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

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.

37

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

at

Montana State College

Approved:

A. H. Post
Head, Major Department

J. C. Hide
Chairman, Examining Committee

Leon Johnson
Dean, Graduate Division

Bozeman, Montana
August, 1958

ACKNOWLEDGEMENT

The writer wishes to express his gratitude to Mr. Ralph E. Campbell, Soil Scientist, Western Soil and Water Management Research Branch, SWC, ARS, USDA, whose cooperation, advice, and encouragement made this project possible.

The writer also wishes to express his appreciation to the staff of the Agronomy and Soils Department of Montana State College for their advice and assistance in the planning and execution of this project, and especially to Dr. J. C. Hide, who assisted in the planning of the project and the preparation of the manuscript, and Dr. M. G. Klages, who helped with the soil analyses.

Acknowledgement is also due Dr. B. A. Krantz, Dr. F. G. Viets, Jr., and Dr. P. L. Brown, all of the Western Soil and Water Management Research Branch, SWC, ARS, USDA, and Dr. Robert S. Whitney, of the Colorado State University, all of whom provided suggestions relative to the treatments used in the experiments.

The writer wishes to express his gratitude to the personnel of the Soil Conservation Service, USDA, for their assistance in selection of experimental sites and in obtaining the soil profile descriptions.

Further acknowledgement is given to Mr. Torlief Aasheim, Superintendent of the Huntley Branch Station, who made the facilities of the station available for this project.

TABLE OF CONTENTS

LIST OF TABLES

Page

Context Tables

Appendix Tables

LIST OF FIGURES

Page

Context Figures

Appendix Figures

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 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 subsoil 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. Post[1], 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_2O_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_2O 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 P_2O_5 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_2O_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 Cochrane 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.

	Dry Matter Yield, gms./pot				% Dry Matter			
	Subsoil		Surface soil		Subsoil		Surface soil	
Treatment	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.

	Subsoil Amendment				Surface Soil Amendment				
Fertilizer	None	Manure	Vermiculite	Ave.	None	Manure	Vermiculite	Ave.	Grand Ave.
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	12.8	12.8	13.0

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	12.0	12.6	13.2

Amendments

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

L.S.D.$_{.05}$ = 0.6 L.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	1.4	1.4	1.5	2.0	2.8	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	10.4	12.0	12.0	12.4	12.5	12.6	13.0	13.2	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	20.8	20.8	21.1	22.7

Amendments

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

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

Soils

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

Significant at 1% level.

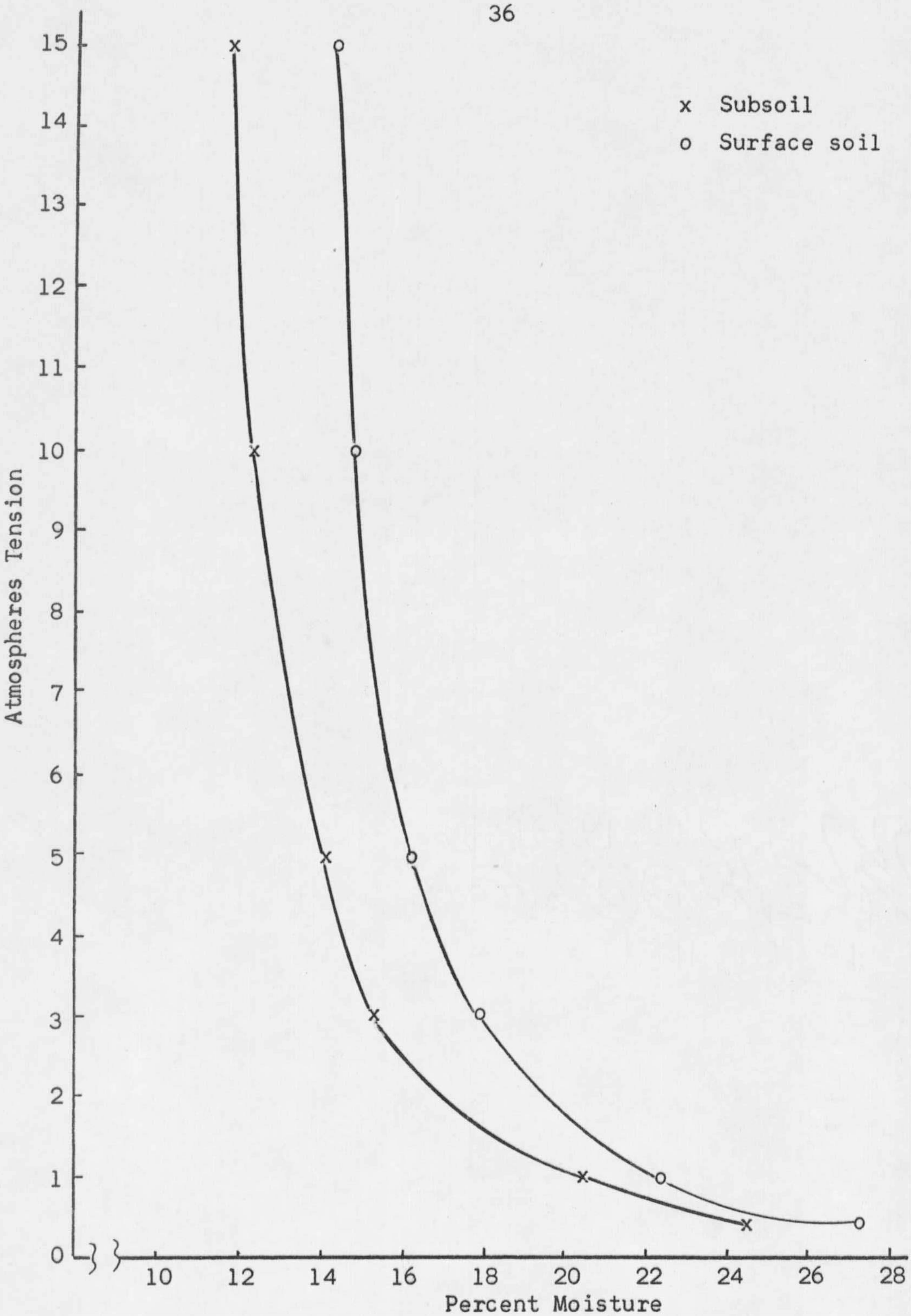

Figure 1. Moisture tension curves for surface soil and subsoil used in greenhouse pot experiment.

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 x 2P factorial. This analysis shows a highly significant nitrogen effect and an N x 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 I	II	III	IV	V	Mean
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

$L.S.D._{.05} = 15.1$ C.V. = 12.0%
$L.S.D._{.01} = 20.2$

[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 I	II	III	IV	V	Mean lbs./ plot	Tons/ acre-70% moisture
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 C.V. = 11.8%
$_{.01}$ = 6.0

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

Treatment	Yield
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 I	II	III	IV	V	Mean
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

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

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

Treatment	Replication I	II	III	IV	V	Mean
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