



Restoring productivity to areas where the surface soil has been removed by land leveling
by John O Reuss

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree
of Master of Science in Soils

Montana State University

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Abstract:

Two field experiments using silage corn were conducted in the Yellowstone Valley on areas where the surface soil had been removed during land leveling operations. A greenhouse study using both surface soil and subsoil from one of these areas was conducted with barley as the indicator crop.

Greenhouse tests Subsoil to which both nitrogen and phosphorus had been added yielded an average of 10.4 grams of barley plant material per pot. Check pots yielded an average of 1.5 grams, and pots to which nitrogen alone had been added yielded 2.0 grams. - Pots receiving potash in addition to nitrogen and phosphorus yielded an average of 12.5 grams, a significant increase over the nitrogen plus phosphorus treatment. The addition of nitrogen, phosphorus, and potassium to the subsoil resulted in yields as high as those from similarly treated surface soil.

Field tests: On the subsoil of a Keiser clay loam, yields of corn silage were increased from 15.8 tons per acre to 21.8 tons by the addition of 150 pounds of N and 400 pounds of P₂O₅ per acre. On the subsoil of a Nunn clay loam, the addition of 100 pounds of N and 400 pounds of P₂O₅ per acre increased the yield of corn silage from 12.8 to 22.6 tons per acre.

On the Nunn subsoil, the application of 30 tons of manure per acre previous to plowing resulted in a yield of 19.8 tons of silage per acre as compared to a yield of 12.8 tons on the check. Manure disked into the ground surface after plowing did not increase yields on the Keiser subsoil.

The addition of commercial nitrogen and phosphorus and the application of manure previous to plowing increased the protein and phosphorus content of the corn considerably.

Soil analyses of the various horizons of the Keiser soil show that the levels of organic matter, nitrifiable nitrogen, and available phosphorus in the subsoil are extremely low. Exchangeable potassium is somewhat lower in the subsoil than in the surface soil.

The use of commercial nitrogen and phosphorus resulted in good yields from the subsoil in all experiments.

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Approved:

A. W. Post

Head, Major Department

J. C. Hilde

Chairman, Examining Committee

Leon Johnson

Dean, Graduate Division

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ABSTRACT

Two field experiments using silage corn were conducted in the Yellowstone Valley on areas where the surface soil had been removed during land leveling operations. A greenhouse study using both surface soil and subsoil from one of these areas was conducted with barley as the indicator crop.

Greenhouse test:

Subsoil to which both nitrogen and phosphorus had been added yielded an average of 10.4 grams of barley plant material per pot. Check pots yielded an average of 1.5 grams, and pots to which nitrogen alone had been added yielded 2.0 grams. Pots receiving potash in addition to nitrogen and phosphorus yielded an average of 12.5 grams, a significant increase over the nitrogen plus phosphorus treatment. The addition of nitrogen, phosphorus, and potassium to the subsoil resulted in yields as high as those from similarly treated surface soil.

Field tests:

On the subsoil of a Keiser clay loam, yields of corn silage were increased from 15.8 tons per acre to 21.8 tons by the addition of 150 pounds of N and 400 pounds of P_2O_5 per acre. On the subsoil of a Nunn clay loam, the addition of 100 pounds of N and 400 pounds of P_2O_5 per acre increased the yield of corn silage from 12.8 to 22.6 tons per acre.

On the Nunn subsoil, the application of 30 tons of manure per acre previous to plowing resulted in a yield of 19.8 tons of silage per acre as compared to a yield of 12.8 tons on the check. Manure disked into the ground surface after plowing did not increase yields on the Keiser subsoil.

The addition of commercial nitrogen and phosphorus and the application of manure previous to plowing increased the protein and phosphorus content of the corn considerably.

Soil analyses of the various horizons of the Keiser soil show that the levels of organic matter, nitrifiable nitrogen, and available phosphorus in the subsoil are extremely low. Exchangeable potassium is somewhat lower in the subsoil than in the surface soil.

The use of commercial nitrogen and phosphorus resulted in good yields from the subsoil in all experiments.

INTRODUCTION

Crop production is often unsatisfactory on areas from which the surface soil has been removed. When normal cultural practices are followed, the exposed subsoil is, in most cases, much less productive than the surface soils.

In the past, the main interest in the subsoil fertility problem has been from the standpoint of restoring productivity to eroded areas. This interest has been centered in the humid and subhumid areas where erosion is more pronounced. Some attention has also been given to the more arid areas where wind and water erosion have removed the comparatively thin surface soil.

Another phase of the problem has lately been becoming more acute in irrigated areas. This is the problem of restoring productivity to areas where the surface soil has been removed by land leveling operations. Larger and more efficient earthmoving equipment has made the leveling of uneven lands feasible. The cost of farm labor has made it imperative that irrigation time be cut to a minimum, and the tendency toward more intensive farming requires better control of irrigation water. As a result, more and more fields are being leveled for better irrigation.

This trend has been seriously retarded by the fact that many newly leveled fields are unproductive. The areas where subsoils have been exposed often do not produce satisfactory crops for many years after the leveling operation has been completed. Farmers are reluctant to level fields when there is a good chance that productivity may be seriously decreased, and this makes Soil Conservation Service and Extension Service

personnel reluctant to recommend the practice.

Experience indicates that the problem is most severe on well-developed soils where a heavy lime layer has been exposed.

In order to determine what deficiencies commonly exist in these subsoils and what treatments can be expected to be beneficial, three experiments were conducted. A greenhouse study was conducted on soil taken from a field on the Billings Bench, northeast of Billings, Montana, where a well-developed soil had been leveled. This greenhouse study was followed by a field test on this same area. A field test was also conducted on an alluvial soil on the Huntley Branch Station, Huntley, Montana.

The work was done cooperatively by the Montana Agricultural Experiment Station and the Soil and Water Conservation Research Division of the Agricultural Research Service, United States Department of Agriculture. Field aspects of the work were done at the Huntley Branch Station, while greenhouse and laboratory studies were conducted at Bozeman. Ralph Campbell, Soil Scientist, ARS, and John Reuss, of the Montana Agricultural Experiment Station, were in charge of the work. The results of these studies are reported in this paper.

REVIEW OF LITERATURE

The fact that subsoils are often much less productive than surface soils has been recognized by agriculturists and farmers for many centuries. It has only been in the past 50 years, however, that any real progress has been made in determining the reasons for this well-known phenomenon.

Hilgard (9) discussed this "rawness" of subsoils and presented data to show that the nitrogen content of the surface soil is usually much higher than that of the subsoil. Unfortunately, he maintained that this "rawness" was a problem only with humid soils. He states (page 166), "The irrigator levels, slopes, or terraces his land for irrigation with no thought or discrimination between soil and subsoil, and the cultural result as a rule justifies his apparent carelessness. It is only where from special causes a consolidated or hardpan subsoil is brought to the surface, that the land when leveled shows spotted crops". Hilgard also advocated the use of deep plowing in order to incorporate the subsoil lime with the surface soil, thereby enriching it.

Lipman (12) was one of the first to question Hilgard's views in regard to the productivity of arid subsoils. From his observations, he concluded that "subsoils of arid regions are certainly no less raw than those of semiarid regions and probably only slightly less so than those of humid regions".

Alway, et al. (1, 2), working with loess soils of eastern Nebraska, gives analyses demonstrating the lower nitrogen content of the subsoil as compared to the topsoil. He also showed by greenhouse tests that these subsoils were very unproductive for corn but they exhibited little or

no "rawness" toward inoculated legumes.

Harmer (7) demonstrated that several calcareous subsoils from grasslands in Minnesota did not produce inoculated legumes nearly as well as the surface soil. Some subsoils from forest areas, however, produced legumes nearly as well as the topsoil, while others exhibited considerable rawness. Working with the same samples of calcareous subsoils used by Harmer, McMiller (13) demonstrated that their "rawness" toward legumes could be practically eliminated by the addition of phosphorus and potash.

After about 1919, very little literature appeared on the subject of subsoil productivity until the late 1930's. In 1939, Rost (17) showed that the addition of nitrogen to several subsoils from Minnesota practically eliminated any "rawness" toward non-legumes, while the addition of phosphorus and potash resulted in satisfactory production of leguminous crops. Latham (11) found that the addition of barnyard manure to eroded Cecil sandy loam increased the productivity of the exposed B and C horizons to a fairly good level but did not bring them to as high a level of productivity as a similarly treated topsoil. Hays, et al. (8) found that the productivity of severely eroded but not gullied soils derived from loess in the upper Mississippi Valley can be restored to satisfactory production by fertilization, crop rotation, and increasing organic matter through the use of barnyard manure. Borst (4) noted that alfalfa seeded with 400 pounds per acre of 0-14-6 fertilizer did well on eroded land and provided erosion control.

Bactell, et al. (3) performed a series of experiments in Ohio using artificially desurfaced plots. Thirteen years' data indicated that sub-

soil yields increased in relation to the yields on surface soil with the passing of time. In 13 years, using moderate amounts of manure and low rates of phosphorus and potash (500 pounds per acre of 0-14-6 per 4-year rotation), yields on the subsoil increased from 32% to 89% of the yields on similarly treated surface soil. After 13 years, more liberal applications of fertilizer were applied, including some nitrogen, and yields on both surface soil and subsoil increased greatly. Subsoil plots then yielded about 90% as well as similarly treated surface soil plots. The yields on the subsoil plots receiving nitrogen (40 to 60 pounds per acre) were similar to those on the surface soils receiving no nitrogen. Bulk density and aggregation measurements were made after the experiment had run 13 years. No significant differences were evident between the cropped subsoils and comparable layers which had not been previously exposed.

A limited amount of research has been done using subsoils from the more arid regions. Post¹, working with subsoils from the lower Yellowstone Valley in Montana, found that oats grown in pots on subsoil responded very well to a green manure treatment of chopped clover. Some response was also obtained from the use of phosphorus. After completing a series of laboratory and greenhouse studies on Colorado subsoils, Gardner (6) concluded that a lack of available phosphorus and nitrogen accounted for a large part of the decrease in crop yields when topsoil was removed in leveling operations.

¹ Unpublished data, Annual Report of the Agronomy and Soils Department, Montana Agricultural Experiment Station, 1944-45.

Viets, et al. (23) found that zinc is often deficient in exposed high lime subsoils in eastern Washington.

Since 1945, a series of experiments by Whitney, Gardner, and Robertson (16, 24, 25) has been under way on desurfaced irrigated soils in Colorado. These experiments have shown that, on many high lime subsoils, good crop yields resulted when adequate amounts of phosphorus and nitrogen were supplied either in the form of commercial fertilizers or barnyard manure. The results also indicate that deep placement of fertilizer, especially phosphorus, is most effective. Carryover effects of nitrogen and phosphorus fertilizers, particularly phosphorus, have been evident. High applications of phosphorus have given responses for 8 to 10 years.¹ This demonstrates that phosphorus fixation by lime is not a serious hazard in many high lime subsoils. Nitrogen supplying capacity is usually reduced for many years.

¹ Personal communication with Dr. Robert S. Whitney, Agronomist (Soils), Colorado State University, Fort Collins, Colorado.

MATERIALS AND METHODS

Greenhouse Experiment Using Both Surface Soil and Subsoil

The soil used in the greenhouse study had been tentatively classified as a Keiser clay loam. A complete description of a profile examined near the edge of the leveled area is presented in the Appendix.

The field was leveled in the late summer of 1956 and was selected as an experimental site in October of that year. The land had been fall plowed previous to its selection as an experimental site. Unfortunately, a uniform application of approximately 15 tons per acre of barnyard manure had been applied previous to plowing.

Several bags of soil were collected from various parts of a desurfaced area on the field. Care was taken to not select soil that contained manure from the application made previous to plowing. Cut in this area varied from about 2.0 feet to 0.5 feet. Most of the cut area showed a heavy accumulation of lime. This indicates that the new plow layer after leveling was largely within the C_{ca1} and C_{ca2} horizons of the original profile. These horizons are strongly calcareous and contain splotches and nodules of calcium carbonate. Soil was also collected from the surface layer of an area adjoining the desurfaced area for comparative studies. The two soils were broken down to pass through a 3/8-inch mesh screen, and each was thoroughly mixed.

The experimental design selected was a complete factorial using two soils, three amendments, and five fertilizer treatments. Two replications were used for a total of 60 pots. Treatments were as follows:

- Soils:
1. Subsoil
 2. Surface soil
- Amendments:
1. None
 2. Manure
 3. Vermiculite
- Fertilizers:
1. None
 2. Nitrogen
 3. Nitrogen + Phosphorus
 4. Nitrogen + Phosphorus + Potassium
 5. Nitrogen + Phosphorus + Potassium
+ Trace Elements

The farm operator is interested in bringing the productivity of the leveled areas up to that of the remainder of the field. Thus it is desirable to compare the yields obtained from treatments on leveled areas with those obtained on normal soils. However, with increasing use of commercial fertilizers in the area, it appeared desirable to compare yields of leveled and normal soils at optimum fertility levels. For these reasons, all treatments were imposed on both surface soil and subsoil.

Manure was used as an amendment because it is the most common method of treating these exposed areas. It was added at the rate of 30 tons per acre, or 145 grams per pot. Manure influences both physical and nutritional properties of the soil.

Since physical condition is a factor that could cause reduced productivity, vermiculite was used as a method of improving the physical condition, which is often very poor on these subsoils. It was added at a rate sufficient to increase the original volume by one-fourth.

Fertilizer treatments were made with the following materials and rates:

Nitrogen at the rate of 200 pounds of N per acre, or 1.5 grams of ammonium nitrate per pot.

Phosphorus was used at the rate of 400 pounds of P_2O_5 per acre, or 2.3 grams of triple superphosphate per pot.

Potassium at the rate of 200 pounds K_2O per acre, or 1 gram KCl per pot.

Trace elements were supplied at the following rates: 10 pounds zinc, 10 pounds copper, 4 pounds boron, 40 pounds manganese, and 200 pounds magnesium per acre.

Rates of all treatments except vermiculite were calculated on the basis of the surface area of the pots. All treatments were thoroughly mixed with the soil before the soil was placed in the pots.

Oil cans of 5-quart capacity were used for pots. These are about 6.5 inches in diameter and 9.5 inches in depth. Ten pounds of soil were used in each pot.

Twenty seeds of Titan barley were planted in each pot at a depth of 1 inch on January 15, 1957. Artificial lighting was used to increase the length of day to 16 hours. This was supplied by four 150-watt incandescent bulbs placed approximately 3 feet above the plants.

Moisture characteristic curve data were obtained by the use of a pressure membrane apparatus after the methods of Richards (14, 15, 22). Pots were weighed periodically and allowed to dry to approximately 3 atmospheres tension before watering. Sufficient tap water was added to bring the moisture content to about $1/3$ atmosphere tension.

Pots were systematically rotated twice weekly to minimize the effect

of varying conditions within the greenhouse. Growth measurements were taken twice weekly, and the mean height of the plants in each pot was recorded.

Harvesting was done on March 7, approximately two weeks after heading. Green weights were recorded, and the samples were dried at about 70° C. and reweighed.

Field Experiment on Paul Creek Farm, Northeast of Billings, Montana

This experiment was conducted on the area from which the subsoil for the greenhouse experiment had been taken. The area had been fall plowed and had had a uniform application of 15 tons per acre of barnyard manure previous to plowing. Results of the greenhouse experiment were considered in selecting the treatments used in this experiment. Ten treatments were selected. These are given in table I.

Table I. Treatments used on field experiment on Keiser subsoil.

	Treatments			
	Lbs. N/A	Lbs. P ₂ O ₅ /A		
1.	0	0		
2.	150	0		
3.	300	0		
4.	0	400		
5.	150	400		
6.	300	400		
7.	300	400	+	100 lbs. K ₂ O per acre
8.	0	0	+	30 tons Manure per acre
9.	150	400	+	30 tons Manure per acre
10.	300	200		

The first six treatments comprise a 3N x 2P factorial. The remaining treatments were selected as representing possible practical treatments. Silage corn was the selected crop.

The treatments were laid out in a randomized block pattern. Plot size was 12 feet by 30 feet. A field layout diagram is given in figure 4 in the Appendix. An irregular pattern was necessary due to the shape of the desurfaced area.

Seventy-five percent of the P₂O₅ and 90 percent of the N desired on each plot was applied on May 7, 1957. Anhydrous ammonia (82% N) was used

as a source of nitrogen and phosphoric acid (52% P_2O_5) was used as a phosphorus source. Application was made with a commercial applicator, using shoes spaced 12 inches apart and running 6 inches deep. This method of application was used to secure deep placement since the area had already been plowed. The applicator was not well adapted for plot work, and considerable difficulty was encountered in getting a uniform application on the plots.

The manure treatments were spread on the ground surface and disked in, as was the potassium treatment. Potassium was supplied in the form of KCl (60% K_2O).

The remaining portion of the fertilizer was applied in a band 4 inches deep and 4 inches to the side of the row at planting time. Triple superphosphate (42% P_2O_5) was used as a phosphorus source and ammonium nitrate (33% N) as a nitrogen source for this application.

The area was planted to DeKalb 46 hybrid corn on May 26. Rows were spaced 36 inches apart. Fair stands were obtained over the entire area, but unfortunately, shortly after emergence the area was cultivated twice by an inexperienced operator and considerable corn was either cut out or covered. This made it impossible to thin to a uniform stand, so the area was not hand thinned.

Plots were cut on September 9. Yield samples were taken from a 20-foot length from each of two rows from each plot. Each sample was weighed immediately. A subsample was dried at 70° C. to constant weight and reweighed. Samples were then ground and thoroughly mixed for analysis. Stalk counts were made of each plot at harvest.

The soil profile was examined at two locations on an undisturbed area adjacent to the desurfaced area on August 16, 1957. At this time, the soil profile was described, and this description is included in the Appendix. Samples of soil from each profile horizon or subhorizon at both locations were taken at this time.

Field Experiment on the Huntley Branch Station, Huntley, Montana

This experiment was conducted on Field P of the Huntley Branch Station. The field was leveled in the summer of 1956 and a desurfaced area selected for the experiment. Cut on the area varied from 2.0 feet to 0.4 feet.

The soil has been tentatively classified as Nunn clay loam. It is alluvial and of comparatively recent origin. Little soil development had taken place, and there is very little evidence of a lime layer. The subsoil includes stratified materials ranging from loamy sand to clay loam. The cut area had exposed a sandy layer of considerably lighter texture than the surface soil. A complete profile description is given in the Appendix.

The treatments were laid out in a randomized block pattern with three replications, as shown in figure 5 of the Appendix. Plot size was 20 feet by 30 feet. Table II shows the treatments selected. The manure and phosphorus treatments were applied to the ground surface in the fall of 1956. Land was then fall plowed and irrigated.

The area was planted June 1, 1957, to Funks G-35A hybrid corn, planted in 36-inch rows. Nitrogen was applied at planting time in a band 3 inches to the side of the row and 3 to 4 inches deep. Ammonium nitrate was used as a nitrogen source.

The corn was hand thinned on June 25 to a stand of 45 plants per 30-foot row, which is equivalent to a population of about 22,000 plants per acre.

Table II. Treatments used on field experiment on Nunn subsoil.

	Treatments			
	Lbs. N/A	Lbs. P ₂ O ₅ /A		
1.	0	0		
2.	400	0		
3.	0	400		
4.	100	400		
5.	200	400		
6.	400	400		
7.	0	0	+	30 tons Manure per acre
8.	400	0	+	30 tons Manure per acre
9.	0	400	+	30 tons Manure per acre
10.	100	400	+	30 tons Manure per acre
11.	200	400	+	30 tons Manure per acre
12.	400	400	+	30 tons Manure per acre

The crop was harvested at silage stage, September 9. Four rows 20 feet long were cut from each plot and weighed. A sample of 12 to 15 stalks was taken at random and dried at about 70° C. The dried samples were then weighed and the percent moisture calculated. These moisture percentages were used to calculate the dry matter yields. The dried samples were ground and a subsample taken for analysis.

Analytical Methods Used on Soil and Plant Samples

Plant Analysis. Phosphorus determinations on the plant material were made by Mr. David Dickey of the Agricultural Research Service at Bozeman, Montana, using a colorimetric procedure employing ammonium molybdate and ammonium vanadate reagents for color development. Nitrogen determinations were run by the State Grain Laboratory at Montana State College, using a standard Kjeldahl procedure.

Soil Analysis. Cation exchange capacity was determined by saturating the exchange complex with sodium from sodium acetate and replacement of sodium using ammonium acetate. The extracted sodium was determined using a flame photometer. Soluble sodium and potassium were determined on the saturation extract using the flame photometer. Soluble calcium plus magnesium was then determined on the extract by versenate titration. Exchangeable potassium was determined in an ammonium acetate extract, using the flame photometer. The procedures given in USDA Handbook No. 60 (22) were followed for these analyses. Total soil nitrogen was determined by the Kjeldahl method as described by Jackson (10---page 183).

Organic matter determinations were made by the Walkley-Black chromic acid digestion method (10---page 219). Total carbon was calculated from these results by assuming a factor of 0.77 as representing that portion of the total organic carbon oxidizable by this method. Nitrifiable nitrogen was determined by the method of Stanford and Hanway (20), using a soil-vermiculite mixture incubated for two weeks. Nitrates were then determined by a colorimetric procedure, using phenoldisulphonic acid. Sodium bicarbonate extraction was used to determine available phosphorus (10---

page 163).

Mechanical analyses were run using the Bouyoucos hydrometer. A settling time of 40 seconds was allowed for the sand fraction and 2 hours for the sand plus silt. Moisture characteristics data were obtained using the pressure membrane apparatus of Richards (14, 15, 22).

Statistical Methods. The standard analysis of variance for randomized block experiments was used in most cases. Where applicable, the analysis for factorial arrangement of treatments as given by Cochran and Cox (5) was used. Mean separation was accomplished by use of an L.S.D. or by use of the S.S.R. test of Duncan (21).

EXPERIMENTAL RESULTS

Results of Greenhouse Experiment Using Both Surface Soil and Subsoil

Pots were planted January 15. By January 23, emergence was practically complete. Stands were excellent and no differences in emergence were noted between the various treatments. Height measurements taken twice weekly starting 9 days after emergence indicate that increases in height were nearly linear until about 37 days after emergence. Little or no increase in height occurred after the 37th day. The manured subsoil with no commercial fertilizer added was the only treatment that did not follow this pattern. The reduced growth on this treatment was not evident until about 19 days after emergence. Data from these measurements are included in the Appendix.

The results of mechanical analysis on these soils are given in table III.

Table III. Results of mechanical analysis (hydrometer method) on surface soil and subsoil used in greenhouse pot experiment.

	% Sand	% Silt	% Clay
Subsoil	45	16	39
Surface soil	48	19	33

These show the subsoil to be slightly higher in clay and lower in sand and silt than the surface soil. Moisture tension curves are given in figure 1. Even though higher in clay, the subsoil shows a lower water content at all tensions. This is undoubtedly due to lower organic matter content. The moisture released as tension increases from $1/3$ to 3 atmospheres is similar for the two soils.

Extreme chlorosis and reduced growth were apparent on the subsoil pots receiving no fertilizer, and considerable purple coloring was present in the stems. The pots to which commercial nitrogen without phosphorus was added were not quite as chlorotic as the checks, but growth improvement was slight except on the manure plus nitrogen treatment. Growth on these pots was greater than on pots receiving either manure or nitrogen alone but less than on pots to which both nitrogen and phosphorus had been added.

Yields of the individual pots and their percentage dry matter are given in table IV. These are total dry matter yields. The greenhouse experiment was terminated before grain yields were secured so that the data could be used in planning treatments for the field experiment. In most cases, duplication between replications was good.

Mean dry matter yields for all treatments are shown in table V. The analysis of variance of the dry matter yields for the complete experiment is given in table VI. The effects of fertilizers, amendments, and soils, as well as all interactions, are highly significant.

The yields from the subsoil pots were analyzed separately to determine the effect of the treatments on the subsoil. This analysis is given in table VII. Yield differences for the various fertilizer treatments, amendments, and the fertilizer by amendment interaction are all highly significant. Mean separation of the fertilizer effects indicates that the NPK + trace element treatment was not significantly different from either the NP or the NPK treatments, but the NPK treatment was significantly higher than the NP. All other treatments were significantly different.

The analysis of variance for the percentage dry matter is shown in

table VIII. The unfertilized treatment had the highest percent dry matter, the N treatment the lowest, and the NP, NPK, and NPK + trace element treatments were intermediate. The amendments, averaged for all fertility levels, show that the manure resulted in the highest dry matter percentage, vermiculite intermediate, and no amendment the lowest.

Table IV. Yields of dry matter and dry matter percentages for each treatment and replication for surface soil and subsoil. Greenhouse study, 1957.

Treatment	Dry Matter Yield, gms./pot				% Dry Matter			
	Subsoil		Surface soil		Subsoil		Surface soil	
	I	II	I	II	I	II	I	II
None	1.7	1.3	8.7	7.8	21.2	19.1	24.2	25.2
N	2.2	1.8	9.2	10.1	17.1	17.8	19.7	18.7
NP	9.1	11.6	12.8	11.9	19.6	19.6	21.5	19.8
NPK	12.3	12.7	11.0	13.0	19.7	20.4	19.5	19.4
NPKT	13.3	10.7	11.5	12.7	21.0	20.1	21.0	20.5
Manure	2.8	2.8	8.6	9.1	22.4	24.7	22.8	24.0
Manure + N	8.4	8.6	10.8	11.1	22.0	19.5	20.5	21.3
Manure + NP	13.5	11.6	13.3	13.6	20.9	21.4	20.6	21.4
Manure + NPK	12.6	12.1	11.6	12.3	21.5	20.2	20.9	22.8
Manure + NPKT	12.5	12.8	12.6	12.7	21.5	21.3	21.6	21.5
Vermiculite	1.3	1.4	7.1	8.2	21.3	22.2	19.3	26.1
Ver. + N	1.1	1.6	9.1	11.1	14.3	19.5	23.0	20.6
Ver. + NP	13.5	12.6	15.0	14.6	21.0	21.2	20.7	21.9
Ver. + NPK	14.4	15.1	13.5	14.7	21.0	19.7	22.1	21.9
Ver. + NPKT	13.0	13.5	14.4	15.0	20.5	20.9	20.4	22.5

Table V. Mean dry matter yields of barley from various treatments on both subsoil and surface soil. Greenhouse study, 1957.

Fertilizer	Subsoil Amendment				Surface Soil Amendment				Grand Ave.
	None	Manure	Vermic-	Ave.	None	Manure	Vermic-	Ave.	
			ulite				ulite		
O	1.5	2.8	1.4	1.9	8.2	9.6	7.2	8.3	5.1
N	2.0	8.5	1.4	4.0	9.6	11.0	10.1	10.2	7.1
NP	10.4	12.5	13.0	12.0	12.4	13.4	14.8	13.5	12.8
NPK	12.5	12.4	14.8	13.2	12.0	12.0	14.1	12.7	13.0
NPKT	12.0	12.6	13.2	12.6	12.1	12.2	14.7	13.0	12.8
Ave.	7.7	9.8	8.7	8.7	10.9	11.6	12.2	11.5	

Table VI. Analysis of variance of dry matter yields of barley from surface soil and subsoil. Greenhouse study, 1957.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	59	1,059.03	
Replications	1	0.86	0.86
Amendments	2	23.49	11.75 **
Fertilizers	4	687.69	171.92 **
Soils	1	120.98	120.98 **
Amend. x Fert.	8	56.46	7.06 **
Amend. x Soils	2	8.37	4.18 **
Soils x Fert.	4	127.87	31.97 **
Amend. x Fert. x Soils	8	16.55	2.07 **
Error	29	16.77	0.5872

C.V. = 7.55%

S.S.R. Mean Separation (Fertilizers), 5% Level

	O	N	NP	NPKT	NPK
$\bar{y}$ gms./pot	5.1	7.1	<u>12.8</u>	12.8	<u>13.0</u>

Table VII. Analysis of variance of dry matter yields of barley from subsoil. Greenhouse study, 1957.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	29	784.92	
Replications	1	0.07	0.700
Amendments	2	22.05	11.025 **
Fertilizers	4	693.16	173.290 **
Fert. x Amend.	8	60.08	7.510 **
Error	14	9.56	0.6829

C.V. = 9.5%

Fertilizers - S.S.R. Mean Separation, 5% Level

	O	N	NP	NPKT	NPK
$\bar{y}$ gms./pot	1.9	4.0	<u>12.0</u>	<u>12.6</u>	13.2

Amendments

	None	Manure	Vermiculite
$\bar{y}$ gms./pot	7.7	9.8	8.7

L.S.D._{.05} = 0.6L.S.D._{.01} = 0.8

All differences highly significant.

Amendments x Fertilizers - S.S.R. Mean Separation, 5% Level

Amend.	V	V	O	O	M	M
Fert.	O	N	O	N	O	N
$\bar{y}$ gms./pot	<u>1.4</u>	<u>1.4</u>	<u>1.5</u>	<u>2.0</u>	<u>2.8</u>	8.5

Amend.	O	M	O	M	O	M	V	V	V
Fert.	NP	NP	NPKT	NPK	NPK	NPKT	NP	NPKT	NPK
$\bar{y}$ gms./pot	<u>10.4</u>	<u>12.0</u>	<u>12.0</u>	12.4	12.5	12.6	<u>13.0</u>	<u>13.2</u>	14.8

Table VIII. Analysis of variance of dry matter percentages of barley from surface soil and subsoil. Greenhouse study, 1957.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	59	203.80	
Replications	1	2.63	2.63 N.S.
Amendments	2	19.29	9.64 *
Fertilizers	4	63.26	15.80 **
Soils	1	18.00	18.00 **
Amend. x Fert.	8	7.23	0.90 N.S.
Amend. x Soils	2	6.14	3.07 N.S.
Soils x Fert.	4	9.16	2.29 N.S.
Amend. x Soils x Fert.	8	21.30	2.66 N.S.
Error	29	56.79	1.958

Fertilizers - S.S.R. Mean Separation, 5% Level

	N	NPK	NP	NPKT	O
$\bar{y}$ gms./pot	19.5	<u>20.8</u>	20.8	<u>21.1</u>	22.7

Amendments

	None	Manure	Vermiculite
$\bar{y}$ gms./pot	20.2	21.6	21.0

L.S.D._{.05} = 0.6Soils

	Subsoil	Surface Soil
$\bar{y}$ gms./pot	20.4	21.5

Significant at 1% level.

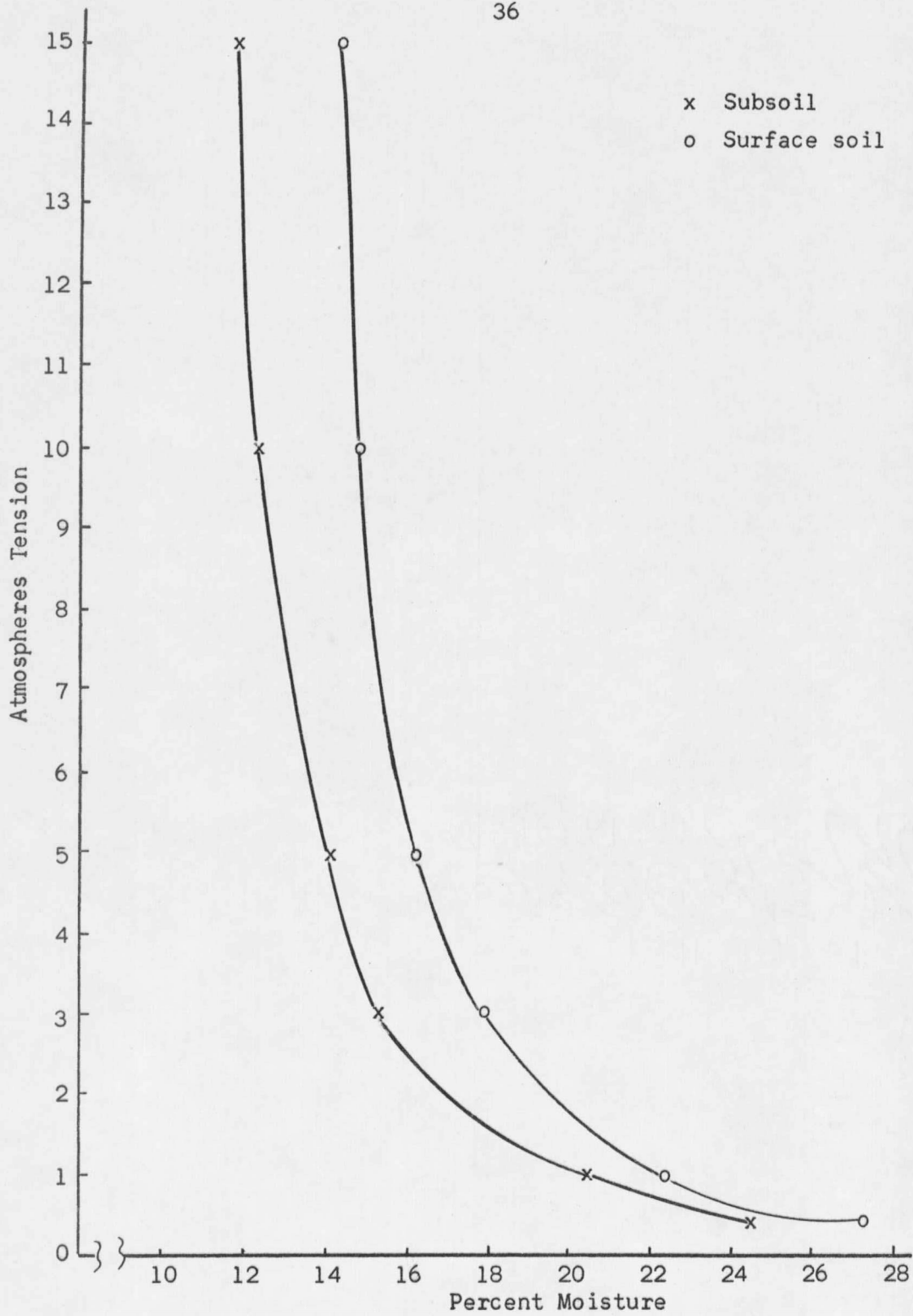


Figure 1. Moisture tension curves for surface soil and subsoil used in greenhouse pot experiment.

Results of Field Experiment on Keiser Subsoil

Plant Growth Characteristics. Severe purpling of the young corn plants was evident on the plots that did not receive phosphorus. This effect disappeared during the later stages of growth. Definite chlorosis was evident during the later stages on those plots not receiving additional nitrogen.

Plant Yields. Green weight yields of corn silage from all plots are reported in table IX.

Dry weight yields are reported in table X. S.S.R. mean separation is given in terms of tons of silage per acre at 70% moisture. Table XI presents the analysis of variance of the first six treatments as a $3N \times 2P$ factorial. This analysis shows a highly significant nitrogen effect and an $N \times P$ interaction that approaches significance.

Dry matter percentages are given in table XII. A highly significant difference due to treatment is shown by the analysis of variance. This was largely a lowering of dry matter percentage on the plots receiving nitrogen fertilizer but not additional phosphorus. Phosphorus fertilizer when used alone did not influence the percentage dry matter in the crop. When phosphorus was used in combination with nitrogen, the influence of nitrogen on dry matter percentage was reduced.

The number of stalks per plot at harvest is shown in table XIII. Analysis of covariance to adjust yields, using stalk counts as an independent variable, was impractical due to the fact that the stalk counts were not independent of treatment. This adjustment would be desirable because of poor stands. However, nitrogen should influence stalks per plant and

apparently did. This is shown by the analysis of variance in table XIII. The analysis of variance for the number of stalks per plot on treatments 1 to 6, analyzed as a factorial, is shown in table XIV. This shows a significant N x P interaction as the main factor in increasing the number of stalks per plot at harvest.

Yield samples taken from plots on adjacent surface soil averaged 21.7 tons per acre, or about the same as the average from the top-yielding treatment on the desurfaced area.

Table XV shows the phosphorus content of the dried plant material. The effect of treatment is highly significant. Table XVI shows the analysis of variance of treatments 1 to 6 as a 3N x 2P factorial. The effect of nitrogen fertilization on the phosphorus content is highly significant, while phosphorus fertilization had little or no effect. The N x P interaction approaches significance at the 5% level.

Table XVII shows the protein content of the plant material. There is a highly significant difference due to treatment, practically all of which is due to nitrogen fertilization.

The total pounds of P_2O_5 per acre taken up by the above-ground portions of the plant are given in table XVIII. The increase in uptake due to treatment is relatively small. The greatest uptake was on the 150-400-0 treatment. The mean uptake for this treatment was 55.6 pounds of P_2O_5 per acre, an increase over the check of only 19.4 pounds of P_2O_5 . The analysis of variance shows the effect of treatments to be highly significant. The factorial analysis of treatments 1 to 6, given in table XIX, shows that most of the increase in total uptake was due to

nitrogen fertilization. The N x P interaction is significant at the 5% level, and the phosphorus effect approaches significance.

The total uptake of nitrogen is given in table XX. Maximum uptake was 155 pounds per acre on the 300-0-0 treatment, with the 150-400-0 treatment and the 150-400-0 + manure approaching this figure with 153 and 152 pounds per acre, respectively. This compares with 95 pounds per acre on the check. Recovery of added nitrogen was 39% on the 150-400-0 treatment and 20% on the 300-0-0 treatment.

Table IX. Green weight yields of corn harvested for silage from field experiment on Keiser subsoil.¹

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	90.4	78.5	79.4	75.8	83.1	81.4
2. 150-0-0	102.7	106.2	95.6	115.5	95.7	103.1
3. 300-0-0	107.1	90.2	109.8	100.0	124.1	106.2
4. 0-400-0	70.4	82.9	94.7	91.2	83.7	84.6
5. 150-400-0	121.2	99.4	102.7	109.4	116.1	109.8
6. 300-400-0	79.5	102.1	74.6	112.4	106.0	94.8
7. 300-400-100	98.0	103.3	100.9	125.1	110.9	107.6
8. Manure, 30 T/A	64.4	90.7	89.4	91.9	92.0	85.7
9. 150-400-0 + M	90.8	105.6	115.9	113.0	116.5	108.3
10. 300-200-0	94.1	90.1	120.9	69.1	96.8	94.2

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	11,017.30	
Replications	4	722.81	180.70 N.S.
Treatments	9	5,306.40	589.60 **
Error	36	4,988.49	138.57

L.S.D. .05 = 15.1

L.S.D. .01 = 20.2

C.V. = 12.0%

¹ Yields are in pounds harvested per plot (120 square feet).

Table X. Dry weight yields of corn harvested for silage from field experiment on Keiser subsoil.¹

Treatment	Replication					Mean lbs./ plot	Tons/ acre-70% moisture
	I	II	III	IV	V		
1. 0-0-0	27.5	27.2	23.1	23.4	26.6	25.6	15.8
2. 150-0-0	25.9	31.0	27.2	34.6	27.9	29.3	18.1
3. 300-0-0	30.2	24.9	30.7	30.0	36.1	30.4	18.8
4. 0-400-0	22.1	26.9	30.2	27.4	26.1	26.5	16.4
5. 150-400-0	39.9	29.8	32.9	36.0	37.3	35.2	21.8
6. 300-400-0	25.6	31.1	24.2	32.8	31.4	29.0	18.0
7. 300-400-100	32.4	31.0	29.2	30.9	31.8	31.0	19.2
8. Manure, 30 T/A	19.6	28.1	25.5	26.8	25.2	25.0	15.5
9. 150-400-0 + M	33.5	29.0	36.0	32.7	32.3	32.7	19.6
10. 300-200-0	26.7	26.8	36.5	23.0	30.6	28.7	17.7

¹ Yields of individual plots are reported on the basis of pounds harvested per plot (120 square feet).

Table X continued.

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	915.91	
Replications	4	32.14	8.04
Treatments	9	452.70	50.30**
Error	36	431.07	11.97

L.S.D. .05 = 4.4
 .01 = 6.0

C.V. = 11.8%

S.S.R. Mean Separation, 5% Level (figures are tons silage per acre)

<u>Treatment</u>	<u>Yield</u>
0-0-0 + Manure	15.5
0-0-0	15.8
0-400-0	16.4
300-200-0	17.7
300-400-0	18.0
150-0-0	18.1
300-0-0	18.8
300-400-100	19.2
150-400-0 + Manure	19.6
150-400-0	21.8

Table XI. Analysis of variance as a 3N x 2P factorial of dry weight yields of treatments 1 to 6 of corn harvested for silage from field experiment on Keiser subsoil.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	29	572.25	
Nitrogen	2	194.22	97.11 **
Phosphorus	1	25.02	25.02 N.S.
N x P	2	67.05	33.52 (Sig. at 10% level)
Error	24	285.96	11.91

Table XII. Percentage dry matter of corn harvested for silage from field experiment on Keiser subsoil.

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	30.4	34.7	29.1	30.9	32.0	31.42
2. 150-0-0	25.3	29.2	28.5	30.0	29.2	28.44
3. 300-0-0	28.2	27.5	28.0	30.0	29.1	28.56
4. 0-400-0	31.4	32.5	31.9	30.1	31.2	31.42
5. 150-400-0	32.2	30.0	32.0	32.9	32.1	31.84
6. 300-400-0	32.2	30.5	32.5	29.2	29.7	30.82
7. 300-400-100	33.1	30.0	28.9	24.7	28.7	29.08
8. Manure, 30 T/A	30.5	31.0	28.6	29.2	27.4	29.30
9. 150-400-0 + M	31.7	31.9	31.1	28.9	27.7	30.26
10. 300-200-0	29.7	28.5	30.2	33.3	31.6	30.60

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	194.35	
Replications	4	4.18	1.04 N.S.
Treatments	9	70.23	7.80 *
Error	36	119.94	3.33

$$\text{L.S.D.}_{.05} = 2.34$$

Table XIII. Number of corn stalks harvested per 40 feet of row from field experiment on Keiser subsoil.

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	62	63	54	51	54	56.8
2. 150-0-0	57	63	52	59	52	56.6
3. 300-0-0	61	60	62	62	63	61.6
4. 0-400-0	54	56	54	59	52	55.0
5. 150-400-0	70	74	59	60	65	65.6
6. 300-400-0	58	59	46	69	62	58.8
7. 300-400-100	62	72	63	72	63	66.4
8. Manure, 30 T/A	48	54	56	60	58	55.2
9. 150-400-0 + M	73	56	70	65	60	64.8
10. 300-200-0	57	55	64	50	50	55.2

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	2,154	
Replications	4	96	24.00 N.S.
Treatments	9	953	105.90 **
Error	36	1,105	30.69

L.S.D. .05 = 7.13

.01 = 9.55

Table XIV. Analysis of variance as a 3N x 2P factorial of number of corn stalks harvested per 40 feet of row from treatments 1 to 6 of field experiment on Keiser subsoil.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	29	1,066.0	
Replications	4	217.6	54.4 N.S.
Nitrogen	2	154.6	77.3 (Approaches sig. at 5%)
Phosphorus	1	16.2	16.2 N.S.
N x P	2	214.0	107.0 *
Error	20	463.6	23.2

Table XV. Phosphorus percentages of total dry plant material from corn harvested for silage from field experiment on Keiser subsoil.

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	.160	.176	.165	.205	.149	.171
2. 150-0-0	.139	.144	.154	.182	.200	.161
3. 300-0-0	.205	.200	.170	.205	.205	.197
4. 0-400-0	.149	.154	.160	.160	.176	.160
5. 150-400-0	.193	.176	.170	.200	.218	.194
6. 300-400-0	.182	.188	.212	.188	.232	.200
7. 300-400-100	.182	.188	.182	.205	.225	.196
8. Manure, 30 T/A	.149	.160	.160	.182	.205	.171
9. 150-400-0 + M	.165	.170	.200	.212	.218	.193
10. 300-200-0	.193	.182	.225	.200	.200	.200
Mean	.172	.174	.180	.194	.203	.184

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	.027436	
Replications	4	.007236	.001809**
Treatments	9	.011542	.001282**
Error	36	.008658	.0002405

L.S.D. for treatment

.05 = .020

.01 = .027

Table XVI. Analysis of variance as a 3N x 2P factorial of phosphorus percentages of total plant material of corn harvested for silage from treatments 1 to 6 of field experiment on Keiser subsoil.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	29	.017091	
Replications	4	.003412	.000853 N.S.
Nitrogen	2	.005676	.002838 **
Phosphorus	1	.000326	.000326 N.S.
N x P	2	.001921	.000960 (Sig. at 10% level)
Error	20	.005756	.0002878

Table XVII. Protein percentages¹ of total dry plant material from corn harvested for silage from field experiment on Keiser subsoil.

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	6.3	6.9	6.6	5.3	6.8	6.38
2. 150-0-0	8.8	6.8	8.2	7.1	8.8	7.94
3. 300-0-0	9.2	9.3	8.0	8.8	8.7	8.80
4. 0-400-0	6.4	6.1	8.8	5.9	6.9	6.82
5. 150-400-0	8.4	7.7	8.2	5.3	7.9	7.50
6. 300-400-0	9.2	8.0	7.0	9.0	8.2	8.28
7. 300-400-100	8.7	8.4	7.9	8.4	8.7	8.42
8. Manure, 30 T/A	6.0	7.1	7.3	6.5	6.0	6.58
9. 150-400-0 + M	7.6	8.0	8.2	8.2	8.1	8.02
10. 300-200-0	9.1	8.4	8.8	9.1	9.0	8.88

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	60.62	
Replications	4	2.54	0.635 N.S.
Treatments	9	36.95	4.106 **
Error	36	21.13	0.587

L.S.D. .05 = 0.99
 .01 = 1.32

¹ Protein = N x 6.25.

Table XVIII. Total pounds of P_2O_5 per acre taken up by corn grown for silage on Keiser subsoil.

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	36.6	39.8	31.7	40.0	33.0	36.2
2. 150-0-0	30.0	37.1	34.8	52.3	46.3	40.1
3. 300-0-0	51.5	41.4	39.3	51.3	61.5	49.0
4. 0-400-0	27.5	34.4	40.1	36.5	38.8	35.5
5. 150-400-0	64.1	43.6	46.5	60.0	63.8	55.6
6. 300-400-0	38.7	47.0	42.6	51.4	56.0	47.1
7. 300-400-100	48.5	49.0	44.1	52.7	59.5	50.8
8. Manure, 30 T/A	24.3	37.4	33.9	39.0	43.0	35.5
9. 150-400-0 + M	46.0	41.0	59.8	57.6	58.5	52.6
10. 300-200-0	42.9	40.5	68.4	38.2	50.9	48.2
Mean	41.0	41.1	44.1	47.9	51.1	45.1

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	5,179.97	
Replications	4	777.21	194.30*
Treatments	9	2,578.18	286.46**
Error	36	1,824.58	50.68

L.S.D. .05 = 9.2
 .01 = 12.3

Table XIX. Analysis of variance as a 3N x 2P factorial of total pounds of P_2O_5 taken up by corn grown for silage on treatments 1 to 6 of field experiment on Keiser subsoil.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	29	2,966.75	
Nitrogen	2	979.54	489.77 **
Phosphorus	1	143.38	143.38 (Sig. at 10% level)
N x P	2	467.33	233.66 **
Replications	4	586.85	146.71 *
Error	20	789.65	39.48

Table XX. Total pounds of N per acre taken up by corn grown for silage on Keiser subsoil.

Treatment	Replication					Mean
	I	II	III	IV	V	
1. 0-0-0	101	109	89	72	105	95
2. 150-0-0	132	122	130	143	143	134
3. 300-0-0	161	135	143	153	182	155
4. 0-400-0	82	95	155	94	105	106
5. 150-400-0	195	133	157	111	171	153
6. 300-400-0	137	145	99	171	149	140
7. 300-400-100	164	151	134	151	158	152
8. Manure, 30 T/A	68	116	108	102	88	96
9. 150-400-0 + M	148	135	124	152	152	142
10. 300-200-0	141	126	182	122	160	146

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	49	42,928	
Treatments	9	25,110	2,790 **
Replications	4	1,404	351 N.S.
Error	36	16,414	455.9

L.S.D._{.05} = 27.2
 .01 = 36.9

Table XXI. Analysis of variance as a 3N x 2P factorial of total pounds of N taken up by corn grown for silage on treatments 1 to 6 of field experiment on Keiser subsoil.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	29	28,091	
Nitrogen	2	13,512	6,756 **
Phosphorus	1	208	208 N.S.
N x P	2	1,569	769 N.S.
Replications	4	1,560	390 N.S.
Error	20	11,242	562

Results of Field Experiment on Nunn Subsoil

Plant Growth Characteristics. Good stands were obtained throughout the experiment. As in the previous experiment, those plots not receiving phosphorus showed severe purpling in the early stages. This effect disappeared in the later stages. Chlorosis and firing of the lower leaves, indicating nitrogen deficiency, was noted during the later stages on the plots receiving neither commercial nitrogen nor manure. This effect was more pronounced on those plots receiving phosphorus than on the check plots.

Plant Yields. Green weight yields are given in table XXII. Analysis of variance shows a highly significant difference due to treatment. Dry matter yields are reported in table XXIII. Analysis of variance shows significance at the 1% level due to treatment. Mean separation by the S.S.R. method shows that all treatments receiving either manure or both nitrogen and phosphorus fertilizers were significantly different from the check and those receiving only nitrogen or phosphorus fertilizer alone. This indicates that the N x P interaction is significant. Table XXIV shows an analysis of variance of the dry matter yields as a factorial experiment with six fertilizer and two manure treatments. This analysis shows that the fertilizer effect, the manure effect, and the fertilizer by manure interaction are all highly significant.

Figure 2 shows a graphic presentation of the yield data. When adequate phosphorus was supplied, the effect of rates of nitrogen was not linear but reached a maximum at about 100 pounds of nitrogen per acre.

Table XXV shows percentage dry matter. A significant difference

due to treatment is shown by the analysis of variance. The mean separation is rather difficult to interpret, but apparently the difference in moisture content is tied up with the nitrogen-phosphorus balance.

The phosphorus content of the plant material is shown in table XXVI. A highly significant difference due to treatment is shown by the analysis of variance. Additions of phosphorus and manure tended to increase the phosphorus content of the plant. Nitrogen fertilization had little or no effect on the phosphorus content of the plant material in this experiment.

The protein content of the plant material is shown in table XXVII. A highly significant difference due to treatment is shown by the analysis of variance. This increase is due almost entirely to nitrogen fertilization or the addition of manure. The effect of nitrogen rates on protein content is shown in figure 3. When adequate phosphorus was supplied, the protein content reached a maximum when 200 pounds of fertilizer nitrogen were applied per acre.

Total uptake of phosphorus by the above-ground portions of the plant is given in table XXVIII. The effect of treatment is highly significant. The uptake was affected by phosphorus fertilization, by nitrogen fertilization, and by the addition of manure. The greatest total uptake was 72.6 pounds of P_2O_5 per acre on the 400-400 + manure treatment. This compares to 27.1 pounds of P_2O_5 per acre on the check. The highest uptake attained without manure was 64.9 pounds of P_2O_5 per acre on the 200-400 treatment.

The total pounds of nitrogen per acre taken up by the above-ground portions of the plant are shown in table XXIX. A highly significant difference due to treatments is shown by the analysis of variance. The

total uptake of nitrogen was increased by nitrogen fertilization, phosphorus fertilization when used in addition to nitrogen fertilization, and by the use of manure. The 100-400 treatment resulted in an uptake of 153.5 pounds of nitrogen per acre as compared to 52.3 pounds on the 0-400 treatment and 56.3 pounds on the check. This is virtually 100% recovery of the 100 pounds per acre of added nitrogen. The total uptake on the 200-400 treatment was 171.5 pounds per acre, or a recovery of about 58% as compared to the check. Maximum uptake was 194.5 pounds of nitrogen per acre on the 400-400 + manure treatment.

Table XXII. Green weight yields of corn harvested for silage from field experiment on Nunn subsoil.¹

Treatment	Replication			Mean
	I	II	III	
1. 0-0	136	152	151	146
2. 400-0	172	204	174	183
3. 0-400	93	101	177	124
4. 100-400	216	218	255	229
5. 200-400	237	237	239	238
6. 400-400	234	236	221	230
7. 0-0 + Manure	241	212	215	223
8. 400-0 + Manure	214	234	206	215
9. 0-400 + Manure	251	199	224	225
10. 100-400 + Manure	257	237	259	231
11. 200-400 + Manure	245	249	242	245
12. 400-400 + Manure	260	240	255	232

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	65,192	
Replications	2	417	208.5 N.S.
Treatments	11	55,758	5,068.9 **
Error	22	9,017	409.9

L.S.D._{.05} = 34.5
 .01 = 46.6

C.V. = 10.1%

¹ Yields are in pounds harvested per plot (240 square feet).

Table XXIII. Dry weight yields of corn harvested for silage from field experiment on Nunn subsoil.

Treatment	Replication			Mean
	I	II	III	
	Lbs. per 240 sq. ft.			
1. 0-0	39.2	42.7	42.3	41.4
2. 400-0	45.9	55.9	45.6	49.1
3. 0-400	27.0	26.6	51.9	35.2
4. 100-400	74.3	66.7	78.3	73.1
5. 200-400	70.4	66.8	77.0	71.4
6. 400-400	73.9	72.4	61.0	69.1
7. 0-0 + Manure	69.6	64.4	57.6	63.9
8. 400-0 + Manure	64.8	63.9	61.4	63.4
9. 0-400 + Manure	76.8	60.5	71.9	69.7
10. 100-400 + Manure	77.6	67.5	78.5	74.5
11. 200-400 + Manure	68.6	70.5	77.4	72.2
12. 400-400 + Manure	74.6	64.6	76.5	71.9

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	7,093.48	
Replications	2	142.57	71.28
Treatments	11	5,957.07	541.55**
Error	22	993.84	45.17

L.S.D. .05 = 11.4

C.V. = 10.7%

.01 = 15.5

S.S.R. Mean Separation, 5% Level--tons per acre at 70% moisture

N	0	0	400	400	0	400	0	200	400	200	100	100
P	400	0	0	0	0	400	400	400	400	400	400	400
M	0	0	0	M	M	0	M	0	M	M	0	M
	9.6	12.8	15.2	19.6	19.8	21.4	21.5	22.1	22.2	22.4	22.6	23.1

Table XXIV. Analysis of variance as a 6 Fertilizer x 2 Manure treatment factorial of dry weight yields of corn harvested for silage from field experiment on Nunn subsoil.

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	7,093.38	
Replications	2	142.57	71.28
Fertilizers	5	3,088.06	617.61**
Manure	1	1,454.15	1,454.15**
Manure x Rep.	2	80.32	40.16
Fert. x Rep.	10	533.11	53.31
Manure x Fert.	5	1,414.86	282.97**
Error	10	380.32	38.03

Table XXV. Percentage dry matter of corn harvested for silage from field experiment on Nunn subsoil.

Treatment	Replication			Mean
	I	II	III	
1. 0-0	28.8	28.1	28.0	28.3
2. 400-0	26.7	27.4	26.2	26.8
3. 0-400	29.1	26.3	29.3	28.2
4. 100-400	34.4	30.6	30.7	31.9
5. 200-400	29.7	28.2	32.2	30.0
6. 400-400	31.6	30.7	27.6	29.9
7. 0-0 + Manure	28.9	30.4	26.8	28.7
8. 400-0 + Manure	30.3	27.3	29.8	29.1
9. 0-400 + Manure	30.6	30.4	32.1	31.0
10. 100-400 + Manure	30.2	28.5	30.3	29.7
11. 200-400 + Manure	28.0	28.3	32.0	29.4
12. 400-400 + Manure	28.7	26.9	30.0	28.5

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	123.63	
Replications	2	9.41	4.70
Treatments	11	61.29	5.57*
Error	22	52.93	2.41

$$L.S.D..05 = 2.6$$

S.S.R. Mean Separation, 5% Level

N	400	0	0	400	0	400	200	100	400	200	0	100
P	0	400	0	400	0	0	400	400	400	400	400	400
M	0	0	0	M	M	M	M	M	0	0	M	0
	26.8	28.2	28.3	28.5	28.7	29.1	29.4	29.7	29.9	30.0	31.0	31.9

Table XXVI. Phosphorus percentages of dried total plant material from corn harvested for silage from field experiment on Nunn subsoil.

Treatment	Replication			Mean
	I	II	III	
1. 0-0	.154	.144	.176	.158
2. 400-0	.124	.182	.119	.142
3. 0-400	.225	.165	.200	.196
4. 100-400	.154	.188	.193	.178
5. 200-400	.225	.205	.225	.218
6. 400-400	.205	.255	.182	.214
7. 0-0 + Manure	.188	.205	.200	.197
8. 400-0 + Manure	.193	.225	.188	.202
9. 0-400 + Manure	.232	.212	.212	.218
10. 100-400 + Manure	.218	.225	.218	.220
11. 200-400 + Manure	.240	.205	.232	.225
12. 400-400 + Manure	.263	.212	.247	.240

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	0.039880	
Replications	2	0.000126	0.000063 N.S.
Treatments	11	0.027830	0.002530 **
Error	22	0.011924	0.000542

L.S.D. .05 = 0.039
 .01 = 0.054

Table XXVII. Protein¹ percentages of dried total plant material from corn harvested for silage from field experiment on Nunn subsoil.

Treatment	Replication			Mean
	I	II	III	
1. 0-0	4.7	4.6	4.7	4.66
2. 400-0	8.1	8.4	7.9	8.13
3. 0-400	4.8	5.0	5.3	5.03
4. 100-400	7.3	7.1	7.3	7.23
5. 200-400	8.0	8.6	8.3	8.29
6. 400-400	8.1	8.3	8.8	8.39
7. 0-0 + Manure	6.3	6.7	6.1	6.36
8. 400-0 + Manure	8.6	9.0	9.1	8.89
9. 0-400 + Manure	7.6	6.6	6.8	6.99
10. 100-400 + Manure	7.5	8.4	8.0	7.96
11. 200-400 + Manure	8.6	8.8	8.6	8.66
12. 400-400 + Manure	9.1	8.7	8.6	8.79

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square	
Total	35	70.51		
Replications	2	0.09	0.045	N.S.
Treatments	11	68.32	21.091	**
Error	22	2.10	0.0954	

L.S.D._{.05} = 0.520
 .01 = 0.708

¹ Protein = N x 6.25.

Table XXVIII. Total pounds of P_2O_5 per acre taken up by corn grown for silage on Nunn subsoil.

Treatment	Replication			Mean
	I	II	III	
1. 0-0	25.1	25.5	30.9	27.1
2. 400-0	23.6	42.3	22.6	29.5
3. 0-400	25.2	18.3	43.2	28.9
4. 100-400	47.5	52.0	62.9	54.1
5. 200-400	65.9	57.0	72.0	64.9
6. 400-400	63.0	76.7	46.1	61.9
7. 0-0 + Manure	54.4	54.9	47.9	52.3
8. 400-0 + Manure	52.0	59.7	47.9	53.1
9. 0-400 + Manure	74.1	53.3	63.3	63.5
10. 100-400 + Manure	70.4	63.2	71.2	68.2
11. 200-400 + Manure	68.5	60.0	74.5	67.6
12. 400-400 + Manure	81.7	57.7	78.5	72.6

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	11,004.10	
Replications	2	74.25	37.12 N.S.
Treatments	11	8,893.88	808.53 **
Error	22	2,035.97	92.54

L.S.D._{.05} = 16.3
 .01 = 22.1

Table XXIX. Total pounds of N per acre taken up by corn grown for silage on Nunn subsoil.

Treatment	Replication			Mean
	I	II	III	
1. 0-0	54	57	58	56.3
2. 400-0	108	136	104	115.9
3. 0-400	38	39	80	52.3
4. 100-400	158	137	166	153.5
5. 200-400	163	167	185	171.5
6. 400-400	174	174	156	167.8
7. 0-0 + Manure	127	125	102	117.9
8. 400-0 + Manure	162	167	162	163.5
9. 0-400 + Manure	170	116	142	142.5
10. 100-400 + Manure	169	165	182	171.8
11. 200-400 + Manure	171	180	193	181.1
12. 400-400 + Manure	200	193	191	194.5

Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	35	77,009	
Replications	2	178	89
Treatments	11	71,995	6,545 **
Error	22	4,836	219.8

L.S.D. .05 = 25.1
 .01 = 29.1

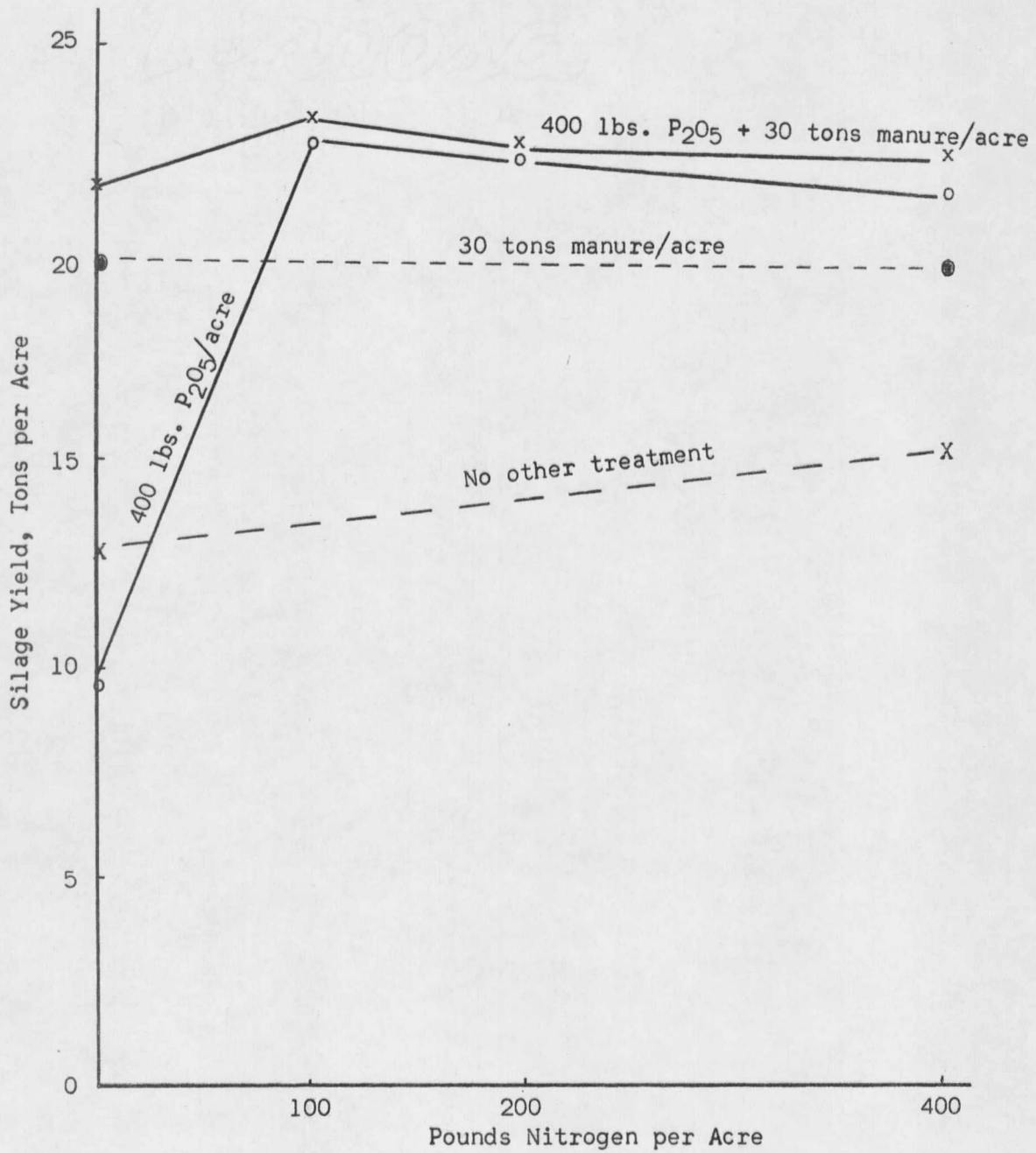


Figure 2. Effect of treatments on yields of corn silage from field experiment on Nunn subsoil.

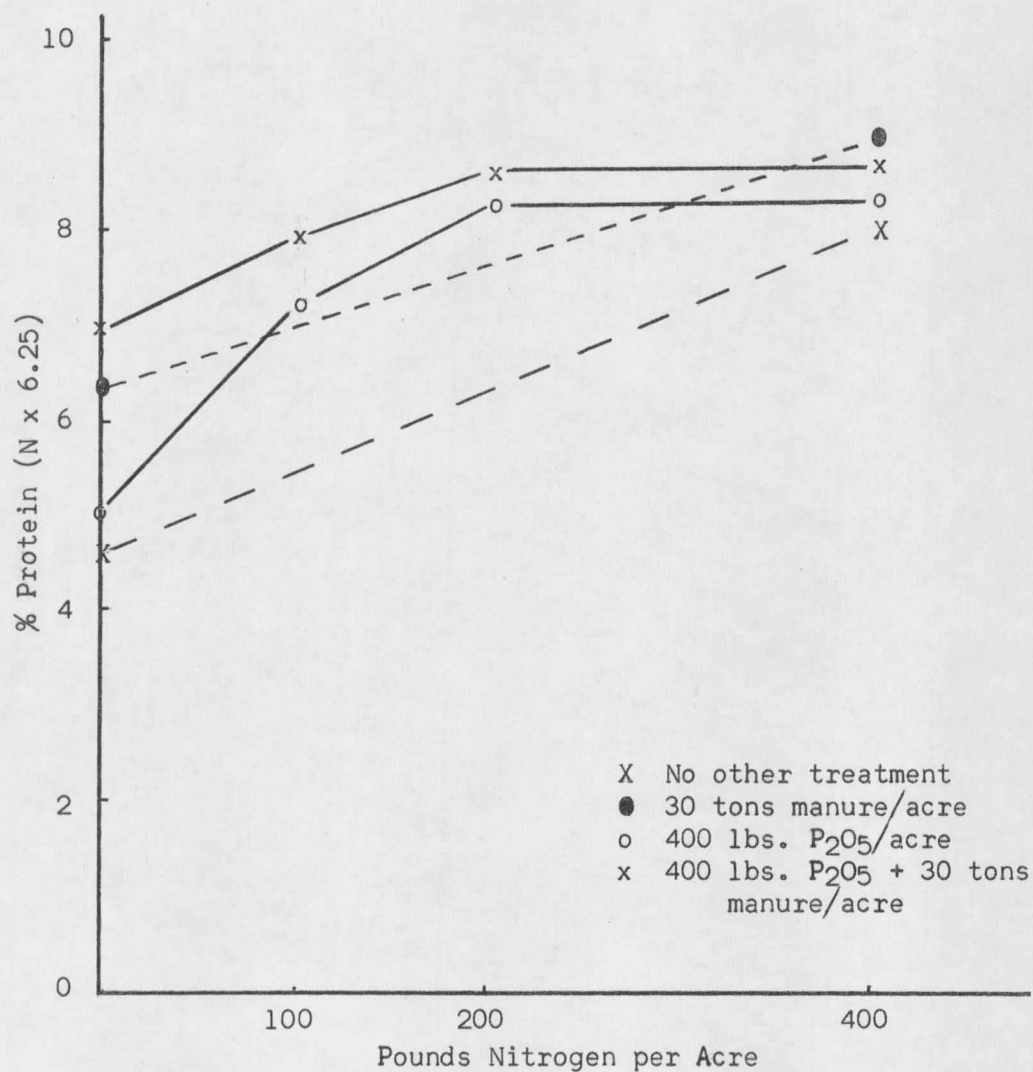


Figure 3. Effect of treatments on protein content of corn harvested for silage from field experiment on Nunn subsoil.

Results of Soil Analyses of Profile Samplings from Keiser Soil

The soil analysis results reported here are from two profile samplings taken adjacent to the field experiment on the Paul Creek farm.

Table XXX shows the results of mechanical analysis. The upper 2 feet showed similar results from both profiles. The A horizon is slightly higher in clay than the B horizon. Below 2 feet, profile No. 1 has a texture very similar to that of the A horizon, while profile No. 2 is considerably higher in sand at the lower depths. Apparently there is considerable variation in the texture of the subsoil below 2 feet.

The total nitrogen and organic carbon contents of the different horizons are shown in table XXXI. Both carbon and nitrogen decrease rapidly below the plow layer, and there is a tendency for the C:N ratio to narrow progressively with depth. The sample from the 36- to 60-inch depth at the second sampling site is the only one that did not show this tendency.

The results of the nitrifiable nitrogen analysis are given in table XXXII. The decrease in nitrifiable nitrogen with increasing depth is more extreme than that for total nitrogen.

Sodium bicarbonate soluble phosphorus is shown in table XXXIII. The phosphorus levels of the surface soil are quite low, but there is still a striking decrease in available phosphorus below the surface layer.

Cation exchange capacity measurements are given in table XXXIV. These show a lower exchange capacity in the subsoil than in the plow layer. The exchange capacity of the B horizon is lower than that of the A horizon by about 5 milliequivalents per 100 grams. Exchange capacities of samples from profile No. 1 were about the same in the lower depths as in the B

horizon, but profile No. 2 shows a progressive lowering of exchange capacity with depth. This would be expected in view of the lower clay content in the deeper layers of profile No. 2.

Soluble cation analyses are shown in table XXXV. Soluble Na is about the same at all depths. Soluble K is slightly higher in the plow layer than in the subsoil, but no clear-cut pattern is evident. The sum of soluble Ca + Mg is variable, but these divalent ions are dominant among the soluble ions.

Electrical conductivities of the saturation extracts and pH of saturated pastes are given in table XXXVI. Conductivities are well below the saline range in all cases. The plow layer is slightly higher in conductivity than the subsoil, but all other layers are similar. The pH of all samples was in the range of 7.7 to 7.8.

Exchangeable K is given in table XXXVII. There is a definite decrease in exchangeable K below the plow layer. The B horizon contains an average of 57% as much exchangeable K as the A horizon. The B horizon averaged 48.5 milliequivalents of K per 100 grams of soil. This is not extremely low, but deficiencies of potassium would be much more likely to develop in the subsoil than in the surface soil.

Table XXX. Mechanical analysis¹ of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Depth inches	% Sand	% Silt	% Clay	Textural Class
Profile No. 1					
A _p	0-8	45	20	35	Border--clay loam, sandy clay loam - sandy clay
B ₃	8-13	47	22	31	Sandy clay loam
C _{cal}	13-22	44	20	36	Clay loam
C _{ca2}	22-38	44	20	36	Clay loam
C	38-62	46	17	37	Sandy clay
Profile No. 2					
A _p	0-8	45	19	36	Border--clay loam, sandy clay
B ₃	8-13	47	20	33	Sandy clay loam
C _{cal}	13-26	43	23	34	Clay loam
C _{ca2}	26-36	51	21	30	Sandy clay loam
C	36-60	55	15	30	Sandy clay loam

¹ Hydrometer method.

Table XXXI. Organic matter and total nitrogen analysis of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Depth inches	% O.M. ¹	% Organic Carbon ²	% N ³	C:N Ratio
Profile No. 1					
A _p	0-8	1.79	1.04	0.114	9.1
B ₃	8-13	0.84	0.49	0.058	8.5
C _{cal}	13-22	0.66	0.38	0.050	7.6
C _{ca2}	22-38	0.53	0.31	0.042	7.4
C	38-62	0.41	0.24	0.036	6.7
Profile No. 2					
A _p	0-8	1.71	0.99	0.114	8.8
B ₃	8-13	0.86	0.50	0.063	7.9
C _{cal}	13-26	0.62	0.36	0.048	7.5
C _{ca2}	26-36	0.43	0.25	0.034	7.4
C	36-60	0.40	0.23	0.028	8.2

¹ Assume % O.M. = % C x 1.724.

² By Walkley-Black method, assume 77% recovery.

³ By Kjeldahl method.

Table XXXII. Nitrifiable nitrogen analysis of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Profile No. 1		Profile No. 2	
	Depth	ppm N	Depth	ppm N
	inches		inches	
Ap	0-8	69.5	0-8	67.2
B ₃	8-13	12.0	8-13	13.2
C _{cal}	13-22	3.6	13-26	7.2
C _{ca2}	22-38	1.2	26-36	3.0
C	38-62	1.2	36-60	1.2

Table XXXIII. Sodium bicarbonate soluble phosphorus analysis of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Profile No. 1		Profile No. 2	
	Depth	ppm P ₂ O ₅	Depth	ppm P ₂ O ₅
	inches		inches	
Ap	0-8	13	0-8	9
B ₃	8-13	4	8-13	1.5
C _{cal}	13-22	2.5	13-26	1.5
C _{ca2}	22-38	1	26-36	2.5
C	38-62	2.5	36-60	3

Table XXXIV. Cation exchange capacity of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Profile No. 1		Profile No. 2	
	Depth	C.E.C.	Depth	C.E.C.
	inches	m.e./100 gms.	inches	m.e./100 gms.
A _p	0-8	25.0	0-8	25.5
B ₃	8-13	19.6	8-13	19.6
C _{ca1}	13-22	20.1	13-26	19.6
C _{ca2}	22-38	20.1	26-36	17.4
C	38-62	21.7	36-60	16.3

Table XXXV. Soluble cation determinations on saturation extract of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Depth inches	Na m.e./100 qms.	K m.e./100 qms.	Ca + Mg m.e./100 qms.
Profile No. 1				
Ap	0-8	0.064	0.0091	0.255
B ₃	8-13	0.060	0.0075	0.216
C _{cal}	13-22	0.059	0.0069	0.194
C _{ca2}	22-38	0.054	0.0074	0.296
C	38-62	0.060	0.0085	0.283
Profile No. 2				
Ap	0-8	0.051	0.0085	0.294
B ₃	8-13	0.043	0.0066	0.186
C _{cal}	13-26	0.057	0.0063	0.179
C _{ca2}	26-36	0.044	0.0065	0.182
C	36-60	0.048	0.0071	0.160

Table XXXVI. Electrical conductivity of the saturation extract and pH of the saturated paste of samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Depth inches	E.C. mmhos/cm.	pH
Profile No. 1			
A _p	0-8	0.55	7.7
B ₃	8-13	0.50	7.7
C _{cal}	13-22	0.44	7.8
C _{ca2}	22-38	0.47	7.8
C	38-62	0.48	7.8
Profile No. 2			
A _p	0-8	0.52	7.8
B ₃	8-13	0.42	7.8
C _{cal}	13-26	0.44	7.8
C _{ca2}	26-36	0.40	7.8
C	36-60	0.44	7.8

Table XXXVII. Exchangeable potassium determinations on samples from two profiles taken from the area adjacent to the leveling experiment on Keiser subsoil.

Horizon	Profile No. 1		Profile No. 2	
	Depth inches	Exch. K m.e./100 gms. soil	Depth inches	Exch. K m.e./100 gms. soil
Ap	0-8	0.85	0-8	0.83
B ₃	8-13	0.48	8-13	0.49
C _{cal}	13-22	0.54	13-26	0.45
C _{ca2}	22-38	0.56	26-36	0.47
C	38-62	0.64	36-60	0.48

DISCUSSION

The results of the three experiments indicate that lack of available nitrogen and phosphorus are the major factors limiting crop yields on the subsoils tested.

In the greenhouse study, the average yield of total plant material on subsoil receiving no treatment was 1.5 grams as compared to an average yield of 10.4 grams when nitrogen and phosphorus were added. Nitrogen alone was of little benefit in the greenhouse study. As no treatment was included using only phosphorus, the effectiveness of the N + P treatment could have been due to either phosphorus or to an N x P interaction. The ineffectiveness of phosphorus alone in increasing yields in the field experiments indicates that the N x P interaction was probably the most important factor.

Manure alone did not increase yields greatly in the greenhouse. The manure plus nitrogen treatment, however, yielded 8.5 grams as compared to 2.8 grams for manure alone. This indicates that the manure more nearly supplied the phosphorus than the nitrogen requirements of the plants. It is possible that part of the available nitrogen was lost from the manure in processing, as it had been dried and ground previous to mixing with the soil.

A definite response was obtained from potassium used in combination with nitrogen and phosphorus. The NPK treatment with no amendment added averaged 12.5 grams per pot as compared to 10.4 grams for the NP treatment. The average yield of all subsoil pots receiving NPK was 13.2 grams as compared to 12.0 grams for the NP treatments. Mean separation by the S.S.R.

method shows these means to be significantly different at the 5% level (table VII).

Trace elements gave no response in this study.

The surface soil in arid areas frequently has good structure, but soil aggregates in the subsoil are often weak and disperse readily in water. Cut areas consequently puddle, and physical condition may be a problem. For these reasons, vermiculite was selected as a treatment that would increase pore space without major effects on the nutrient status of the soil.

Vermiculite alone gave no response. However, the best subsoil yields were on pots that had had both fertilizer and vermiculite added. The yields of the subsoil pots receiving vermiculite plus NP or vermiculite plus NPK were significantly higher than the pots receiving the same fertilizer treatments but no vermiculite. This indicates that the additional aeration provided by the vermiculite was of some benefit where the fertility level was sufficiently high to attain good yields.

When adequately fertilized, the subsoil yielded as well as the similarly treated surface soil. All subsoil pots receiving the NPK treatment averaged 13.2 grams per pot as compared to 13.0 grams for the similarly treated surface soil, and the average of the NPK and NPKT treatments was very similar for the two soils. This definitely indicates that lack of fertility is the major factor limiting crop production on the subsoil.

The field experiments on both Nunn and Keiser subsoils showed a definite response to commercial nitrogen. The factorial analysis of treatments 1 to 6 of the experiment on Keiser subsoil shows a highly significant response to nitrogen (table XI). The 400-0-0 treatment on the Nunn subsoil

is higher than the check treatment but not significantly so (table XXIII). These results differ from the greenhouse experiment where nitrogen alone was of very little benefit.

The use of commercial phosphorus fertilizers without nitrogen was not effective in increasing yields in either field. The phosphorus treatment gave a slightly higher yield than the check on the Keiser subsoil and a somewhat lower yield on the Nunn subsoil. The yield differences due to phosphorus alone were not significant in either case.

The N x P interaction approached significance on the Keiser subsoil. The experimental design used on the Nunn subsoil was of a type in which the interaction as such could not be tested. The mean separation shows all treatments receiving nitrogen and phosphorus to be significantly higher than those receiving nitrogen or phosphorus alone. This definitely indicates that the interaction is significant.

There seems to be a difference in the effectiveness of the nitrogen and phosphorus at different ratios. The two top-yielding treatments on the Keiser subsoil were 150-400-0 + manure and 150-400-0, while on the Nunn subsoil, top yields were attained with the 100-400-0 and 100-400-0 + manure. The treatments having a higher N:P ratio yielded less in both cases. This contrasts to the fact that when nitrogen was used alone, the higher rates were more effective.

Manure was very effective in increasing yields in the experiment on the Nunn subsoil. There was no significant difference between any of the treatments receiving manure nor between any treatments receiving manure and those receiving both nitrogen and phosphorus from commercial sources.

The experiment on the Keiser subsoil had a moderate application of manure over the whole area previous to fall plowing. Additional manure disked into the ground surface in the spring was of no benefit. The differences in results on the two experiments could be due to the placement, or may be because the previous application of manure on the Keiser subsoil was sufficient to meet what fertility requirements could be met by manure application.

Potash did not respond on the Keiser subsoil and was not used on the Nunn subsoil.

The stalk counts taken at harvest showed a significant increase due to the N x P interaction on the Keiser subsoil. These were taken in the hope of using stalk counts as an independent variable in an analysis of covariance to adjust the yields for uneven stands due to improper cultivation. This proved impractical due to the fact that the stalk counts were dependent on treatment. This may be due to the well-fertilized plants being better able to survive the covering at cultivation. Other factors, such as seedling survival or number of stalks per plant, could enter in here.

There were differences in percentage dry matter in all experiments. In most cases, dry matter percentage was lowered by the addition of nitrogen alone. Nitrogen added with phosphorus generally did not lower the dry matter percentage.

The protein content of the corn plants was raised considerably by the addition of nitrogen. Manure also raised the protein content somewhat on the Nunn subsoil. The addition of 400 pounds of nitrogen per acre raised

the crude protein from 4.66% to 8.13% on this experiment. On the Keiser subsoil, the addition of 300 pounds of nitrogen per acre raised the crude protein from 6.38% to 8.80%. The uniform application of manure probably accounts for the check being higher in protein on this experiment than on the Nunn subsoil. Phosphorus had no effect on the protein content.

The phosphorus content of the plants showed significant differences due to treatment in both experiments. These differences were not consistent in the two field experiments. In the experiment on Nunn subsoil, the phosphorus level of the total plant material was increased by the addition of commercial phosphorus or manure. The increases in phosphorus content on the Keiser subsoil, however, were due not to phosphorus fertilization but to the addition of nitrogen and perhaps to the N x P interaction.

The total uptake of nitrogen and phosphorus was affected by fertilization. The maximum recovery of nitrogen on the Keiser subsoil was 39%, and on the Nunn subsoil as high as 100% of added nitrogen was recovered. The 39% figure is not particularly high. The recovery of 100% of the nitrogen applied is unusual but was attained when added in combination with phosphorus. The recovery of added phosphorus was quite low percentagewise, but high rates were used and it is likely that the benefits from this one application will be long lasting.

The results of the soil analyses corroborate those of the greenhouse and field experiments. The organic matter and total nitrogen decreased rapidly below the plow layer, while nitrifiable nitrogen decreased tremendously. Sodium bicarbonate soluble phosphorus also was much lower in the subsoil than in the surface layer. Exchangeable potassium was

considerably lower in the subsoil than in the surface soil, although the decrease is not as great as it is for nitrogen or available phosphorus. The other soil analyses showed slight differences between the surface soil and the subsoil. There were some differences in cation exchange capacity due to the lower organic matter in the subsoil, and also some differences in texture. These differences, however, would probably not materially affect the productivity of the soil.

The soil analyses indicate that the major factors limiting productivity are the lack of available nitrogen and phosphorus. Potassium would probably become limiting in the subsoil before it would in the surface soil. These results substantiate the conclusions drawn from the field and greenhouse studies.

Silage corn does not respond to phosphorus applications in this area nearly as readily as do some other crops. It is very probable that, had sugar beets or alfalfa been used as a test crop on these soils, the phosphorus response would have been much greater.

SUMMARY AND CONCLUSIONS

Field tests were conducted on two areas from which the surface soil had been removed during land leveling operations. A greenhouse study was conducted using both subsoil and surface soil from one of these areas. Soil analyses were made on the various horizons of a profile taken from one of these areas.

In the greenhouse study, yields of barley plant material were extremely low on the untreated subsoil and on subsoil to which nitrogen alone was added. Good yields were obtained from the subsoil when both nitrogen and phosphorus were added. The addition of potash in combination with nitrogen and phosphorus resulted in a significant increase in yields as compared to the nitrogen plus phosphorus treatment. Vermiculite mixed with the subsoil to improve aeration did not increase yields at low fertility levels but did increase yields slightly on well-fertilized subsoil. Manure alone did not result in satisfactory yields on the subsoil in the greenhouse study. Well-fertilized subsoil yielded as well as the similarly treated surface soil.

The addition of nitrogen in combination with phosphorus resulted in excellent yields of corn silage in both field experiments. Top yields resulted from quite similar treatments in both locations.

The addition of 100 pounds of N and 400 pounds of P_2O_5 resulted in the production of 22.6 tons of silage per acre on the subsoil of a Nunn clay loam. This compares to a yield of 12.8 tons per acre on the check plots.

The addition of 150 pounds of N and 400 pounds of P_2O_5 per acre resulted in a yield of 21.8 tons of silage per acre on the subsoil of a

Keiser clay loam compared to 15.8 tons on the check. Yields were increased somewhat by the addition of nitrogen without phosphorus on this experiment.

Manure applied previous to plowing was very effective in increasing yields on Nunn subsoil. Manure disked into the ground surface after plowing was not effective in increasing yields on Keiser subsoil.

The protein and phosphorus content of the corn silage was raised considerably by fertilization. Utilization of the added phosphorus was relatively poor percentagewise, but carryover effects would be anticipated. Nitrogen was utilized quite efficiently when used at moderate rates and in combination with phosphorus. On the Nunn subsoil, the addition of 100 pounds of N and 400 pounds of P_2O_5 resulted in the uptake of 97 pounds more nitrogen than from the check.

Soil analyses show that nitrogen and available phosphorus are extremely low in the subsoil. Exchangeable potassium is somewhat lower in the subsoil than in the plow layer.

From these data, it is evident that the major factors limiting crop production on these subsoils are the lack of available nitrogen and phosphorus. These deficiencies can be overcome by the use of commercial sources of these elements or by plowing down heavy applications of barnyard manure. In most cases, the most practical treatment would probably be a combination of the two.

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APPENDIX

Description of Keiser Clay Loam Profile Taken from Area
Adjacent to Leveling Experiment on Paul Creek Farm

This description was made by Mr. Ted Miller, Soil Scientist, USDA, Soil Conservation Service.

This is a medial thin solum Brown soil occurring on smooth benches of Pleistocene Age. It is developed in moderately fine textured alluvium 60 inches deep over alluvial gravels. This soil exhibits weak prismatic to strong fine and medium blocky structure, and a zone of lime accumulation at 8 to 14 inches of depth.

Profile: (Description taken in alfalfa field 30 feet west of leveled field on Paul Creek farm).

- | | | |
|------------------|-----------|--|
| Ap | 0 - 8" | Very dark grayish brown (10YR 3.5/2, moist) heavy clay loam; strong fine to medium blocky structure; firm when moist; slightly sticky and slightly plastic when wet; calcareous; abrupt boundary to |
| B ₃ | 8 - 13" | Dark grayish brown (2.5Y 4/2, moist) clay loam; moderate medium prismatic structure breaking to moderate fine blocky; firm when moist; slightly sticky and slightly plastic when wet; strongly calcareous; clear boundary to |
| C _{ca1} | 13 - 22" | Dark grayish brown (2.5Y 4/2, moist) clay loam; weak medium blocky to massive structure; strongly calcareous with splotches and nodules of calcium carbonate; gradual boundary to |
| C _{ca2} | 22 - 38" | Very dark grayish brown (2.5Y 3/2, moist) clay loam; massive structure; firm when moist; slightly sticky and slightly plastic when wet; strongly calcareous with many splotches and nodules of lime; gradual boundary to |
| C | 38 - 62"+ | Dark grayish brown (2.5Y 4/2, moist) clay loam; massive structure; firm when moist; slightly sticky and slightly plastic when wet; calcareous. |

Scattered gravels throughout entire profile.

Description of Nunn Clay Loam Profile Taken from Area
Adjacent to Leveling Experiment on the Huntley Branch Station

This description was made by Mr. James Meshnick, Soil Scientist, USDA, Soil Conservation Service.

314A1 Nunn clay loam, nearly level.
1F4X

This is a medial Brown soil developed in stratified, moderately fine textured materials on sloping side fans and fan terraces. The upper 10 to 30 inches of the profile is predominantly clay loam and light silty clay loam with the lower stratas consisting of loams and clay loams. The unit is mapped in association with Fly Creek and Glendive soils.

Fly Creek soils are lighter textured and have more variably stratified sub-strata with more weakly developed sola. Glendive soils are developed in coarse textured materials with little stratification and weak development.

Profile: (Description taken approximately 1,675 feet south of main Huntley Irrigation Canal; on east side of north-south fence which is the west boundary of Field H; Huntley Experiment Station).

- | | | |
|------------------|---------|--|
| A ₁₁ | 0 - 1" | Grayish brown (10YR 5/2, D) to dark gray (10YR 4/1, M) clay loam; moderate fine granular structure; soft when dry; friable when moist; nonsticky and nonplastic when wet; no reaction with dilute HCl; pH 7.4. Clear, smooth boundary. |
| A ₁₂ | 1 - 4" | Pale brown (10YR 6/2.5, D) to dark grayish brown (10YR 3.5/2, M) heavy clay loam; moderate medium granular structure; slightly hard when dry; friable when moist; slightly sticky and slightly plastic when wet; no reaction with dilute HCl; pH 7.5. Gradual boundary. |
| B _{1ca} | 4 - 5" | Light brownish gray (10YR 6/2, D) to dark grayish brown (2.5Y 4/2 M) light silty clay loam; moderate medium blocky structure; thin patchy clay skins on vertical surfaces of peds; slightly hard when dry; friable when moist; slightly sticky and slightly plastic when wet; slight reaction with dilute HCl; pH 7.5. Clear, smooth boundary. |
| B _{2ca} | 5 - 12" | Grayish brown (2.5Y 5.5/2 D) to dark grayish brown (2.5Y 4/2 M) heavy silty clay loam; compound structure of weak medium prisms and moderate medium blocks; clay skins moderately thick, continuous on vertical faces and patchy on horizontal faces of the peds; slightly hard |

when dry; friable when moist; sticky and plastic when wet; strong reaction with dilute HCl; pH 8.2. Gradual boundary.

- B_{3ca} 12 - 21" Grayish brown (2.5Y 5.5/2 D) to light olive brown (2.5Y 5/3 M) clay loam; weak medium prismatic and weak medium blocky structure; clay skins thin; continuous on vertical faces and patchy on horizontal ped faces; slightly hard when dry; friable when moist; slightly sticky and slightly plastic when wet; strong reaction with dilute HCl; pH 8.2. Clear boundary.
- C₁ 21 - 24 $\frac{1}{2}$ " Light olive brown (2.5Y 5/3 D) to olive brown (2.5Y 4/3 M) light silty clay loam; moderate coarse blocky structure; slightly hard when dry; friable when moist; slightly sticky and slightly plastic when wet; slight reaction with dilute HCl; common thread lime; pH 7.8. Gradual boundary.
- C₂ 24 $\frac{1}{2}$ - 46" Light brownish gray (2.5Y 6/3 D) to light olive brown (2.5Y 5/4 M) loam; weak fine blocky to massive structure; soft when dry; friable when moist; nonsticky and non-plastic when wet; strong reaction with dilute HCl; pH 8.0. Gradual boundary.
- C₃ 46 - 60" Stratified loams and sandy loams.

Table XXXVIII. Growth measurements made on barley plants in greenhouse experiment using both surface soil and subsoil.

Treatment	Days After Emergence										
	9	12	15	19	22	25	29	32	36	39	43
Height in cms.											
<u>Subsoil</u>											
1. Check	17.5	21.0	24.0	26.0	27.0	28.0	27.5	29.0	31.5	32.5	34.0
2. N	18.0	21.0	23.5	24.0	28.5	29.0	32.0	34.0	38.0	39.5	39.5
3. NP	19.5	23.5	29.0	37.0	41.0	47.0	55.0	59.0	65.5	65.5	65.0
4. NPK	22.0	25.5	33.0	39.0	45.0	55.0	60.0	65.5	73.0	73.0	73.0
5. NPKT	21.0	25.5	32.5	38.5	44.0	52.5	59.5	64.0	69.5	70.0	73.0
6. Manure	18.0	21.5	28.0	31.0	33.0	33.5	34.5	36.5	38.5	39.0	38.5
7. M + N	21.0	23.5	30.0	36.5	41.0	47.0	52.5	56.5	61.5	63.0	63.0
8. M + NP	21.5	27.5	33.0	40.0	47.5	55.0	59.5	64.0	65.5	65.0	65.0
9. M + NPK	21.5	25.5	31.5	37.5	44.5	52.5	59.5	63.5	66.0	66.0	66.0
10. M + NPKT	22.5	26.0	31.5	39.0	46.0	52.0	58.0	60.0	65.5	66.0	66.0
11. Vermiculite	13.5	18.5	21.0	23.5	25.5	24.5	25.5	26.0	28.0	28.0	28.5
12. V + N	15.5	19.0	21.0	22.5	23.5	24.5	25.0	26.5	30.5	32.5	33.5
13. V + NP	18.5	23.5	31.0	40.0	47.0	53.0	59.5	66.5	71.0	71.5	72.0
14. V + NPK	19.0	25.0	33.0	41.0	47.0	53.5	62.5	67.5	75.0	75.0	76.0
15. V + NPKT	19.5	23.5	31.5	40.0	46.5	52.5	60.0	64.5	72.0	72.0	72.0
<u>Surface Soil</u>											
16. Check	18.5	24.0	30.5	37.0	41.0	46.5	50.5	55.5	59.5	61.5	62.0
17. N	20.0	23.0	29.5	35.0	39.0	45.0	51.5	57.5	63.5	65.5	65.5
18. NP	19.5	24.5	31.0	38.5	45.5	52.5	57.5	62.5	67.0	67.0	67.0
19. NPK	20.5	25.5	32.0	38.0	43.0	50.5	56.5	60.5	66.0	67.5	67.5
20. NPKT	21.0	25.5	31.5	37.0	42.5	50.0	57.5	61.5	68.0	68.0	68.0
21. Manure	20.5	25.0	31.0	36.5	42.5	46.5	51.0	55.5	62.5	62.5	63.0
22. M + N	20.5	23.5	32.0	37.0	44.5	47.5	52.0	59.0	61.0	61.0	61.0

Table XXXVIII continued.

Treatment	Days After Emergence										
	9	12	15	19	22	26	29	32	36	39	43
	Height in cms.										
23. M + NP	21.5	25.5	31.0	38.5	46.0	54.0	59.5	64.5	66.0	66.0	66.5
24. M + NPK	20.5	25.5	31.5	36.5	41.5	48.0	54.0	57.5	62.0	64.5	64.5
25. M + NPKT	21.0	28.0	33.0	38.5	45.0	51.0	57.0	61.5	68.0	68.0	68.0
26. Vermiculite	18.0	22.5	29.5	35.0	37.5	42.0	47.0	52.0	58.0	59.5	59.5
27. V + N	16.5	20.5	28.0	36.5	39.5	45.5	52.5	59.0	65.0	68.5	69.0
28. V + NP	19.0	25.0	31.5	41.5	47.0	52.5	60.0	64.0	71.5	72.5	72.5
29. V + NPK	20.0	24.5	31.0	39.5	45.0	51.0	57.5	63.0	71.0	71.0	71.0
30. V + NPKT	18.0	23.5	30.5	39.5	47.0	51.0	59.5	64.0	71.5	72.0	72.0

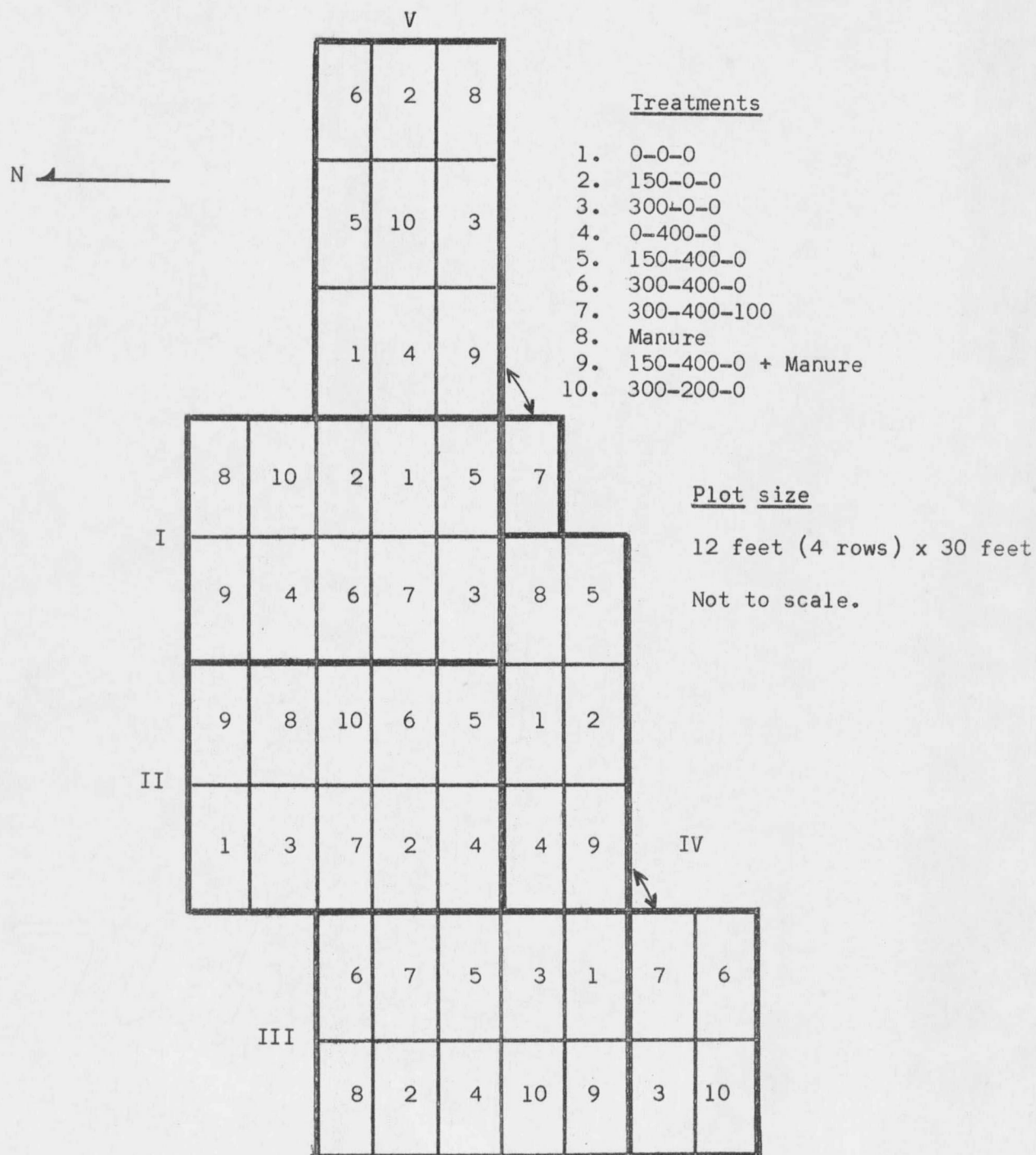


Figure 4. Field plot diagram of leveling experiment on Keiser clay loam subsoil.

	III				II				I			
	5	9	4	12	10	1	7	2	6	11	3	8
N ←	3	11	10	7	6	9	8	12	1	5	2	4
	6	8	1	2	11	5	3	4	12	9	7	10

Treatments

1. 0-0-0
2. 400-0-0
3. 0-400-0
4. 100-400-0
5. 200-400-0
6. 400-400-0
7. 0-0-0 + 30 tons manure per acre
8. 400-0-0 + 30 tons manure per acre
9. 0-400-0 + 30 tons manure per acre
10. 100-400-0 + 30 tons manure per acre
11. 200-400-0 + 30 tons manure per acre
12. 400-400-0 + 30 tons manure per acre

Plot size

20 feet x 30 feet

Not to scale.

Figure 5. Field plot diagram of leveling experiment on Nunn clay loam subsoil.

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