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CONTENTS

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John A. Toogood[1] and C. O. Rost[2]

OF THE MANY ELEMENTS used by our common field crops, nitrogen, phosphorus, potassium, and calcium are the most important. This follows from the fact that decreases in yields are largely due to deficiencies of these elements in the soil. In general, southwestern Minnesota soils are adequately supplied with calcium, so the remaining three elements are the major nutrients to be considered in this area.

In 1940 a test-demonstration soil management program was set up in Minnesota with the Tennessee Valley Authority, the Minnesota Agricultural Extension Service, and the University of Minnesota Division of Soils cooperating. Representative farms throughout the western half of the state were selected to serve for farm-sized tests and demonstrations. The program for each of these farms 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 and management program.

When phosphate fertilizers were applied, about 20 per cent of each field was left as a control or check. All of the phosphate for the rotation was applied at the time of planting the small grain with a legume or legume-grass mixture. No other commercial fertilizer was used. The phosphate fertilizer applied was calcium metaphosphate (0-63-0), containing 63 pounds of available phosphate (P_2O_5) per 100 pounds. It was used at the rate of 33 pounds of 0-63-0 (or 20 pounds of P_2O_5) per acre for each year the land remained in a legume or a legume-grass mixture, including the year seeded. In most cases this meant an application of 66 or 100 pounds. Common rotations were (a) small grain—hay or pasture—corn (b) small grain—hay—hay or pasture—corn—corn.

Effects of this soil management program were measured by sampling the various crops grown and determining yields. The data obtained are summarized in a recent publication by Burson, Harris, and Rost *(4)*[3]. Comparison of yields on check and treated areas showed increases in yields of all crops in the rotation following the application of the phosphate. Corn on treated areas, even three or four years after the application, exceeded yields on the check area by an average for the state of 6.5 bushels per acre. On farms of Clarion

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[3] Numbers in parentheses refer to corresponding numbers in Literature Cited, page 13.

and Webster soils the average gains were 5.3 bushels of corn, 8.2 bushels of oats, and 0.85 tons of alfalfa hay per acre. These increases, together with increases in yields of straw, in protein content, in phosphorus content of hay, and in total digestible nutrients, are strong evidence of a higher level of productivity achieved by the soil management program. Whether the reason for this high level is the application of the phosphate, the increased use of legumes and grasses, or the use of a good rotation, does not concern us here. Of more importance is whether yields could be even further increased by greater or more frequent use of commercial fertilizers, including nitrogen and potash as well as phosphate.

The object of the present study was to investigate the fertility level of common soil types in southwestern Minnesota and to determine, if possible, the adequacy of their supply of major plant nutrients. The soil types studied were mostly members of the Clarion and Webster soil series, but a few of the Marshall and Kransburg series were also included.

REVIEW OF LITERATURE

Many fertility trials in Iowa, Minnesota, and South Dakota have been reported. Schreiner and Anderson (*13*), among others, give ample evidence of the deficiency of available P_2O_5 in Black Prairie and Chernozem soils. It is now well known that adequate applications of superphosphate have a lasting effect.

The importance of nitrogen fertilizers as well as phosphate for boosting the yield of small grains has been shown by Nelson, Lawton, and Black (*10*) for Iowa, and by Worzella and Puhr (*19*) for South Dakota. Many other workers have demonstrated its value in all the states of the corn belt. The rate generally recommended for nitrogen was 20 pounds per acre of elemental N. Worzella and Puhr found no response to potash fertilizers on Chernozem soils. Nelson, Lawton, and Black found that nitrogen deficiency restricted the response of oats to phosphate and potash fertilizers.

The effect of the inclusion of nitrogen in mixed fertilizer for corn was studied by Miles (*9*). The conclusion was that while amounts of 9 pounds or more per acre of elemental N might increase yields; amounts less than 6 pounds actually decreased yields.

Since 1940 several fertility trials have been conducted on the Black Prairie soils of Minnesota. Rost, *et al.* (*12*) used 100 pounds per acre of 0-20-0, 0-20-20, and a complete fertilizer with up to 4 per cent nitrogen. They found corn yields in McLeod, Cottonwood, and Martin counties in 1942 were increased 8.7 bushels per acre on Clarion soils and 8.0 bushels on Webster from 0-20-0. They found increases of 11.0 bushels on Clarion and 11.7 bushels on Webster from 0-20-20. The complete fertilizer showed no advantage over 0-20-20.

In 1946 Duncan, Burson, and Huntsinger (*6*) compared 125 pounds per acre of 11-48-0 with 125 pounds per acre of 0-47-0 on oats in Nobles County. The former treatment boosted yields 11.2 bushels per acre, the latter treatment 9.2 bushels. The conclusion drawn was that the use of nitrogen on small grains would be worth while when grain prices are high.

What are the minimum amounts of the major nutrients needed in the soil? Data by Jenny (*8*) indicate that 4,000 pounds per acre of total nitrogen would be an adequate amount of this nutrient. It is well known, however, that the nature of the organic matter and the rate of nitrification are important in determining the value of this total amount of nitrogen in the soil.

The quantity of readily available P_2O_5 needed is not easily defined except within wide limits. Dühring *(5)*, using the Mitcherlich method of arriving at the number of nutrient units required for maximum yields, gives these figures for the plow layer: 194 pounds per acre for 95 per cent of maximum yield, 300 pounds for 99 per cent, and 445 pounds for 99.9 per cent. Blair and Prince *(1)*, working with alfalfa, concluded a soil was adequately supplied if the surface six inches contained over 200 p.p.m. This would amount to 400 pounds per acre.

The minimum amount of exchangeable potash has been set at various levels by different workers. Dühring calculated that 95 per cent of the maximum yield can be obtained with 125 pounds per acre of K_2O, 99 per cent with 195 pounds, and 99.9 per cent with 312 pounds.

Winters *(18)* estimated that 90 per cent of the maximum yield of corn could be obtained with 155 pounds per acre of exchangeable K_2O, and that 160 pounds per acre are needed for a 90 per cent yield of alfalfa.

Truog *(15)* estimated that 160 pounds per acre are needed for good yields of alfalfa, corn, and cereals, and double or treble this amount for special crops. He estimated that crops depend for over 75 per cent of their potash supply on readily available forms in the soil.

Bray *(2,3)*, using an extracting solution that indicated from 60 to 386 pounds per acre of K_2O in a number of soils, found 300 pounds per acre to be the minimum for corn.

Many chemical analyses of soils in the corn belt have been made. The most accurate picture observed was that given by Walker and Brown *(17)* who reported the means and standard deviations of the nitrogen content of a large number of samples of Iowa soils. Thus for Clarion loams the mean was 4,368 pounds, with a standard deviation of 1,040 pounds; for Webster silty clay loams the figures were 4,158 and 2,316; for all drift soils in Iowa, 3,720 and 2,290; and for Marshall silt loams 4,029 and 1,070. The large amount of variation is striking.

The amount of readily available phosphate is only a small percentage of the total and varies according to several factors. Truog set 172 pounds per acre of P_2O_5 as the minimum requirements, under Wisconsin conditions, for general farming on the better soils and up to 344 pounds for garden, truck, and special crops.

The amount of total potash in the soil is usually very high but the quantity available to crops is only a small percentage of the total. Volk *(16)* found the replaceable K_2O in a wide variety of soils to vary from 17 pounds to 648 pounds per acre. He considered any amount over 360 as high.

METHODS

The methods used to test the fertility levels of the soils referred to above consisted of a combination of greenhouse experiments, field experiments, and soil analyses. Greenhouse experiments were conducted on five soil types during the winter of 1946-47 and on three soil types during the following winter. Soil from the part of the field which had received no metaphosphate and soil from the treated portion were compared with respect to their responses to nitrogen, phosphate, and potash fertilizers—alone and in all possible combinations. An oats and alfalfa mixture was used as the test crop.

Field experiments consisted of fertilizer test plots on corn in seven fields and on oats seeded with legumes in eight fields. Laboratory analyses included determinations of the total nitrogen, readily available phosphorus, exchangeable potash, moisture equivalent, and pH of 98 surface and subsurface soil samples. The phosphate-fixing power and base exchange capacity on the surface samples and on some of the others was also determined.

Greenhouse Tests

The greenhouse tests consisted of both factorial and Latin square designs. In the former, applications of N, P_2O_5, and K_2O were made on soil from the check and phosphated areas of seven fields. The rates used were 175 pounds per acre of ammonium sulfate (20.5 per cent N), 200 pounds per acre of 47 per cent superphosphate, and 140 pounds per acre of 60 per cent muriate of potash. All possible combinations of these three fertilizers on the check and on the treated soil required sixteen different treatments, and three replications were made of these combinations for each soil type. An oats and alfalfa mixture was grown and harvested as hay when the oats were mature. Dry weights were determined and the data subjected to statistical analysis. In the Latin square design high rates of N and P_2O_5 fertilization were used together with (a) no potash, (b) 60 per cent muriate at 70 pounds, and (c) 60 per cent muriate at 140 pounds per acre. The specific object here was to test the need for potash when large amounts of available nitrogen and phosphate were on hand. The four treatments were arranged in two Latin squares of 16 pots each. For all the greenhouse tests two-gallon crocks were used with eight kilograms of the soil placed in each.

The analysis of the factorial experiments is summarized in table 1, in which T refers to the metaphosphate-treated soil under the soil management program. The analysis shows that the phosphate fertilizer gave significant increases at the one per cent level on all soils, including a Webster silt loam and a Clarion loam in which a legume had just been plowed down. The responses to N varied. Webster soils from Martin County showed no significant response, either in the case of one soil where a green manure had been turned under or in the case of another which had just produced a heavy crop of corn. A Clarion soil, in spite of having just received a green manure, showed a significant response. Four soils from Nobles County all responded to N at the one per cent level. In no case was there any significant response to potash.

Table 1. Summary of F Values in Analysis of Variance of Seven 2^4 Factorial Experiments

Variation due to	Field Number and Soil Type						
	1 Webster silt loam	2 Webster silt loam	3 Clarion loam	4 Kranzburg silt loan	5 Kranzburg silt loam	6 Marshall silt loam	7 Clarion silt loam
Replications	2.95	.... †	3.01	1.19	1.60	1.61	....
Treatments	5.07‡	3.62‡	2.61*	17.10‡	17.98‡	14.90‡	14.82‡
N	....	2.36	4.64*	133.26‡	230.63‡	41.50‡	78.76‡
P	64.83‡	42.17‡	28.50‡	100.55‡	18.07‡	150.72‡	93.89‡
K	1.18	....	....	1.17	....	....	....
T	....	....	....	....	2.40	6.48*	24.38‡
N x P	1.23	....	....	9.01‡	10.84‡	9.76‡	14.24‡
N x K	1.61	....	....	....	....	1.34	....
N x T	....	2.56	....	....	....	1.54	....
P x K	....	1.42	....	3.80	....	1.68	....
P x T	....	....	1.24	3.68	5.22*	3.96	3.05
K x T	....	....	....	1.31	....	....	....

‡ F exceeds 1 per cent level of significance.
* F exceeds 5 per cent level of significance.
† Values smaller than 1.00 omitted.

Table 2. Average Yields in Latin Square Experiment

Treatment	Grams of oven-dry hay per pot
1. Check	12.34
2. N at 80 pounds per acre and P_2O_5 at 80 pounds per acre	22.94
3. Same as (2) plus K_2O at 42 pounds per acre	23.36
4. Same as (2) plus K_2O at 84 pounds per acre	23.82

Of the seven soils used only two showed any difference in yield between the phosphate-treated soil (T) and the check, and in both cases the check yielded higher. The N x P interaction was significant on the four soils from Nobles County but not on the three from Martin County. The P x T interaction (T refers to metaphosphate treatment) was significant in only one case, suggesting that on the whole the response to phosphate was the same on both check and treated soils.

Table 2 shows the average yields in the Latin square experiment. Statistical analysis showed the standard error of these means to be 0.67, from which it follows that nitrogen and phosphorus together increased the yields markedly and potash at the higher rate increased them still further.

A second-growth alfalfa crop was harvested in the case of five of the factorial experiments. As shown in table 3 analysis of the yields showed some significant main effects. There was a response to N fertilizer on soils which had just produced a corn crop, but none on soils which had just received a green manure. (Soils 4 and 7 were collected after a corn crop, soils 1 and 3 after a green manure.) In general there was a highly signficant response to phosphate fertilizer, and in two cases a response to potash was evident.

Field Experiments

Several different types of experiments were conducted on the test demonstration farms in 1947. Split-plot experiments on oats and oat-and-legumes mixtures were laid out in eight fields. Six of these designs were identical, and there were four replicates in each field. The other two were the same except that the farm-cooperator applied no metaphosphate. The treatments used were:

a. On the check or unphosphated strip
1. Check
2. P—at rate equivalent to cooperator's application on phosphated area.
3. PN—Phosphate as in 2 plus 20 pounds per acre of N (100 pounds ammonium sulfate).
4. PK_1—Phosphate as in 2 plus 30 pounds per acre of K_2O (50 pounds of 60 per cent muriate of potash).
5. NPK_1—NP as in 3 plus 30 pounds per acre of K_2O (50 pounds of 60 per cent muriate of potash).

Table 3. Summary of F Values for Second-Growth Alfalfa Yields

Treatment	Field Number and Soil Type				
	1 Webster	3 Clarion	4 Kranzburg	6 Marshall	7 Clarion
N	.......†	....	6.26*	....	15.66‡
P	56.82‡	3.22	39.19‡	10.61‡	43.42‡
K	....	7.21*	....	8.37‡	1.95
T	....	6.06*	20.25‡	2.35	....

† Values less than 1.0 omitted.
‡ These values exceed the one per cent level of significance.
* These exceed the five per cent level.

6. NPK_2—NP as in 3 plus 60 pounds of K_2O (100 pounds of 60 per cent muriate of potash).

b. On phosphate-treated soil.

1. P—an application of 0-63-0 by the cooperator.
2. NP—20 pounds N (100 pounds ammonium sulfate) plus P as in 1.
3. PK_1—Phosphate as in 1 plus 30 pounds per acre of K_2O.
4. NPK_1—NP as in 2 plus 30 pounds per acre of K_2O.
5. NPK_2—NP as in 2 plus 60 pounds per acre of K_2O.

Square yard samples from each plot were harvested to determine yields. Results of the six similar tests are given in table 4. Statistical analysis showed that in this season there was no significant difference in yields due to residual phosphate from previous treatments. There was a highly significant increase for the N in the NP, NPK_1, and NPK_2 treatments over the check or residual phosphate. The increase for K as shown by differences between the NP and NPK treatments was not significant. The response to phosphate was significant only at the 7 per cent level. Results on the other two fields showed similar responses to N fertilizer but in addition showed a significant response to P and K_1 when these were applied together. Separately neither P nor K_1 caused significant increases.

A design resembling a split-plot was used to lay out experiments in duplicate on each of six corn fields. Here N, P, and K were used, together with all their possible combinations, on both check and phosphated areas. The fertilizers and acre rates of application were 55 pounds ammonium sulfate (11 pounds N), 43 per cent superphosphate at 110 pounds (52 pounds P_2O_5), and 60 per cent muriate of potash at 133 pounds (80 pounds K_2O). The weather conditions were unsuitable for the growth of a good crop in 1947. In both Martin and Nobles counties rainfall was about 100 per cent above average in April and at least 25 per cent above average in June. At Fairmont in Martin County, July rainfall was about one inch, or about two-and-a-half inches less than average, and at Worthington in Nobles County there was less than half an inch of precipitation during the whole of the month of July. August

Table 4. Average Yield of Oats in Bushels Per Acre from Replicates on Fields Receiving Phosphate

Treatment	Field number and soil type					
	4 Kranzburg silt loam	8 Kranzburg silt loam	9 Webster silt loam	10 Webster silt loam	11 Clarion loam	12 Clarion loam
On check area						
O	34.1	40.7	20.7	17.9	39.9	16.7
P	38.1	37.6	20.0	23.7	48.5	14.6
NP	49.1	54.3	42.8	28.9	53.0	36.2
PK_1	36.8	41.0	22.4	25.0	47.2	18.3
NPK_1	56.1	54.1	38.6	26.1	60.6	38.1
NPK_2	53.6	53.0	39.2	30.4	50.5	33.7
On phosphated area						
P*	32.2	40.6	27.1	21.6	39.8	18.1
P‡	33.7	38.5	26.5	18.6	42.5	16.0
NP	55.1	55.7	38.8	27.9	55.4	40.7
PK_1	31.8	43.1	25.7	18.2	44.6	22.5
NPK_1	53.1	57.6	41.5	27.8	51.7	35.7
NPK_2	51.8	59.4	38.4	28.3	52.1	37.4

* Plots adjacent to O plot on check area.
‡ Plots adjacent to P plot on check area.

Table 5. Average Yields of Corn in Bushels Per Acre from Two Replicates

Treatment	Field number and soil type						
	14 Clarion loam	15 Clarion loam	16 Clarion loam	17 Clarion loam	18 Webster silt loam	19 Barnes loam	Average
On check areas							
O	37.8	50.5	61.0	62.2	56.6	57.4	54.3
N	36.8	57.1	61.3	62.7	51.8	61.3	55.2
P	34.2	53.5	61.7	67.8	58.6	63.1	56.5
K	42.4	54.1	62.3	60.2	57.0	62.2	56.4
NP	36.1	56.0	63.4	71.1	54.7	60.8	57.0
NK	33.6	60.3	62.8	57.7	60.3	58.2	55.5
PK	36.3	58.1	68.0	65.5	62.2	56.6	57.8
NPK	38.5	62.2	65.6	65.9	60.0	57.9	58.4
On phosphated areas							
O	35.7	59.7	62.5	61.5	50.9	51.4	53.6
N	37.2	64.2	61.2	58.4	48.6	57.1	54.5
P	34.5	54.4	61.5	68.1	53.4	60.8	55.5
K	37.0	62.3	60.1	61.0	58.9	53.6	55.5
NP	31.6	61.3	64.4	66.7	59.2	57.4	56.8
NK	39.4	65.1	62.3	60.6	51.9	51.3	55.1
PK	38.1	57.7	66.4	62.2	59.9	58.7	57.2
NPK	34.1	63.5	64.7	64.4	61.5	59.4	58.0

rainfall was average at Fairmont but almost an inch and a half below average at Worthington. Coupled with the dry summer was a higher-than-average temperature during August at both these points. Nevertheless, the yields show some significant increases in the yield of corn (table 5). These increases occurred on plots receiving phosphate alone and on plots receiving complete fertilizer, and these responses were the same on both the check and phosphated areas. Had weather conditions been more favorable, greater increases might have been expected. Analysis showed that at the 6 per cent level of significance, yields on check areas narrowly exceeded those on phosphated areas.

A factorial experiment using similar treatments was set up on the phosphated area of one corn field. Here the check yielded 83.3 bushels per acre. While all the fertilized plots produced more, the increases were not statistically significant.

A third type of experiment consisted merely of the treatments of N and PK on the check area and of NP, PK, and NPK on the phosphated area of a single field. The yields here showed a tendency for the phosphated area to outyield the check area where PK was applied but not where N was applied. N itself appeared to bring about the largest increases. The data are shown in table 6.

Table 6. Yields of Corn from Three Replicates on a Kranzburg Silt Loam in Nobles County

Treatment	Replicate I	Replicate II	Replicate III	Average
On check				
N	53.4	43.6	45.9	47.6
PK	38.5	39.2	39.4	39.0
On treated area				
NP	42.7	45.0	48.3	45.3
NPK	36.5	43.1	42.5	40.7
PK	41.0	41.3	38.2	40.2

Soil Analysis

Ninety-eight soil samples were analyzed. Of this number fifty-eight were from the top six inches and the remainder from the 6- to 12-inch layer. The tests made have already been enumerated. For the determination of nitrogen the Kjeldahl method was used. The distilled ammonia was collected in a 4 per cent boric solution which was then titrated with standard acid, using a mixed bromcresol green-methyl red indicator. Readily available phosphorus was determined by the Truog method *(14)* using a spectrophotometer. Exchangeable potash was determined by a gravimetric procedure described by Peech *(11)*. Phosphate fixing power was found by treating the soil with known amounts of phosphate and then extracting. This procedure has been outlined by Heck *(7)*. For base exchange capacity a method described by Peech for calcareous soils was used. Ammonium acetate was used to saturate the complex and the excess was then removed by washing with alcohol. Then by distilling off the ammonia left in the soil, the base exchange capacity was determined. Moisture equivalent and pH were found by the customary methods.

The average analysis for the various soil series was calculated. These together with the ranges are shown in table 7. The Webster soils were highest in total nitrogen content, with an average of over 6,700 pounds per acre in the surface six inches. Clarion soils averaged 5,400 pounds and Kranzburg and Marshall soils, 4,020 pounds. The subsurface samples averaged 5,400, 4,300 and 3,100 pounds, respectively. In readily available phosphorus (P) the Webster soils were highest with 133

Table 7. Averages and Ranges of Results of Soil Analysis

	Clarion		Webster		Kranzburg and Marshall	
	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
Number of samples	22	18	23	13	12	8
Pounds per acre of N	5,400	4,320	6,740	5,380	4,020	3,100
Range	3,800-	2,880-	4,860-	3,660-	3,780-	2,720-
	6,720	5,800	10,080	6,820	4,440	3,540
Pounds per acre of P	83	122	133	148	53	52
Range	19-	42-	46-	70-	29-	35-
	188	342	252	352	85	100
Pounds per acre of K	287	258	282	315	343	243
Range	144-	114-	86-	119-	224-	208-
	489	358	471	482	469	273
Per cent P fixed	30.9	....	22.5	....	29.2	....
Range	20.6-	....	5.5-	....	21.6-	....
	44.8	....	60.4	....	37.5	....
pH	5.95	6.2	6.45	6.3	5.5	5.8
Range	5.3-	5.4-	5.3-	5.4-	5.1-	5.2-
	7.3	7.4	7.5	7.4	6.0	6.2
Base exchange capacity—m.e.	31.2	26.0(6)*	37.2	41.1(4)	22.9	22.9(4)
Range	21.7-	20.4-	25.3-	39.1-	21.5-	21.0-
	41.6	32.6	47.6	42.1	23.9	24.9
Moisture equivalent	28.3	28.3	31.9	33.5	25.5	26.6
Range	19.2-	19.2-	23.6-	28.4-	23.9-	25.4-
	32.0	32.7	37.4	36.2	27.7	28.1

* Numbers in brackets refer to number of samples averaged in particular cases.

pounds per acre and the Kranzburg and Marshall soils lowest with 53 pounds per acre. The subsurface samples of the Clarion and Webster soils averaged higher than the surface samples in available phosphorus. While highest in available phosphorus, the Websters were the lowest in phosphate fixing power. There was in fact a significant negative correlation for all the surface samples between available phosphorus and phosphate fixing ability. In exchangeable potassium (K) the Websters were lowest with 282 pounds per acre in the surface samples, while the Kranzburg and Marshall samples averaged 343 pounds per acre. According to the pH readings the soils were all slightly acid except for some of the Websters. The base exchange capacities varied from an average of 22.9 m.e. per 100 gms. for Kranzburg and Marshall samples up to an average of 37.2 m.e. for surface samples of Websters. These were in close agreement with the moisture equivalent, with which they showed a high correlation. The Webster soils with their high base exchange capacity might have been expected to be highest in exchangeable potash. The fact that they were not may be due to the presence of an abundance of calcium and magnesium carbonates usually found in these soils.

The results of the analysis were studied in connection with the greenhouse and field tests. The analytical data, while accurate enough, showed no large differences in nitrogen, available phosphorus, and exchangeable potash supplied on the check and phosphate-treated soils. At least there was no indication that the phosphated areas were superior to the check areas in fertility level, which was corroborated by both greenhouse tests and field plot yields.

In greenhouse experiments soils which tested high in nitrogen and phosphorus responded favorably to treatment with these elements. Two soils testing 163 and 310 pounds per acre of exchangeable K showed a response in alfalfa yields from potash fertilizer, but at the same time three other soils testing 204, 273, and 395 pounds showed no responses. In the Latin square experiment the exchangeable K level was 215 pounds per acre, but when large amounts of nitrogen and phosphorus were available oats responded to additions of potash. Growing conditions in the greenhouses are highly favorable but the root space is limited. This suggests the possibility of increased yields under field conditions in favorable seasons from applications of potash.

During the one field season weather conditions were not favorable for optimum yields of corn. Rainfall was inadequate during the summer and temperatures higher than normal prevailed. Under such conditions good correlation between soil analysis and response to fertilizer treatment might not be expected. As in the greenhouse trials, however, soils containing as much as 5,000 pounds per acre of nitrogen responded to nitrogen fertilizer. Response to phosphate was variable due to factors such as moisture and temperature rather than the supply of phosphorus in the soil.

The soil which produced 83.3 bushels per acre of corn in the field trials and showed no significant increase in yield from any fertilizer treatment carried the following amounts of nutrients per acre: total N, 3,520 pounds; available P, 102 pounds; and exchangeable K, 161 pounds. Other corn plots, averaging 81 pounds per acre of available P at the end of the season, showed a response to phosphate fertilizer. With about 13 pounds used by the corn crop the total at the start of the season was close to 95 pounds. We might conclude from this that 100 pounds per acre of readily

	Clarion silt loams	Webster silt loans
Pounds per acre of N	4,850	6,720
Pounds per acre of available P	106	148
Pounds per acre of exchangeable K	229	288
Per cent of P_2O_5 fixed	30.9	24.9
pH	5.9	6.4
Base exchange capacity	30.8	38.4
Moisture equivalent	28.1	33.4

available P is a minimum for corn. The nitrogen level for a fertile soil would appear to be close to 4,000 pounds per acre in this area. The corresponding figure for exchangeable K suggested by the tests is 165 pounds per acre.

In this connection we may well examine the analytical data for two very productive farms. Fifteen Clarion and 19 Webster soil samples from these farms averaged as shown above.

These data indicate in a general way the levels of nutrients and of some other characteristics to be expected in fertile soils in southwestern Minnesota.

With heavier applications of phosphate on the grain-legume-grass mixture it is conceivable that the phosphate needs of the corn crop could also be met, particularly since continued applications might possibly increase the amount of total phosphates in the soil. Maximum returns from the rotations might be obtained by increasing the yield of green manure and improving its quality with heavier applications of phosphate (plus potash when alfalfa is used), and by including brome or timothy with the legume to prolong the period of decomposition of the organic matter.

SUMMARY

It is generally believed that the maintenance of organic matter and nitrogen is one of the important problems in the corn belt. A large proportion of the important corn soils originally carried a grassland vegetation. Climatic conditions were such that the biological pressure was relatively low and organic matter accumulated. Under cultivation, however, decomposition and nitrification has been speeded up. The annual replacement of organic matter formerly made by the native grasses is not generally equalled.

As carried out thus far, the soil management program under investigation has laid stress on hay and pasture crops, on the following of an organized rotation, and on the use of green manures—a single application of phosphate fertilizer for the entire rotation.

While the soils under consideration carry very considerable amounts of nitrogen, the tests indicate a lack of readily available nitrogen. The use of 20 pounds of N per acre is advisable for optimum yields of small grains and, in particular, for oats. Various workers have stressed the importance of increasing the amount of nitrogen available to oats in order to improve their response to phosphate fertilizers.

There can be no doubt about the need of phosphate fertilizers on these soils. The present investigation raises the question as to whether 20 pounds of P_2O_5 per acre for each year of legume in the rotation is sufficient to meet the needs for maximum yields of all crops in the rotation. The results suggest that a larger amount might prove more profitable. Whether this fertilizer should all be applied in advance of the seeding of legume or whether it should be divided and a part applied for the corn crop is yet to be determined.

CONCLUSIONS

Experiments were conducted on certain Black Prairie and Chernozem soils of southwestern Minnesota with the object of determining their fertility levels with respect to the major plant nutrients: nitrogen, phosphorus, and potassium. Greenhouse experiments during the two winters, 1946-47 and 1947-48, field experiments during the 1947 growing season, and chemical analysis were used to help in the determination.

Assuming that a suitable management program is practiced on these soils, that is, a fertilized and inoculated legume or legume-grass mixture is included in an organized rotation and used as a green manure, the following conclusions seem to be justified:

1. Phosphate is usually the limiting nutrient, particularly for legumes and corn, but also for small grains. Applications of 20 pounds of P_2O_5 per acre for each year of legume in the rotation appear to be inadequate for maximum yields. Either a heavier application on the head of the legume or an extra application on the corn crop is needed.
2. Applications of 20 pounds per acre of N will be beneficial on small grains.
3. Nitrogen fertilizers on small grains increase the grains' response to phosphate fertilizers.
4. Potash fertilizers give little response as yet in these soils. Webster soils and soils high in N and available P show some response.
5. For the ordinary field crops in southwestern Minnesota a supply of about 100 pounds per acre of readily available P is essential, but other conditions such as the amount and distribution of rainfall may well raise or lower this level.
6. About 165 pounds per acre of exchangeable K seems to be a minimum.
7. The soils testing lowest in readily available P showed the greatest phosphate fixing power.
8. Correlation of base exchange capacity and exchangeable K appeared to be negative, and between base exchange capacity and moisture equivalent, positive.

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