. per acre
Clarion-Webster	Highly productive, dark-colored medium- and fine-textured prairie soils with lime. Level to rolling.	Brown, Jackson, Kandiyohi, Martin, Murray, Nobles, Watonwan	8.2	3.2	1.5	1.0	.85	1.30	.43	5.3
Barnes-Parnell	Dark-colored, medium- and fine-textured prairie soils high in lime. Undulating to strongly rolling.	Nobles, Mahnomen, Murray, Norman, East Polk, Stevens, Swift, Yellow Medicine	6.4	4.2	2.8	2.1	.97	.99	.69	7.2
Fargo-Bearden	Dark, heavy silt loams and clays. Nearly level. Derived from lake-laid deposits. Lime plentiful but drainage often inadequate.	Kittson, Marshall, Norman, West Polk	2.7	5.1	3.3	2.0	1.35	1.29	......	6.5
Taylor-McDougald	Gray, wooded soils. Sandy loams to clay loams. Level to undulating. Lime plentiful.	Roseau	9.0	1.9	4.0	1.0	.66	.97	......	16.0
Ulen-Sioux	Black sandy loams with loose subsoils. Level to undulating. Drouthy.	Red Lake, Kittson, Marshall, Norman, West Polk	3.5	4.0	2.7	.5	.65	.76	......	15.3
Wadena-Hubbard	Dark-colored sandy soils. Upper soil holds moisture fairly well but subsoil drouthy. Undulating to rolling. Lime variable.	Becker, Swift	13.8	8.3	......	1.8	.82	......	......	15.5
Kittson-Peat	Dark-colored. Lime plentiful. Undulating to rolling.	Becker, Kittson, Roseau, Marshall, Pennington, Red Lake, Mahnomen	5.8	6.3	1.9	.3	.79	.65	......	4.9

* *For a more complete description and location of the soil association areas, see Minnesota Agricultural Experiment Station Bulletin 392, "Principal Soil Regions of Minnesota," and Minnesota Agricultural Extension Service Folder 131, "Soils of Minnesota."*

Table II. Protein, Phosphorus, and Calcium Content of Alfalfa Hay Grown on Untreated and Phosphated Land on Five Soil Associations*

Year	No. of fields	Yield ck.†	Tons per acre phos.†	Protein Ck.	Protein % phos.	Calcium Ck.	Calcium % phos.	Phosphorus Ck.	Phosphorus % phos.	Per cent gain
				Clarion-Webster Association						
1942	6	3.40	4.34	19.77	19.98	1.78	1.74	0.27	0.34	....
1943	9	2.60	3.95	19.74	19.81	1.07	1.07	0.26	0.30	....
1944	5	2.18	3.21	17.60	18.29	1.89	1.89	0.22	0.24	....
1945	6	2.38	4.16	19.94	21.21	1.75	1.75	0.20	0.28	....
Average	26	2.69	3.94	19.38	19.88	1.53	1.54	0.24	0.29	20.9
				Barnes-Parnell Association						
1942	4	1.68	2.76	21.84	21.37	1.98	2.03	0.24	0.30	....
1943	5	1.79	3.36	19.28	21.25	....	....	0.26	0.32	....
1944	2	2.55	3.08	19.71	20.05	1.73	1.77	0.22	0.22	....
1945	4	1.62	2.57	19.42	22.54	1.60	1.85	0.23	0.30	....
Average	15	1.81	2.95	20.05	21.47	1.62	1.73	0.24	0.29	20.8
				Kittson-Peat Association						
1942	1	1.36	2.37	19.34	19.44	2.28	2.18	0.22	0.32	....
1943	9	2.15	3.02	18.77	19.15	1.50	1.54	0.27	0.29	....
1944	1	1.12	1.88	19.41	19.82	2.02	1.92	0.21	0.18	....
1945	3	1.17	2.16	21.62	22.25	1.78	1.80	0.20	0.26	....
Average	14	1.81	2.71	19.47	19.88	1.74	1.74	0.24	0.29	20.8
				Ulen-Sioux Association						
1943	4	1.27	1.92	17.81	19.18	....	....	0.26	0.31	....
1945	3	2.29	3.32	21.49	23.00	2.00	1.70	0.26	0.34	....
Average	7	1.71	2.52	19.39	20.82	....	....	0.26	0.32	23.1

* Chemical analyses were made by Freida L. Hammers, Division of Soils, University of Minnesota.
† Check on untreated and phosphate-treated land, respectively.

Table II. Protein, Phosphorus, and Calcium Content of Alfalfa Hay Grown on Untreated and Phosphated Land on Five Soil Associations*—continued

Year	No. of fields	Yield ck.†	Tons per acre phos.†	Protein		Calcium		Phosphorus		Per cent gain
				Ck.	% phos.	Ck.	% phos.	Ck.	% phos.	
Fargo-Bearden Association										
1943	3	1.53	2.89	18.33	18.19	2.06	2.12	0.19	0.22	....
1944	2	1.22	2.98	17.94	18.98	1.91	1.65	0.15	0.20	....
1945	2	2.83	5.05	19.31	19.15	1.50	1.41	0.19	0.27	....
Average	7	1.81	3.53	18.50	18.72	1.86	1.61	0.18	0.23	27.8
All Soil Associations										
1942	11	2.59	3.57	20.48	20.44	1.89	1.89	0.25	0.32	....
1943	30	2.08	2.86	18.97	19.61	1.40	1.42	0.25	0.29	....
1944	10	1.96	3.00	18.27	18.93	1.78	1.82	0.21	0.22	....
1945	18	2.04	3.44	20.29	21.75	1.76	1.74	0.22	0.29	....
Average	69	2.13	3.14	19.45	20.20	1.63	1.64	0.24	0.29	20.8

* Chemical analyses were made by Freida L. Hammers, Division of Soils, University of Minnesota.
† Check on untreated and phosphate-treated land, respectively.

Table III. Crop Yield Increases by Counties

County	Year	Oats	Barley	Wheat	Flax	Alfalfa	Alfalfa-brome	Red clover	Corn
		Bu.	Bu.	Bu.	Bu.	Ton	Ton	Ton	Bu.
Becker	1942	7.60	10.00	4.20	......	.80	......	......	......
	1943	1.90	2.80	......	......	1.12	......	......	......
	1944	4.90	6.80	......	......	.60	1.65	......	6.10
	1945	11.10	......	1.20	......	.02	......	......	......
	1946	6.30	—2.10	—1.70	1.00	1.07	.96	......	......
Average		6.26	6.70	.27	1.00	.74	1.31	......	6.10
Brown	1941	—0.40	—2.30	1.20	.70	.65	......	.33	......
	1942	12.00	3.20	.90	.30	.92	......	.70	6.00
	1943	2.30	—4.60	1.10	.90	1.03	......	.96	8.15
	1944	4.30	......	......	1.90	.57	......	......	6.00
	1945	5.10	......	......	......	.92	......	......	3.15
	1946	—2.50	—1.10	2.50	—.50	.75	.44	.58	—2.87
Average		3.58	.23	1.04	.70	.82	.44	.69	4.94
Jackson	1941	......	......	......	—.10	.74	......	.09	......
	1942	3.50	......	......	2.80	1.40	......	1.09	6.90
	1943	14.60	......	2.40	1.20	1.22	......	......	.58
	1944	12.80	......	......	—.20	.90	1.43	.63	5.20
	1945	5.20	......	......	......	1.04	......	......	1.99
	1946	6.30	16.40	......	.30	1.06	.81	......	6.91
Average		11.43	16.40	2.40	.70	1.05	1.00	.96	3.85
Kandiyohi	1941	.80	4.20	......	1.40	.62	......	.07	......
	1942	1.30	6.40	......	—.10	.92	......	......	......
	1943	9.60	......	......	—2.20	1.47	......	......	7.36
	1944	5.90	3.40	......	......	1.01	......	......	7.70
	1945	8.90	......	......	......	2.36	......	......	4.83
	1946	2.10	......	......	.10	.69	1.24	......	2.90
Average		4.89	4.92	......	.10	1.02	1.24	.07	5.45

Table III. Crop Yield Increases by Counties—continued

County	Year	Oats	Barley	Wheat	Flax	Alfalfa	Alfalfa-brome	Red clover	Corn
		Bu.	Bu.	Bu.	Bu.	Ton	Ton	Ton	Bu.
Kittson	1941	2.80	8.90	....	....	.45	....	....	....
	1942	2.40	2.40	1.10	....	.53	....	....	....
	1943	4.00	10.00	3.50	....	.75	....	....	....
	1944	—1.40	....	—.90	....	.85	....	....	....
	1945	4.90	6.20	7.70	....	1.01	....	....	....
	1946	12.30	5.60	6.80	2.2	.58	....	....	....
Average		4.40	5.88	3.98	2.2	.66	....	....	....
Mahnomen	1941	6.90	4.00	4.30	....	.72	....	....	....
	1942	14.30	9.70	6.30	....	1.02	....	....	....
	1943	4.10	3.90	8.60	....	.73	....	....	....
	1944	9.30	3.30	3.70	....	.75	....	....	—.90
	1945	3.80	....	.70	....	.61	....	....	....
	1946	—2.90	8.70	5.90	....	.81	1.13	....	9.47
Average		5.11	5.44	3.93	....	.79	1.13	....	7.40
Marshall	1941	3.50	5.70	4.30	....	.83	....	....	....
	1942	7.90	5.10	2.60	.00	.65	....	....	....
	1943	3.50	....	....	....	.77	....	....	....
	1944	—1.20	1.70	—.60	—.60	.86	.72	....	.60
	1945	7.80	2.80	.70	....	.85	.47	....	....
	1946	8.70	8.30	4.50	3.20	.76	.05	....	....
Average		6.81	5.52	2.96	1.71	.76	.39	....	.60
Martin	1941	1.00	....	....	.70	1.48	....	.32	....
	1942	5.60	....	....	—2.40	.90	....	....	6.90
	1943	5.60	7.80	3.50	1.50	1.03	....	.44	4.65
	1944	15.90	....	....	1.60	.95	.64	.84	9.20
	1945	21.30	....	....	....	1.06	.84	....	6.24
	1946	—1.20	....	....	2.20	.52	.72	.80	4.83
Average		8.66	7.80	3.50	1.05	1.03	.73	.65	7.14

Table III. Crop Yield Increases by Counties—continued

County	Year	Oats	Barley	Wheat	Flax	Alfalfa	Alfalfa-brome	Red clover	Corn
		Bu.	Bu.	Bu.	Bu.	Ton	Ton	Ton	Bu.
Murray	1942	5.60	1.10		.30	1.56		2.09	
	1943	9.80			2.10	2.00	1.12		
	1944	10.60	—1.20		6.10	1.62	.91		11.30
	1945	8.60				.25	.95		—1.44
	1946	1.00	5.30			.52	.84		.80
Average		5.23	1.73		1.57	1.41	.96	2.09	4.41
Nobles	1941	8.90	1.70		.30	.27		—.05	
	1942	1.50	.20		.42	.94		.43	9.20
	1943	12.90			.40	1.17	1.26	.29	5.10
	1944	8.70			2.70	1.10	1.03	.96	4.40
	1945	4.70			4.00	1.09	1.12	1.54	.07
	1946	5.50	.39			.41	.42		1.85
Average		7.42	.83		.59	.84	.93	.56	3.36
Norman	1941	2.40	6.10	2.30	1.20	.65			
	1942	6.90	8.90	3.00	—3.60	.96			
	1943	1.70	2.90	2.80		.63			
	1944	—.30	—.30	2.00		.71	.80		7.80
	1945	3.10	14.80	4.70	4.50	.51	.30		
	1946	6.00	2.30	1.40	2.60	1.42			11.12
Average		3.20	5.34	2.56	1.46	.79	.55		8.63
Pennington	1941	7.70	8.10	3.60		.65			
	1942	2.30	—5.20		0.0	.64			
	1943	4.80	—4.20			.86			
	1944	—7.90	13.30	5.90		.72	.15		
	1945	.50	6.30	4.40		.81	.24		
	1946	3.30	4.80	2.70	3.0	.49	—.04		
Average		2.03	4.33	3.94	1.5	.71	.11		

Table III. Crop Yield Increases by Counties—continued

County	Year	Oats	Barley	Wheat	Flax	Alfalfa	Alfalfa-brome	Red clover	Corn
		Bu.	Bu.	Bu.	Bu.	Ton	Ton	Ton	Bu.
Polk (East)	1941	13.80	11.60	7.40	....	.52	....	....	....
	1942	10.20	3.80	9.00	....	.58	....	....	....
	1943	5.30	1.70	3.70	.20	.76	....	....	....
	1944	12.20	4.20	4.50	....	.92	....	....	7.90
	1945	8.30	—1.50	4.30	....	1.05	....	....	....
	1946	10.90	18.60	2.80	.40	.93	....	1.52	11.75
Average		9.73	6.02	4.11	.27	.78	....	1.52	8.67
Polk (West)	1941	1.40	....	....	....	.79	....	....	....
	1942	5.80	3.50	4.50	—2.20	.86	....	....	....
	1943	3.20	3.10	4.20	3.60	1.36	....	....	....
	1944	1.50	9.60	.50	....	1.30	1.10	....	8.20
	1945	3.00	8.10	2.20	1.60	1.28	1.35	....	7.08
	1946	8.60	5.10	.80	....	.87	.66	....	11.52
Average		3.79	5.30	2.22	1.00	1.03	1.05	....	8.67
Red Lake	1941	15.00	2.10	.60	2.90	.52	....	....	....
	1942	6.90	11.40	4.10	....	.55	....	....	....
	1943	6.80	.20	3.80	2.30	.95	....	....	....
	1944	7.70	7.40	1.70	....	.17	.47	....	7.40
	1945	4.30	4.80	2.60	....	.71	....	....	....
	1946	17.30	6.60	—.90	—5.70	1.46	....	....	....
Average		8.27	6.03	1.72	.45	.70	.47	....	7.40
Roseau	1941	.50	....	2.10	....	.58	....	....	....
	1942	4.50	3.40	1.80	1.50	1.37	....	....	....
	1943	7.20	....	2.40	—1.30	.55	....	....	....
	1944	15.40	4.00	1.10	1.00	.68	.94	....	16.00
	1945	8.30	3.50	5.80	....	1.08	1.07	....	....
	1946	6.10	13.30	8.80	.80	.61	.34	....	....
Average		6.49	7.90	5.26	.99	.80	.75	....	16.00
Steele	1945	6.00	....	....	....	....	....	....	....
	1946	6.90	14.70	1.20	....	....	.52	....	....
Average		6.48	14.70	1.20	....	....	.52	....	....

Table III. Crop Yield Increases by Counties—continued

County	Year	Oats	Barley	Wheat	Flax	Alfalfa	Alfalfa-brome	Red clover	Corn
		Bu.	Bu.	Bu.	Bu.	Ton	Ton	Ton	Bu.
Stevens	1941	4.90	6.00	—1.60	....	.36	....	....	....
	1942	9.50	4.80	....	3.40	.58	....	....	....
	1943	8.60	2.80	3.00	—.50	1.85	....	....	10.44
	1944	3.20	6.90	1.50	....	.97	....	....	7.70
	1945	7.60	4.10	—1.80	....	1.71	....	....	8.24
	1946	.20	4.60	—.60	....	.92	....	....	14.26
Average		5.41	4.79	.36	1.45	1.15	....	....	9.89
Swift	1942	14.70	8.20	4.10	3.50	.57	1.17	....	....
	1943	17.00	....	.30	2.90	1.33	1.34	....	3.32
	1944	9.30	....	1.20	5.00	1.07	1.70	....	17.60
	1945	16.70	....	....	....	1.21	.31	....	7.83
	1946	2.30	....	—6.20	2.80	1.28	....	.28	15.27
Average		8.97	8.20	.71	3.53	1.09	1.45	.28	12.14
Watonwan	1941	3.20	....	....	1.70	1.09	....	....	....
	1942	6.50	.80	....	1.90	1.40	....	....	....
	1943	9.80	....	....	—2.20	1.55	1.45	1.37	3.78
	1944	14.40	....	....	....	1.32	1.18	.11	—4.90
	1945	19.70	....	....	....	.85	....	....	7.43
	1946	—1.70	....	....	—.70	.80	....	....	4.84
Average		8.93	.80	....	—.50	1.37	1.36	1.19	3.69
Yellow Medicine	1941	—1.30	—.50	.60	1.50	.17	....	....	....
	1942	—11.30	.05	....	3.30	1.30	....	.00	5.60
	1943	—.80	....	9.70	3.50	1.74	1.68	....	7.40
	1944	2.80	....	4.90	.90	1.06	1.15	....	7.60
	1945	3.10	....	....	....	.26	.99	....	2.98
	1946	—6.30	—.30	....	1.10	.16	.85	....	15.36
Average		—.96	—.31	2.50	2.12	1.10	1.16	....	8.08

Note: Yields for 1940 are not considered typical because all the phosphate fertilizer was applied too late in the spring, was top-dressed, and was not thoroughly worked into the soil.

Table IV. Annual Average Increases of Straw Yields and Weights per Bushel of Small Grains by Counties

County	Year	Straw yield increases				Weight per bushel increases			
		Oats	Barley	Wheat	Flax	Oats	Barley	Wheat	Flax
		Ton	Ton	Ton	Ton	Lbs.	Lbs.	Lbs.	Lbs.
Becker	1942	......	......	......	......	1.2	4.7	—2.3	......
	1943	.06	.05	.26	......	.8	3.5	—1.0	......
	1944	.00	—.26	.18	......	.5	2.5	2.0	......
	1945	.11	......	.10	......	1.3	......	.0	......
	1946	.04	—.07	—.25	.38	—1.2	—1.0	—.7	.1
Brown	1942	......	......	......	......	1.3	3.0	......	—1.2
	1943	.02	—.11	.01	.20	2.6	.0	4.7	—.2
	1944	—.06	......	......	.08	1.0	......	......	—1.0
	1945	.07	......	.28	......	—1.1	......	......	......
	1946	.09	.02	.12	—.02	—.5	—1.5	.5	1.0
Jackson	1942	......	......	......	......	—1.6	......	......	.3
	1943	.32	......	......	.10	1.8	......	2.0	.5
	1944	.33	......	......	—.02	.2	......	......	.0
	1945	.04	......	......	......	—.1	......	......	......
	1946	.03	—.24	......	.17	—.3	—4.0	......	.0
Kandiyohi	1942	......	......	......	......	—5.2	—.9	......	—.7
	1943	.12	......	......	—.21	3.4	......	......	.0
	1944	.47	.14	......	......	1.0	.1	......	......
	1945	.12	......	......	......	—.1	......	......	......
	1946	.08	......	......	.07	.1	......	......	—.3
Kittson	1942	......	......	......	......	—1.0	.2	—.4	......
	1943	.07	—.02	.08	......	.0	1.0	1.3	......
	1944	—.07	......	.09	......	.4	......	.0	......
	1945	.06	.17	.40	......	.2	6.0	.0	......
	1946	—.01	—.06	.25	.16	2.0	—.7	—.5	1.0

Table IV. Annual Average Increases of Straw Yields and Weights per Bushel of Small Grains by Counties—continued

County	Year	Straw yield increases				Weight per bushel increases			
		Oats	Barley	Wheat	Flax	Oats	Barley	Wheat	Flax
		Ton	Ton	Ton	Ton	Lbs.	Lbs.	Lbs.	Lbs.
Mahnomen	1942					1.4	.9	1.1	
	1943	1.00	.09	.30		.2	3.0	2.0	
	1944	.13	.53	0.0		—.3	—.2	1.2	
	1945	.13		1.0		.4		.8	
	1946	.19	.09	.25	.16	.3	.0	.0	
Marshall	1942					—.2	—1.5	.0	—2.3
	1943	.23				.0			
	1944	.11	.22	—.09	.80	.8	1.5	—.2	.5
	1945	.17	.30	—.02		—.4	2.3	1.0	
	1946	.15	.21	.36	.28	.2	3.4	—.3	1.0
Martin	1942					1.0			1.0
	1943	.25	.15	.12	.22	—.1	1.8	.5	.9
	1944	.23			.09	.7		1.0	—1.5
	1945	.17				.0			
	1946	.02			—.28	—.2			—.5
Murray	1942						2.0		.2
	1943	.20			.26	—1.0			1.0
	1944	.09	.18		7.20	1.0	—.7		1.0
	1945	.09			.24	1.8			7.0
	1946	.04	.12			.8	3.0		
Nobles	1942					1.7	4.8		.7
	1943	.21			.04	3.2			.3
	1944	.06			.05	.0			.5
	1945	.08			.05	.4			6.0
	1946	.13	.10			.3	—.5		

Table IV. Annual Average Increases of Straw Yields and Weights per Bushel of Small Grains by Counties—continued

County	Year	Straw yield increases: Oats	Straw yield increases: Barley	Straw yield increases: Wheat	Straw yield increases: Flax	Weight per bushel increases: Oats	Weight per bushel increases: Barley	Weight per bushel increases: Wheat	Weight per bushel increases: Flax
		Ton	Ton	Ton	Ton	Lbs.	Lbs.	Lbs.	Lbs.
Norman	1942	....	....	....	....	.1	3.2	—.5	—1.7
	1943	.11	.13	.31	....	2.2	.3	.8	....
	1944	.14	.03	—.02	....	.1	1.4	.4	....
	1945	.02	.40	.17	.13	.4	.5	.4	3.0
	1946	.09	.14	.08	.31	—.5	—2.5	1.7	—.5
Pennington	1942	....	....	....	....	—.4	—.3	—2.8	—3.1
	1943	.04	—.01	.12	....	.3	1.0	—2.5	....
	1944	.00	.36	.11	....	—1.0	.0	.3	....
	1945	.02	—.34	.13	....	1.1	3.0	2.2	....
	1946	.10	.08	.11	—.04	—.4	—1.7	1.0	—1.0
Polk (East)	1942	....	....	....	....	.1	—.1	.6	....
	1943	.08	.19	.10	.13	.6	—.5	1.3	.0
	1944	.25	.11	.16	....	1.5	.0	—.9	....
	1945	.06	.07	.13	....	—.2	—2.5	.8	....
	1946	.08	.26	.11	—.04	—.4	—1.7	1.0	—1.0
Polk (West)	1942	....	....	....	....	.9	1.5	.2	.3
	1943	.16	.11	.12	.33	.3	.0	—.3	.0
	1944	.09	.31	.02	....	—1.3	.8	.0	....
	1945	.17	.36	—.02	.10	.4	.5	.4	2.0
	1946	.0	.07	.13	....	.2	2.6	.3	....
Red Lake	1942	....	....	....	....	—.4	—5.6	—.9	....
	1943	.15	—.09	.14	.22	—.4	—1.0	.5	1.0
	1944	.03	.27	.09	....	.3	6.0	.9	....
	1945	.42	.06	.08	....	1.2	3.0	1.3	....
	1946	.12	.07	—.3	—.70	1.2	3.0	.5	0.0

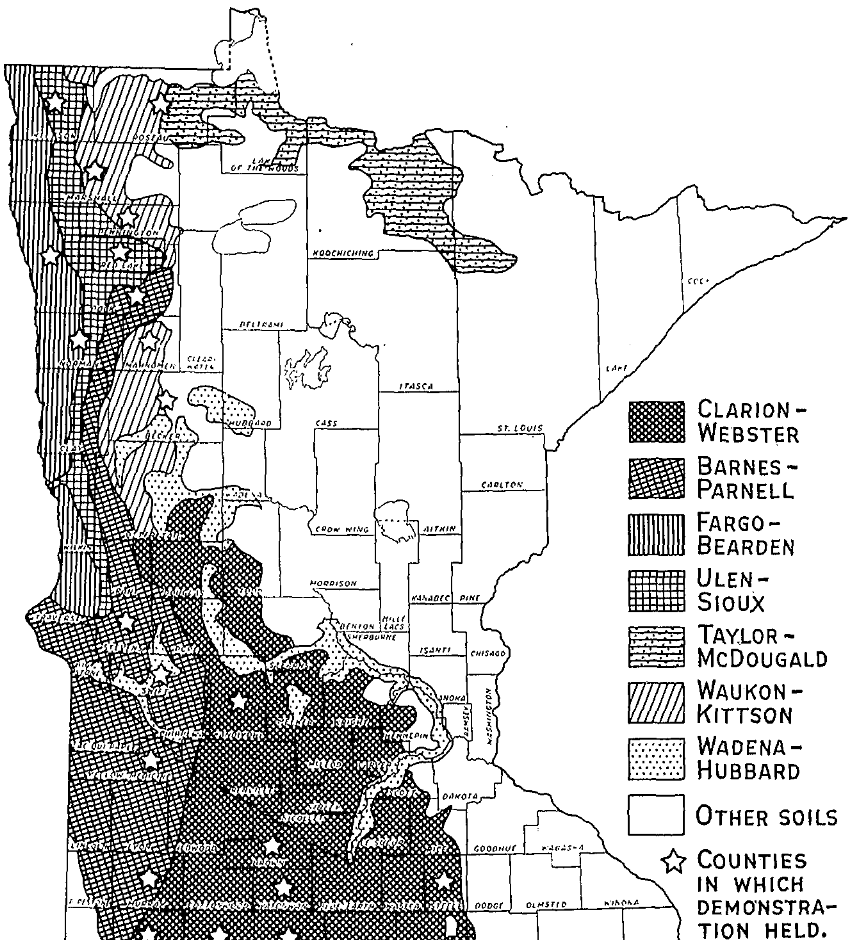
Table IV. Annual Average Increases of Straw Yields and Weights per Bushel of Small Grains by Counties—continued

County	Year	Straw yield increases				Weight per bushel increases			
		Oats	Barley	Wheat	Flax	Oats	Barley	Wheat	Flax
		Ton	Ton	Ton	Ton	Lbs.	Lbs.	Lbs.	Lbs.
Roseau	1942	....	....	....	....	.4	8.0	1.6	0.0
	1943	.12	....	.11	—.02	1.5	....	.7	1.0
	1944	.17	.09	.14	.11	.9	.5	.3	.0
	1945	.14	.25	—1.20	....	1.8	2.0	—1.1	....
	1946	.22	.26	.17	.23	.3	3.7	—1.4	.8
Steele	1945	.10	....	....	....	1.2	....	....	....
	1946	.22	.34	—.23	....	.1	1.0	—.5	....
Stevens	1942	....	....	....	....	—3.1	2.8	....	—2.0
	1943	.01	.18	.61	—.11	1.0	.5	—1.0	1.0
	1944	.16	.21	.06	....	—.7	—.5	—.3	....
	1945	.08	.08	—.07	....	1.3	1.0	—4.0	....
	1946	.10	—.05	—.05	....	.1	2.5	—2.3	....
Swift	1942	....	....	....	....	.8	.5	—.8	1.9
	1943	.20	....	.08	.28	.0	....	1.0	.0
	1944	.24	....	.38	.00	1.6	....	—.2	—1.3
	1945	.21	....	....	....	—.3	....	....	....
	1946	.13	....	—.14	.18	.4	...	—.8	.0
Watonwan	1942	....	....	....	....	—.1	2.2	....	—1.0
	1943	.16	....	....	—.01	.3	....	....	.4
	1944	.08	....	....	....	.6	....	....	....
	1945	.10	....	....	....	—.5	....	....	....
	1946	—.16	....	....	.04	1.5	....	....	.0
Yellow Medicine	1942	....	....	....	....	1.0	—.5	....	.6
	1943	.26	....	.53	.00	2.3	....	1.5	.5
	1944	—.12	....	—.31	—.04	—.4	....	.0	—.3
	1945	.06	....	.00	....	.01	....	.0	....
	1946	—.05	—.01	.13	.11	.4	—1.0	.5	.3

Summary of Observations and Results

1. Phosphate fertilizer increased the productiveness of rotation and renovated permanent pastures.
2. Regular rotations were followed on each farm so that all tillable land was seeded to legumes or legume-grass mixtures at regular intervals.
3. Legume or legume-grass acreage on tillable land was increased 18 per cent after the program was started.
4. Phosphate fertilizer improved the legume and legume-grass stands on all soil associations and with all types of hay and pasture crops.
5. Phosphate fertilizer increased the yield of all crops in the rotation.
6. Phosphate fertilizer made it possible to maintain the crop rotation as planned by insuring good stands and increased yields of legumes and legume-grass mixtures throughout the rotation.
7. Residual effects from phosphate fertilizer lasted for three or four years after application.
8. Increased legume or legume-grass acreage increased the soil organic matter and available nitrogen to provide for a better fertility balance with the residual phosphate fertilizer.
9. Test-demonstration cooperators reported soil erosion was reduced on the more rolling farms. This resulted from the regular use of a good crop rotation and the regular addition of organic matter to the soil.
10. Small grains and flax ripened more uniformly on the phosphated areas than on the untreated areas.
11. Phosphate fertilizer hastened the maturity of corn six to eight days.
12. Livestock preferred phosphated hay to the untreated hay.
13. Livestock, grazing on phosphated pastures, confined their grazing to the phosphated areas.
14. The phosphorus content of alfalfa used for hay or pasture was increased 20.8 per cent over that grown on untreated land.
15. Seventy per cent of the cooperators reported a depraved appetite (lack of phosphorus) in their cattle before the program was started in 1940 but in 1946, 100 per cent said this condition was not now noticeable.
16. Protein production was increased 47 pounds per acre on the phosphated areas over the untreated areas.

Soils Associations and Demonstration Counties



UNIVERSITY FARM, ST. PAUL 1, MINNESOTA

Cooperative Extension Work in Agriculture and Home Economics, University of Minnesota, Agricultural Extension Division and United States Department of Agriculture Cooperating, Paul E. Miller, Director. Published in furtherance of Agricultural Extension Acts of May 8 and June 30, 1914. 20M-4-48