EFFECT OF TOPSOIL REMOVAL ON SOIL FERTILITY

by

ALBERTO d'HIRIART

Ing. Agr., Universidad Nacional de Cuyo,
Argentina, 1963.

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1969

Approved by:

Major Professor

TABLE OF CONTENTS

INTRODUCTION

In many soils the topsoil (A horizon) is the soil layer of highest fertility. Under these conditions yields of crops are often related to the depth of the topsoil. Where the topsoil is removed or where its thickness is diminished, productivity of the subsoil becomes highly important because it affects crop production and soil management practices much more than on land with topsoil of normal depth.

Subsoil may be exposed as a result of severe erosion. In dry regions the texture and structure of the surface soil are very important factors determining the soil's susceptibility to wind erosion. In humid areas topography appears to be more important than texture and structure, and subsoil exposures are more likely to occur on sloping lands. In irrigated areas, land leveling may cause the exposure of subsoil and the consequent reduction in crop yields. Similarly land forming and terracing may remove the surface soil from portions of a field.

Generally the ranges in properties of subsoils are greater within a given area than are the ranges in surface soil properties. Taking extremes in characteristics, subsoils range in texture from gravel to heavy clay, in reaction from very acid to strongly alkaline, in fertility from very low to very high, and in structure and consistency from granular and friable, to massive, hard and plastic or even cemented (19).

Since all these properties are significant to plant growth, the problems of growing plants on truncated soils, will differ from one kind of subsoil to another. The physical properties may be the limiting factor in some cases, and problems such as difficulties in tillage operations, seed bed preparation, formation of crusts, reduced infiltration and percolation may occur.

In other cases when subsoils have good physical conditions, fertility levels may be responsible for low yields. These can often be improved by adding fertilizers. However, if the physical condition of the subsoils is unfavorable for plant growth, additions of plant nutrients to a decapitated soil may have little effect on crop yields.

Since subsoil exposures occur in many areas it is important to determine if it is possible to bring subsoil productivity up to that of the original topsoil. Therefore, the purpose of this study was to establish whether or not the productivity of the subsoil could be efficiently restored by the use of inorganic fertilizers and manure.

REVIEW OF LITERATURE

Alway, McDole, and Rost (1) working with loess soils of eastern Nebraska showed that while the subsoils were unproductive for corn they were as productive as the surface soils for inoculated legumes. Harmer (11) concluded that some of the glacial subsoils of Minnesota were as productive for alfalfa as surface soils, when inoculation was assured, but others were quite unproductive, and this was not associated with an especially low nitrogen content or lack of carbonates. Working with the same samples used by Harmer, McMiller (15) found that these subsoils would produce satisfactory crops of inoculated legumes if adequate nitrogen and phosphorus were supplied.

Studying the relative productivity of the A, B, and C horizons of a Cecil sandy loam soil, Latham (14) observed that the A horizon was more than three times as productive as the B, and eleven times as productive as the C horizon. Additions of stable manure resulted in increased yields on all horizons, but this effect was relatively greater in the C horizon. Gardner (10) reported that in Colorado soils a lack of available nitrogen and phosphorus in the subsoil accounted for a large part of the decrease in crop yields following loss of the surface soil.

Whitney, Gardner, and Robertson (18) at Fort Collins, Colorado, studied the comparative effectiveness of manure and commercial fertilizers in restoring the productivity of exposed subsoils. They demonstrated that the major factor involved in limiting the growth on the subsoils was a deficiency of nitrogen and phosphorus, and both manure and commercial fertilizers were effective in producing practically normal yields of corn, sugar beets, and spring wheat.

Smith and Pohlman (17) compared topsoils and subsoils in a greenhouse at three fertility levels, and concluded that surface soils generally were superior to the subsoils after the lime, phosphorus and potassium needs were satisfied. Bachtell, Willard, and Taylor (3) pointed out that on a Canfield silt loam soil, under an adequate fertility program, hay yields were about as high on subsoil as on topsoil. Manure additions were as valuable or even more valuable on subsoil than on topsoil, and phosphate-potash fertilizers were about as effective on subsoil as on topsoil.

Carlson and Grumes (4), in a growth chamber experiment, worked with the Alp, AC and C horizons of a Gardena loam soil. They indicated that barley growth was greatest on the Alp horizon at all fertilizer levels. Applications of nitrogen fertilizer increased yields on all horizons, but phosphorus additions did not. When both nitrogen and phosphorus were added, yields were greater on all horizons than when either was added alone. Total nitrogen in plant tops grown on horizons AC and C was similar, but less than that in plant tops grown on the Alp horizon.

In an experiment involving corn yield responses to rate of nitrogen fertilizer on artificially exposed Marshall subsoil and normal surface soil, Engelstad and Shrader (9) reported that equal corn yields could be obtained on either normal surface soil or on subsoil, provided that adequate nitrogen fertilizer was supplied. Reuss and Campbell (16), studying a Keiser clay loam soil in the greenhouse and Keiser clay loam and Nunn clay loam in the field, found almost no difference in yields between topsoil and subsoil when nitrogen and phosphorus were supplied.

Carlson et al. (5) compared a Gardena fine sandy loam subsoil with an undisturbed soil. Corn was grown the first and third year after land leveling. They observed that nitrogen was the most deficient element in the subsoil, followed by phosphorus and zinc. Manure applications increased corn yields; however, the yields on manured plots were not as high as those obtained with application of nitrogen, phosphorus, and zinc. It was necessary to apply nitrogen, phosphorus, zinc, and manure to make yields on the subsoil equal those on the surface soil.

Working in a fill and cut area of a Hidalgo sandy clay loam, Heilman and Thomas (12) showed that sorghum yields and nitrogen content of the plants were significantly increased by the application of nitrogen fertilizer to the cut area. There was no significant increase in sorghum yields from the application of nitrogen fertilizer to the fill area, although the nitrogen content of the forage was increased. They estimated that the cut area would require 345 pounds of N per acre (386.40 kg /ha) to produce yields equal to those produced on the non-fertilized fill area.

Eck and Ford (6) studied the productivity of Amarillo, Dalhart, and Miles, fine sandy loams, in the greenhouse under nitrogen and phosphorus fertilization. They indicated that nitrogen was more limiting than phosphorus on the topsoils, and phosphorus more limiting than nitrogen on all subsurface horizons. The topsoils outyielded the subsoils when no fertilizer or when nitrogen alone was applied. The subsoils outyielded the topsoils under the phosphorus alone and N + P treatments. They concluded that the subsurface horizons of some soils can be more productive than the topsoil. Fertilizer can be used to compensate for the loss of topsoil and, if fertilizer is applied, rather deep cuts may be made on these soils without impairing yield potential.

Eck, Hauser, and Ford (8) worked with a Pullman silty clay loam soil in greenhouse and field experiments. Without fertilizer the 0 to 5 inch (0 to 13 cm) horizon produced the highest yields, but under high nitrogen and phosphorus levels the 28 to 38 inch (71 to 97 cm) horizon produced yields equivalent to the 0 to 5 inch (0 to 13 cm) horizon and greater than all other nonsurface depths studied. In the field experiment nitrogen and phosphorus were required when 4 or more inches (10 cm) of topsoil was removed, and these nutrients, when added, restored yields where up to 12 inches (30 cm) of topsoil was removed. Yields on heavily fertilized, 16-inch (41 cm) cuts were 80% of those on similarly treated, undisturbed soil.

Studying the productivities of horizons of seven soils of the southern Great Plains, in the greenhouse, Eck, Ford, and Fanning (7) found that without fertilizer, yields on subsurface horizons were inferior to those on topsoils, but with adequate nitrogen and phosphorus additions yield levels were almost as high, as high, or in some cases higher on subsurface horizons than on surface horizons. They concluded that if a conscientious soil management program is followed, surface soil removal will not impair sustained high levels of production of the seven soils examined.

This review indicates that there is a great variation in the results obtained by researchers working with subsoil fertilization. Thus, generalizations cannot be made and local experiments are needed in order to determine the feasibility of restoring subsoil productivity by the use of fertilizers.

MATERIALS AND METHODS

In successive greenhouse experiments studies were conducted on four different Kansas soils: Marshall silt loam, Richfield silt loam, Geary silt loam, and Ladysmith silty clay loam.

Two depths were sampled from each soil. The first 20-cm sample (plow layer) was called "topsoil" and the second 20-cm increment was called "subsoil."

The Marshall silt loam 1/ is a member of the fine-silty, mixed, mesic family of Typic Hapludolls. It has a thick black or very dark brown, silt loam to light silty clay loam, weak, medium subangular blocky to fine granular structure, friable, medium acid A horizon; a dark brown to brown, silty clay loam, moderate, fine subangular blocky structure that has a tendency to form weak medium prismatic aggregates, friable, medium to slightly acid B2 horizon; and a yellowish-brown, silty clay loam and silt loam, massive, friable, neutral, loess B3 and C. The range of depth of the A horizon is 25 to 41 cm, with an average depth of about 30 cm. The combined B horizon is very deep with the C usually starting below 121 cm from the surface. This soil is typically free of carbonates to 305 or more cm. The samples of the Marshall silt loam used in this study were taken from a reseeded bluegrass pasture on a field with slopes ranging from 4 to 6 percent. This field was located northwest

1/ The soil type descriptions which follow were taken from Soil Series Descriptions prepared by Officers of the National Cooperative Soil Survey.

of the farmstead on the Wilber A. Copenhafer farm in Doniphan County. The samples were taken from the NW $\frac{1}{4}$ of Sec. 27, Tp. 3S, Rge. 21E.

The topsoil sample taken from this soil for study consists entirely of the Ap and A1. The "subsoil" is a mixture of the A1, A3, and B21, with most of the material coming from the A horizon.

The Richfield silt loam is a member of the fine, montmorillonitic, mesic family of Typic Argiustolls. It has a grayish-brown silt loam, weak, fine granular structure, friable, neutral A horizon; a dark grayish-brown, heavy silty clay loam, moderate, medium subangular blocky structure, firm B2t horizon; and a C horizon of light colored, weak, granular to massive, friable calcareous loess. The range of depth of the A horizon is 10 to 20 cm, rather typically 17 to 18 cm. The B2t horizon varies from 20 to 36 cm thick with the average about 25 cm. The total B thickness ranges from 30 to about 71 cm. The carbonate accumulation layer starts about 25 to 46 cm below the surface with an average of about 41 cm. The Richfield silt loam samples were taken from Logan County, NW corner of the SE $\frac{1}{4}$ of Sec. 31, Tp. 275, Rge. 35 W. This site was within two miles of the location where the soil type description for the Richfield silt loam used in the Logan County Soil Survey Report was made. The "topsoil" sample taken consisted mainly of the Ap. The "subsoil" sample was B horizon material.

The Geary silt loam is a member of the fine-silty, mixed, mesic family of Udic Argiustolls. It has a dark to very dark grayish-brown, silt loam, moderate medium and fine granular structure, friable, medium acid A horizon; a brown to dark brown, silty clay loam to silty clay, moderate, medium prismatic slightly hard but friable, medium to slightly acid B horizon; and reddish brown, silt loam, weak, prismatic, friable, slightly acid C horizon. The depth of the A horizon ranges from 15 to 30 cm, with an average of about

20 to 23 cm. The B horizon is about 76 cm deep but ranges from 61 to 102 cm. The soil is typically free of lime to 122 cm even at their western most point of occurrence. The Geary silt loam samples used were taken from Plot 2, Series VI of the Old Soil Fertility Project on the North Agronomy Farm, Manhattan, N center SE $\frac{1}{4}$ of Sec. 1, Tp. 10S, Rge. 7E. The "topsoil" sample taken was mostly A horizon and the "subsoil," B horizon.

The Ladysmith silty clay loam is a member of the fine, montmorillonitic, mesic family of Pachic Paleustolls. It has a thin dark gray, silt loam to light silty clay loam, weak fine granular, friable, medium acid A horizon; a very dark to dark gray, clay, weak, medium blocky, very firm, very hard, slightly acid to neutral B2t; and a light gray, silty clay loam to silty clay, massive, very hard, firm, slightly alkaline C horizon. The transition from the A1 to B2 is clear and smooth. The depth of the A ranges from 15 to 36 cm, and is typically about 23 cm unless erosion has removed topsoil. The B is 76 to 122 cm deep, with an average of about 102 cm, and with lime never found above 76 cm and usually not found above 127 cm. The Ladysmith silty clay loam samples were obtained from an area between terraces on the farm of Mrs. Collins in Geary County, the NE $\frac{1}{4}$ of Sec. 9, Tp. 13 S, Rge. 8 E. The "topsoil" sample used in this study consisted mainly of the A horizon. The "subsoil" sample was B horizon.

These four soils were chosen because of their different properties. Two soils, Marshall silt loam and Richfield silt loam, have permeable, friable subsoils which are quite productive. On the other hand, the Geary silt loam, and particularly the Ladysmith silty clay loam, have dense, compact subsoils which are relatively impermeable to water and to roots, and which make tillage operations difficult when they are exposed at the surface.

Both "topsoil" and "subsoil" were studied under ten fertilizer treatments which consisted of combinations of three levels of nitrogen, N_1, N_2, and N_3, three levels of phosphorus and potassium, $(PK)_1$, $(PK)_2$, and $(PK)_3$, and a treatment including the addition of manure to the highest combination of nitrogen, phosphorus, and potassium.

A general soil fertility test was performed on each topsoil and subsoil sample. These results are given in Table 1. On the basis of these results fertilizer application rates were chosen based on the tables for corn on irrigated soils in "Lime and fertilizer recommendations from soil tests."[2/] Since fertilizer requirements in the greenhouse are higher than those in the field (7), all the rates used in this study were about twice those recommended in the fertilizer recommendation leaflet. The lowest rate used corresponded to the amount of fertilizer necessary to obtain normal yields on the topsoil, the second rate was the amount of fertilizer needed by exposed subsoil to produce normal yields, and the third one was obtained by increasing the fertilizer to a still higher level.

2/ Whitney, D.A. "Lime and fertilizer recommendations from soil tests." Mimeographed circular. Agronomy Department, Kansas State University, February 1, 1968.

Table 1. Results of fertility tests on the four Kansas soils.

Soil		pH	Organic Matter (%)	Available P (kg/ha)	Exchangeable K (kg/ha)
Marshall sil	Topsoil	6.6	3.2	34	383
	Subsoil	6.8	2.7	9	304
Richfield sil	Topsoil	7.9	1.7	59	560+
	Subsoil	7.8	1.0	16	560+
Geary sil	Topsoil	5.9	2.3	27	560+
	Subsoil	6.1	1.7	6	516
Ladysmith sicl	Topsoil	5.9	2.2	17	282
	Subsoil	6.1	1.6	5	308

For the four soils the levels of nitrogen fertilization were N_1=100, N_2=200, and N_3=400 kg of N per hectare. The rates of phosphorus and potassium for the Marshall, Geary, and Ladysmith soils were $(PK)_1$=30 kg of P and 0 kg of K per hectare, $(PK)_2$=60 kg of P and 85 kg of K per hectare, and $(PK)_3$=120 kg P and 170 kg of K per hectare; while the rates for the Richfield soil were $(PK)_1$=no P or K, $(PK)_2$=30 kg of P per hectare and no K, and $(PK)_3$=60 kg of P and 85 kg of K per hectare. The manure application was 45 metric tons per hectare of fresh horse manure for all four soils. The approximate composition of the manure was such that this application added 220 kg of N, 50 kg of P, and 140 kg of K per hectare.

In spite of the difference in the rates of phosphorus and potassium in the Richfield soil, the ten treatments for all soils were designated as follows: $N_1(PK)_1$, $N_2(PK)_1$, $N_3(PK)_1$, $N_1(PK)_2$, $N_2(PK)_2$, $N_3(PK)_2$, $N_1(PK)_3$, $N_2(PK)_3$, $N_3(PK)_3$, and $N_3(PK)_3$+M.

The bulk soils which were collected from the various soil types were air dried, ground, and 2.268-kg samples were potted in 17.5 x 17.5-cm plastic pots. Fertilizers were added as solutions to the whole soil in each pot: nitrogen as NH_4NO_3, phosphorus as $Ca(H_2PO_4)_2 \cdot H_2O$ in the Marshall soil and as $NaH_2PO_4 \cdot H_2O$ in the other three soils, and potassium as KCl.

The pots for each soil type were distributed on the greenhouse bench in a completely randomized block design with six replications. Corn (Zea mays L.) was planted at the rate of ten seeds per pot, and after emergence was thinned to five plants per pot. Plants were watered regularly, keeping the soil moisture approximately between 50% and 100% of available water at field capacity. Dates of planting, harvest, and growth periods are given in Table 2.

Table 2. Planting and harvesting dates and growth period of corn on four Kansas soils.

Soil	Planting date	Harvesting Date	Growth period (days)
Marshall sil	5-11-68	6-10-68	30
Geary sil	6-17-68	7-13-68	26
Ladysmith sicl	7-17-68	8-15-68	29
Richfield sil	9-30-68	11-19-68	50

Corn was harvested when the biggest plants were about 60 cm in height. After harvest plants were ovendried at 70°C, weighed, and analyzed for nitrogen, phosphorus and potassium. Total nitrogen was determined by the Gunning Hibbard procedure (2). After dry-ashing and extraction with 0.1 N HCl, phosphorus was determined according to the Vanadomolybdophosphoric yellow color method outlined by Jackson (13), and potassium was determined by means of the flamephotometer.

Because it would have been necessary to make 480 individual analyses for each of nitrogen, phosphorus and potassium if all plant material were listed, the plant sample numbers were reduced by combining the vegetation from each treatment in replications 1 and 2, replications 3 and 4, and replications 5 and 6. Therefore, while the yields are given on the basis of six replications, the results of the plant analyses are based on only three replications.

Standard methods of statistical analysis were employed to ascertain significance of differences resulting from the different fertilizer treatment. Least significant differences were calculated at the 5% level.

RESULTS

As corn was produced on the different soils at different times of the year, it is not proper to compare yield and nutrient uptake responses on the different soils. Rather the responses for each soil will be presented separately and then general similarities and differences among soils will be pointed out.

In this section tabular material representing average yields and plant composition on the various soils and treatments will be presented. Individual yields, nutrient contents, and statistical tables are recorded in the Appendix (Tables 51 to 82).

Marshall Silt Loam

Crop Yields. Average yields of corn in dry weight per pot for the different fertility treatments are presented in Table 3. These data show that yields generally increased with N and with PK additions, although the increases were not always significant. Table 4 breaks the influence of treatments down into the effect on topsoil and on "subsoil." Generally, crops on both topsoil and "subsoil" responded in the same way to N and PK applications, except for the $N_3(PK)_1$ treatment which increased yields in the topsoil and reduced them in the "subsoil." Table 5 shows the actual differences in yields of the topsoil and "subsoil" on the different treatments. Largest differences were obtained at the lowest levels of PK, with smallest differences with the highest fertility treatment ($N_3(PK)_3$ + M).

Table 3. Effect of fertilization on average dry weight of corn (g/pot) on Marshall silt loam. (Average of 6 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	4.52 abc*	4.14 a	4.24 ab	4.30 x
$(PK)_2$	4.16 a	4.70 bc	4.89 cd	4.58 x
$(PK)_3$	4.48 abc	5.25 de	5.67 ef	5.13 y
$(PK)_3$+M	--	--	6.18 f	
Average	4.39 u	4.70 r	4.93 r**	

*In this and subsequent tables, figures followed by the same letter are not significantly different at the 5% level.

**In this and subsequent tables, average yields of N_3 treatments do not include $N_3(PK)_3$+M yield.

Table 4. Effect of fertilization on average dry weight of corn (g/pot) on topsoil (T) and "subsoil" (S) on Marshall silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	5.39	5.10	5.44
	S	3.65	3.18	3.05
$(PK)_2$	T	5.00	5.55	5.60
	S	3.31	3.84	4.18
$(PK)_3$	T	4.75	5.78	6.06
	S	4.20	4.71	5.28
$(PK)_3$+M	T	--	--	6.36
	S	--	--	6.01

Table 5. Effect of fertilization on differences in average dry weight of corn (g/pot) between topsoil and "subsoil" on Marshall silt loam. (Topsoil minus "subsoil.")

	N_1	N_2	N_3
$(PK)_1$	1.74	1.92	2.39
$(PK)_2$	1.69	1.71	1.42
$(PK)_3$	0.55 ns*	1.07	0.78
$(PK)_3$+M	--	--	0.35 ns

*In this and subsequent tables, differences followed by "ns" are not significantly different at the 5% level.

Nitrogen Content. Results of the analysis of plant material for nitrogen are presented in Tables 6 to 8. These data show an increase in nitrogen content of the plants with increasing N fertilization, but nitrogen in the plants was decreased with PK additions. The $N_3(PK)_3$+M treatment was not significantly different from $N_3(PK)_3$. Nitrogen content of plants grown on the topsoil was always higher than of those on the "subsoil," but the difference was not significant for the $N_3(PK)_3$ treatment. Table 8 shows that differences between topsoil and "subsoil" generally decreased with increasing N and decreased with $(PK)_3$ at N_2 and N_3 levels.

Table 6. Effect of fertilization on average nitrogen content of corn plants (%) grown on Marshall silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	2.87 c	3.00 d	3.37 f	3.08 x
$(PK)_2$	2.46 a	2.88 c	3.33 f	2.89 z
$(PK)_3$	2.38 a	2.76 b	3.15 e	2.76 y
$(PK)_3$+M	--	--	3.06 de	
Average	2.57 u	2.88 r	3.28 w	

Table 7. Effect of fertilization on average nitrogen content of corn plants (%) grown on topsoil (T) and on "subsoil" (S) on Marshall silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	3.18	3.24	3.48
	S	2.56	2.77	3.27
$(PK)_2$	T	2.64	3.12	3.45
	S	2.28	2.64	3.20
$(PK)_3$	T	2.64	2.92	3.20
	S	2.12	2.60	3.10
$(PK)_3$+M	T	--	--	3.22
	S	--	--	2.90

Table 8. Effect of fertilization on differences in average nitrogen content of corn plants (%) grown on topsoil and on "subsoil" on Marshall silt loam. (Topsoil minus "subsoil.")

	N_1	N_2	N_3
$(PK)_1$	0.62	0.47	0.21
$(PK)_2$	0.36	0.48	0.25
$(PK)_3$	0.52	0.32	0.10 ns
$(PK)_3$+M	--	--	0.32

Phosphorus Content. The average amount of phosphorus in the plant material is presented in Tables 9 to 11. These data show that phosphorus content increased with $(PK)_3$ and with manure additions. No significant effect was observed due to nitrogen application. Phosphorus content of the plants grown on the topsoil was always higher than of those grown on the "subsoil," but in the manure treatment not significantly so. Differences between topsoil and "subsoil" tended to decrease both with increased N and PK fertilization.

Table 9. Effect of fertilization on average phosphorus content of corn plants (%) grown on Marshall silt loam. (Average of 3 replications on topsoil and "subsoil.")

	N_1	N_2	N_3	Average
$(PK)_1$	.227 bc	.220 abc	.206 ab	.218 x
$(PK)_2$	.201 ab	.219 ab	.211 ab	.210 x
$(PK)_3$	.239 cd	.240 d	.235 cd	.238 y
$(PK)_3$+M	--	--	.251 d	
Average	.222 u	.217 u	.217 u	

Table 10. Effect of fertilization on average phosphorus content of corn plants (%) grown on topsoil (T) and on "subsoil" (S) on Marshall silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	.296	.272	.254
	S	.159	.168	.157
$(PK)_2$	T	.237	.270	.230
	S	.165	.169	.192
$(PK)_3$	T	.265	.263	.253
	S	.214	.218	.217
$(PK)_3$+M	T	--	--	.265
	S	--	--	.237

Table 11. Effect of fertilization on differences in average phosphorus content of corn plants (%) grown on topsoil and on "subsoil" on Marshall silt loam. (Topsoil minus "subsoil.")

	N_1	N_2	N_3
$(PK)_1$	.137	.104	.097
$(PK)_2$	.072	.101	.038
$(PK)_3$	.051	.045	.036
$(PK)_3$+M	--	--	.028 ns

Potassium Content. Average potassium content of the plants is shown in Tables 12 to 14. The data in Table 12 indicate that nitrogen additions did not influence potassium content of the plant material. However, Table 13 shows that nitrogen additions were accompanied by increased potassium content on the topsoil but by decreased potassium content on the "subsoil." Potassium content of the plants increased with $(PK)_2$ but the $(PK)_3$ level did not cause an additional increase. The highest potassium content was obtained in the $N_3(PK)_3$+M treatment. Table 14 shows that the differences in potassium content of plants on topsoil and on "subsoil" became greater as nitrogen rates increased. The smallest difference was observed in the manure treatment.

Table 12. Effect of fertilization on average potassium content of corn plants (%) grown on Marshall silt loam. (Average of 3 replications on topsoil and "subsoil.")

	N_1	N_2	N_3	Average
$(PK)_1$	4.91 ab	4.90 ab	4.85 a	4.89 x
$(PK)_2$	5.26 c	5.19 bc	5.19 bc	5.21 y
$(PK)_3$	5.15 abc	5.21 bc	4.92 ab	5.09 y
$(PK)_3$+M	--	--	5.61 d	
Average	5.11 u	5.10 u	4.99 u	

Table 13. Effect of fertilization on average potassium content of corn plants (%) grown on topsoil (T) and on "subsoil" (S) on Marshall silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	5.38	5.62	5.62
	S	4.43	4.18	4.08
$(PK)_2$	T	5.88	5.98	6.13
	S	4.63	4.40	4.25
$(PK)_3$	T	5.62	5.98	5.85
	S	4.68	4.43	3.98
$(PK)_3$+M	T	--	--	6.07
	S	--	--	5.15

Table 14. Effect of fertilization on differences in average potassium content of corn plants (%) grown on topsoil and on "subsoil" on Marshall silt loam. (Topsoil minus "subsoil.")

	N_1	N_2	N_3
$(PK)_1$	0.95	1.44	1.54
$(PK)_2$	1.25	1.58	1.88
$(PK)_3$	0.94	1.55	1.87
$(PK)_3$+M	--	--	0.92

Richfield Silt Loam

Crop Yields. Average corn yields are presented in Tables 15 to 17. These data show that yields increased with nitrogen fertilization. They also increased with PK additions but not significantly so with $(PK)_3$. The highest yield was obtained in the $N_3(PK)_3$+ M treatment. Table 16 shows that crops on both topsoil and subsoil responded in a similar way to N and PK fertilization, but, as happened in the Marshall soil, yields were increased on the topsoil and decreased on the subsoil with the $N_3(PK)_1$ treatment. Yield differences between topsoil and subsoil generally increased with increased nitrogen levels. The smallest difference was observed in the manure treatment. In all treatments yields on the topsoil were superior to those on the subsoil. Even in the highest fertility treatment, which produced the smallest yield difference between topsoil and subsoil, the difference was statistically significant.

Table 15. Effect of fertilization on average dry weight of corn (g/pot) on Richfield silt loam. (Average of 6 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	3.36 a	3.70 abc	3.97 bc	3.68 x
$(PK)_2$	3.65 ab	4.33 cde	4.58 ef	4.19 y
$(PK)_3$	3.82 b	4.02 bcd	4.78 f	4.21 y
$(PK)_3$+M	---	---	5.88 g	
Average	3.61 u	4.02 r	4.44 w	

Table 16. Effect of fertilization on average dry weight of corn (g/pot) on topsoil (T) and subsoil (S) on Richfield silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	4.34	4.79	5.75
	S	2.38	2.62	2.19
$(PK)_2$	T	4.82	5.59	6.00
	S	2.49	3.08	3.16
$(PK)_3$	T	5.08	5.14	6.25
	S	2.56	2.90	3.32
$(PK)_3$+M	T	---	---	6.47
	S	---	---	5.29

Table 17. Effect of fertilization on differences in average dry weight of corn (g/pot) between topsoil and subsoil on Richfield silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	1.96	2.17	3.56
$(PK)_2$	2.33	2.51	2.84
$(PK)_3$	2.52	2.24	2.93
$(PK)_3$+M	--	--	1.18

Nitrogen Content. Average nitrogen content of the plants is given in Tables 18 to 20. These data show that nitrogen content of the plant tissue increased both with increased N and PK rates. The highest nitrogen content was obtained in the N_3 level but not in the $N_3(PK)_3$+M treatment. Except for the lowest level of PK and the manure treatment, nitrogen content of the plant material on the subsoil was always higher than on the topsoil. There was a general response to nitrogen fertilization on both topsoil and subsoil but only the subsoil plants responded by increased N content to PK applications. In general, differences between topsoil and subsoil tended to decrease with the addition of nitrogen.

Table 18. Effect of fertilization on average nitrogen content of corn plants (%) grown on Richfield silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	2.25 a	2.60 b	2.76 c	2.54 x
$(PK)_2$	2.60 b	2.76 c	3.11 e	2.82 y
$(PK)_3$	2.65 bc	3.04 de	3.14 e	2.94 z
$(PK)_3$+M	--	--	2.94 d	
Average	2.50 u	2.80 r	3.00 w	

Table 19. Effect of fertilization on average nitrogen content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Richfield silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	2.35	2.81	2.88
	S	2.15	2.39	2.65
$(PK)_2$	T	2.41	2.68	3.09
	S	2.80	2.85	3.13
$(PK)_3$	T	2.22	2.85	3.08
	S	3.09	3.23	3.19
$(PK)_3$+M	T	--	--	3.01
	S	--	--	2.86

Table 20. Effect of fertilization on differences in average nitrogen content of corn plants (%) grown on topsoil and on subsoil on Richfield silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	0.20 ns	0.42	0.23
$(PK)_2$	-0.39	-0.17 ns	-0.04 ns
$(PK)_3$	-0.87	-0.38	-0.11 ns
$(PK)_3$+M	--	--	0.15 ns

Phosphorus Content. Average phosphorus contents of experimental plants are presented in Tables 21 to 23. These data show that phosphorus content of the plants increased with PK applications, but was not affected by nitrogen levels. Differences between topsoil and subsoil decreased with PK fertilization at the N_2 and N_3 levels. Phosphorus content of plants grown on topsoil was significantly higher at the $(PK)_1$ level, but no significant differences occurred in the other treatments.

Table 21. Effect of fertilization on average phosphorus content of corn plants (%) grown on Richfield silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	.167 a	.172 a	.161 a	.167 x
$(PK)_2$	.256 c	.231 b	.272 cd	.253 y
$(PK)_3$	.303 ef	.332 g	.326 fg	.320 z
$(PK)_3$+M	--	--	.283 de	
Average	.242 u	.245 u	.253 u	

Table 22. Effect of fertilization on average phosphorus content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Richfield silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	.219	.225	.209
	S	.114	.120	.113
$(PK)_2$	T	.254	.246	.285
	S	.259	.217	.260
$(PK)_3$	T	.287	.333	.328
	S	.319	.331	.323
$(PK)_3$+M	T	--	--	.292
	S	--	--	.275

Table 23. Effect of fertilization on differences in average phosphorus content of corn plants (%) grown on topsoil and on subsoil on Richfield silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	.105	.105	.096
$(PK)_2$	-.005 ns	.029 ns	.025 ns
$(PK)_3$	-.032 ns	.002 ns	.005 ns
$(PK)_3$+M	--	--	.017 ns

Potassium Content. Average potassium content of the plants is presented in Tables 24 to 26. Potassium in the plant material increased with increased PK rates. No effect due to nitrogen application was found. The highest potassium content was obtained with the manure treatment. Plants grown on both topsoil and subsoil responded similarly to PK fertilization, but while nitrogen tended to increase potassium content of the plants on the topsoil, it decreased it on the subsoil. Therefore, the differences between topsoil and subsoil generally increased with increased nitrogen rates. The smallest difference in potassium content between topsoil and subsoil was obtained in the $N_3(PK)_3$+ M treatment.

Table 24. Effect of fertilization on average potassium content of corn plants (%) grown on Richfield silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	5.82 a	5.82 a	5.84 a	5.83 x
$(PK)_2$	5.98 ab	6.07 abc	6.08 abc	6.04 y
$(PK)_3$	6.34 cd	6.22 bc	6.33 c	6.30 z
$(PK)_3$+M	--	--	6.67 d	
Average	6.05 u	5.99 u	6.08 u	

Table 25. Effect of fertilization on average potassium content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Richfield silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	6.03	6.17	6.50
	S	5.62	5.47	5.18
$(PK)_2$	T	6.12	6.42	6.50
	S	5.85	5.72	5.65
$(PK)_3$	T	6.58	6.42	6.67
	S	6.10	6.02	6.00
$(PK)_3$+M	T	--	--	6.77
	S	--	--	6.57

Table 26. Effect of fertilization on differences in average potassium content of corn plants (%) grown on topsoil and on subsoil on Richfield silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	0.41 ns	0.70	1.32
$(PK)_2$	0.27 ns	0.70	0.85
$(PK)_3$	0.48	0.40 ns	0.67
$(PK)_3$+M	--	--	0.20 ns

Geary Silt Loam

Crop Yields. Average corn yields are given in Tables 27 to 29. These data indicate a general response to PK fertilization, however yields at $(PK)_3$ were not significantly different from those at $(PK)_2$. No significant effect due to nitrogen additions was observed. The highest yield was obtained in the $N_3(PK)_3$+M treatment. Yields on the topsoil were always higher than on the subsoil, and crops on both responded essentially in the same way to fertilization. No consistent trend was observed in yield differences between topsoil and subsoil, but the smallest difference was obtained on the manure treatment. All the differences were statistically significant.

Table 27. Effect of fertilization on average dry weight of corn (g/pot) on Geary silt loam. (Average of 6 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	4.79 a	4.92 ab	5.01 ab	4.91 x
$(PK)_2$	5.27 bc	5.94 e	6.05 e	5.75 y
$(PK)_3$	5.49 cd	5.85 de	6.16 e	5.83 y
$(PK)_3$+M	---	---	6.60 f	
Average	5.18 u	5.57 u	5.74 u	

Table 28. Effect of fertilization on average dry weight of corn (g/pot) on topsoil (T) and subsoil (S) on Geary silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	5.49	5.50	5.69
	S	4.11	4.36	4.34
$(PK)_2$	T	5.66	6.50	6.45
	S	4.89	5.38	5.66
$(PK)_3$	T	6.23	6.33	6.81
	S	4.74	5.38	5.51
$(PK)_3$+M	T	--	--	6.90
	S	--	--	6.30

Table 29. Effect of fertilization on differences in average dry weight of corn (g/pot) between topsoil and subsoil on Geary silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	1.38	1.14	1.35
$(PK)_2$	0.77	1.12	0.79
$(PK)_3$	1.49	0.95	1.30
$(PK)_3$+M	--	--	0.60

Nitrogen Content. Results are presented in Tables 30 to 32. These data show that nitrogen content of the plants increased regularly with nitrogen fertilization at all levels of PK. No effect due to manure or PK additions was observed. Nitrogen in the plants was higher on the topsoil, but the differences between topsoil and subsoil were not always significant.

Table 30. Effect of fertilization on average nitrogen content of corn plants (%) grown on Geary silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	1.86 b	2.74 c	3.40 d	2.67 y
$(PK)_2$	1.79 ab	2.65 c	3.40 d	2.61 xy
$(PK)_3$	1.71 a	2.64 c	3.38 d	2.58 x
$(PK)_3$+M	--	--	3.36 d	
Average	1.79 u	2.68 r	3.39 w	

Table 31. Effect of fertilization on average nitrogen content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Geary silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	1.86	2.80	3.46
	S	1.86	2.67	3.34
$(PK)_2$	T	1.91	2.82	3.47
	S	1.67	2.55	3.33
$(PK)_3$	T	1.84	2.73	3.43
	S	1.58	2.56	3.33
$(PK)_3$+M	T	--	--	3.38
	S	--	--	3.33

Table 32. Effect of fertilization on differences in average nitrogen content of corn plants (%) grown on topsoil and on subsoil on Geary silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	0.00 ns	0.13 ns	0.12 ns
$(PK)_2$	0.24	0.27	0.14 ns
$(PK)_3$	0.26	0.17	0.10 ns
$(PK)_3$+M	--	--	0.05 ns

Phosphorus Content. Average phosphorus content of the plants is shown in Tables 33 to 35. These data show that phosphorus content of the plant material was related to PK and manure applications. Nitrogen addition had no apparent effect on plant phosphorus content. Plants grown on topsoil had more phosphorus than those grown on subsoil, but these differences were not always significant. PK additions decreased the differences in phosphorus content between plants on topsoil and subsoil at the N_2 and N_3 levels. Manure application increased the phosphorus content of the plants in the topsoil, but decreased it in the subsoil.

Table 33. Effect of fertilization on average phosphorus content of corn plants (%) grown on Geary silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	.165 a	.174 a	.167 a	.169 x
$(PK)_2$	.224 b	.223 b	.232 b	.226 y
$(PK)_3$	.296 c	.294 c	.306 c	.299 z
$(PK)_3$+M	---	---	.323 d	
Average	.228 u	.230 u	.235 u	

Table 34. Effect of fertilization on average phosphorus content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Geary silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	.176	.202	.192
	S	.154	.147	.143
$(PK)_2$	T	.221	.243	.244
	S	.226	.204	.219
$(PK)_3$	T	.288	.300	.301
	S	.305	.289	.310
$(PK)_3$+M	T	---	---	.343
	S	---	---	.303

Table 35. Effect of fertilization on differences in average phosphorus content of corn plants (%) grown on topsoil and on subsoil on Geary silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	.022	.055	.049
$(PK)_2$	-.005 ns	.039	.025
$(PK)_3$	-.017 ns	.011 ns	-.009 ns
$(PK)_3$+M	--	--	.040

Potassium Content. Average potassium content of the plants is presented in Tables 36 to 38. These data show that potassium fertilization increased potassium content of the plants. Nitrogen addition at the highest rate decreased plant potassium content at all PK levels. The highest potassium content was obtained on the $N_3(PK)_3$ + M treatment. Potassium content of plants was always higher on topsoil than on subsoil, and the differences between them decreased with PK applications. The smallest difference was obtained on the manure treatment.

Table 36. Effect of fertilization on average potassium content of corn plants (%) grown on Geary silt loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	3.55 b	4.38 e	3.32 a	3.75 x
$(PK)_2$	4.10 d	4.02 cd	3.92 c	4.01 y
$(PK)_3$	4.89 g	4.80 fg	4.69 f	4.79 z
$(PK)_3$+M	--	--	5.85 h	
Average	4.18 r	4.40 w	3.98 u	

Table 37. Effect of fertilization on average potassium content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Geary silt loam.

		N_1	N_2	N_3
$(PK)_1$	T	4.25	4.20	4.18
	S	2.85	2.55	2.47
$(PK)_2$	T	4.95	4.75	4.65
	S	3.25	3.28	3.20
$(PK)_3$	T	5.25	5.35	5.02
	S	4.53	4.25	4.37
$(PK)_3$+M	T	--	--	5.95
	S	--	--	5.75

Table 38. Effect of fertilization on differences in average potassium content of corn plants (%) grown on topsoil and on subsoil on Geary silt loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	1.40	1.65	1.71
$(PK)_2$	1.70	1.47	1.45
$(PK)_3$	0.72	1.10	0.65
$(PK)_3$+M	--	--	0.20 ns

Ladysmith Silty Clay Loam

Crop Yields. Corn yields are given in Tables 39 to 41. These data show that yields increased with N, PK, and manure additions. Plants on topsoil and subsoil responded similarly to fertilization with two exceptions. The $N_3(PK)_1$ treatment decreased yields on the topsoil and increased them on the subsoil. The $N_3(PK)_2$ treatment, on the other hand, increased yields on the topsoil and decreased them on the subsoil. Yields on the topsoil were always higher than on the subsoil, but on the $N_3(PK)_3$ + M treatment not significantly so.

Table 39. Effect of fertilization on average dry weight of corn (g/pot) on Ladysmith silty clay loam. (Average of 6 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	4.92 a	5.52 b	5.56 b	5.33 x
$(PK)_2$	5.71 b	6.38 c	6.47 c	6.19 y
$(PK)_3$	6.26 c	7.03 d	7.35 d	6.88 z
$(PK)_3$+M	---	---	7.74 e	
Average	5.63 u	6.31 r	6.46 r	

Table 40. Effect of fertilization on average dry weight of corn (g/pot) on topsoil (T) and subsoil (S) on Ladysmith silty clay loam.

		N_1	N_2	N_3
$(PK)_1$	T	5.84	6.68	6.57
	S	4.01	4.37	4.54
$(PK)_2$	T	6.51	6.88	7.53
	S	4.91	5.88	5.43
$(PK)_3$	T	6.82	7.53	7.73
	S	5.70	6.53	6.98
$(PK)_3$+M	T	---	---	8.00
	S	---	---	7.94

Table 41. Effect of fertilization on differences in average dry weight of corn (g/pot) between topsoil and subsoil on Ladysmith silty clay loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	1.83	2.31	2.03
$(PK)_2$	1.60	1.00	2.10
$(PK)_3$	1.12	1.00	0.75
$(PK)_3$+M	---	---	0.06 ns

Nitrogen Content. Results are presented in Tables 42 to 44. These data show that nitrogen content of the plants was increased with nitrogen applications, but decreased with PK additions. No effect due to manure was observed. Nitrogen content of the plants grown on the topsoil was never significantly lower than of those grown on the subsoil. Differences in nitrogen content of plants on topsoil and on subsoil increased with N_2 and decreased with N_3 at all PK levels, and were generally increased with increasing PK rates.

Table 42. Effect of fertilization on average nitrogen content of corn plants (%) grown on Ladysmith silty clay loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	2.13 b	3.02 e	3.38 h	2.84 z
$(PK)_2$	1.83 a	2.70 d	3.26 gh	2.60 y
$(PK)_3$	1.73 a	2.50 c	3.21 fg	2.48 x
$(PK)_3$+M	---	---	3.14 ef	
Average	1.90 u	2.74 r	3.28 w	

Table 43. Effect of fertilization on average nitrogen content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Ladysmith silty clay loam.

		N_1	N_2	N_3
$(PK)_1$	T	2.11	2.93	3.35
	S	2.15	3.10	3.41
$(PK)_2$	T	1.82	2.81	3.23
	S	1.85	2.58	3.32
$(PK)_3$	T	1.80	2.68	3.32
	S	1.65	2.32	3.10
$(PK)_3$+M	T	--	--	3.31
	S	--	--	2.97

Table 44. Effect of fertilization on differences in average nitrogen content of corn plants (%) grown on topsoil and on subsoil on Ladysmith silty clay loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	-0.04 ns	-0.17 ns	-0.06 ns
$(PK)_2$	-0.03 ns	0.23	-0.09 ns
$(PK)_3$	0.15 ns	0.36	0.22
$(PK)_3$+M	--	--	0.34

Phosphorus Content. Average phosphorus content of the plants is given in Tables 45 to 47. These data show that phosphorus content increased with increasing PK fertilization. No consistent effect due to nitrogen applications was observed. The highest phosphorus content was obtained in the manure treatment. Phosphorus content of the plants on the topsoil was always higher than of those on the subsoil, but in treatment $N_2(PK)_1$ not significantly so. Differences between topsoil and subsoil increased with PK additions at all nitrogen levels.

Table 45. Effect of fertilization on average phosphorus content of corn plants (%) grown on Ladysmith silty clay loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	.215 b	.216 b	.195 a	.209 x
$(PK)_2$	.224 bc	.233 c	.220 b	.226 y
$(PK)_3$	.282 d	.290 d	.284 d	.285 z
$(PK)_3$+M	---	---	.303 e	
Average	.240 ur	.246 r	.233 u	

Table 46. Effect of fertilization on average phosphorus content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Ladysmith silty clay loam.

		N_1	N_2	N_3
$(PK)_1$	T	.229	.221	.210
	S	.202	.211	.181
$(PK)_2$	T	.252	.246	.242
	S	.197	.220	.197
$(PK)_3$	T	.319	.341	.341
	S	.245	.240	.226
$(PK)_3$+M	T	---	---	.348
	S	---	---	.257

Table 47. Effect of fertilization on differences in average phosphorus content of corn plants (%) grown on topsoil and on subsoil on Ladysmith silty clay loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	.027	.010 ns	.029
$(PK)_2$	.055	.026	.045
$(PK)_3$	.074	.101	.115
$(PK)_3$+M	--	--	.091

Potassium Content. Average potassium content of the plants is presented in Tables 48 to 50. These data show that potassium fertilization increased potassium content of the plants, but nitrogen application decreased it at the N_2 level. The highest potassium content was obtained at the $N_3(PK)_3$ + M treatment. Potassium in the plants grown on the topsoil was always significantly higher than in those grown on the subsoil, and the differences between them decreased with increasing PK and manure applications.

Table 48. Effect of fertilization on average potassium content of corn plants (%) grown on topsoil and on subsoil on Ladysmith silty clay loam. (Average of 3 replications on topsoil and subsoil.)

	N_1	N_2	N_3	Average
$(PK)_1$	3.11 b	2.83 a	2.84 a	2.93 x
$(PK)_2$	3.64 cd	3.49 c	3.58 cd	3.57 y
$(PK)_3$	4.26 f	3.85 c	3.72 de	3.94 z
$(PK)_3$+M	--	--	4.22 f	
Average	3.67 r	3.39 u	3.38 u	

Table 49. Effect of fertilization on average potassium content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Ladysmith silty clay loam.

		N_1	N_2	N_3
$(PK)_1$	T	4.28	4.02	3.90
	S	1.93	1.65	1.78
$(PK)_2$	T	4.65	4.53	4.40
	S	2.63	2.45	2.75
$(PK)_3$	T	5.05	4.80	4.53
	S	3.47	2.90	2.90
$(PK)_3$+M	T	--	--	4.90
	S	--	--	3.55

Table 50. Effect of fertilization on differences in average potassium content of corn plants (%) grown on topsoil and on subsoil on Ladysmith silty clay loam. (Topsoil minus subsoil.)

	N_1	N_2	N_3
$(PK)_1$	2.35	2.37	2.12
$(PK)_2$	2.02	2.08	1.65
$(PK)_3$	1.58	1.90	1.63
$(PK)_3$+M	--	--	1.35

DISCUSSION

The results of this study showed that yields were always higher on topsoil than they were on subsoil, even in the Marshall soil where the "subsoil" was predominantly A horizon material with a little B21 horizon material admixed. When high levels of fertilizer or of manure and fertilizer were added to the subsoil, yields approximating or exceeding those obtained on the topsoils with the lowest level of N and PK were obtained. This indicated that the major cause of the difference in productivity between the topsoils and the subsoils in the greenhouse was a difference in soil fertility. However, when yields on topsoil and subsoil under the same fertilizer treatment were compared, the topsoil yields were always higher, though not always significantly so. This indicated that there probably were other productivity factors also involved in the lower yields on some subsoils even in the greenhouse.

Two of the soils selected for study, Marshall and Richfield, were considered to have quite productive subsoils, so that topsoil removal effects would be minimal. The other two, Geary and Ladysmith, have intractible subsoils under field conditions. However, in the greenhouse the Richfield and the Geary subsoils proved to be inferior to topsoils even under high rates of fertilizer application, while under high fertility, yields on the subsoils of the Marshall and the Ladysmith were not significantly less than the yields on the topsoils. Thus soils may not always react in the greenhouse the same as they will respond in the field. Consequently the productive capacity of subsoils and topsoils needs to be assessed under field conditions as well as in the greenhouse and laboratory.

The nitrogen content of the plants was generally higher on the topsoil than it was on the subsoil. This is understandable since the organic matter content of the topsoil was higher than that of the subsoil. However, on the Richfield soil the nitrogen content of the plants on the subsoil was higher than on the topsoil in over half the treatments. There is no apparent explanation for this fact. The nitrogen content of the plants was increased with each increment of nitrogen fertilizer. This too is understandable. Manure did not affect nitrogen content. This may have been due to the fact that manure was only applied with 400 kg/ha of fertilizer N. Besides the nitrogen in the manure was largely organic nitrogen and the growth period was short so that little decomposition and nitrogen release could occur.

On three soils, Marshall, Geary, and Ladysmith, applications of PK reduced nitrogen content of the plants, while on the Richfield the nitrogen content increased progressively with each increment of PK. One would expect that additions of an anion, such as phosphate, might interfere with the uptake of another anion such as nitrate. This may account for the effect of phosphorus fertilization on nitrogen content on the three soils. In the case of the Richfield soil much less phosphorus was added in the fertilizer treatments than in the other three soils, and the total phosphorus (soil available and fertilizer) was less in most of the treatments in the Richfield soil than in the three eastern soils.

Phosphorus content of plants was generally increased by phosphorus applications. This was expected. Phosphorus content was generally higher in plants from topsoil and was never significantly lower. This likely is a consequence of the higher level of phosphorus in the topsoil. With increasing additions of PK the differences between phosphorus content of plants on topsoil and subsoil became less on the Marshall, Richfield, and Geary. However, on the Ladysmith soil, differences in phosphorus content of plants on topsoil and subsoil became greater as PK was added. This difference in plant response on the different soils cannot be explained. However, it should be noted that the phosphorus level of the Ladysmith soil was lower than in any other soil and the difference between topsoil and subsoil phosphorus was smaller than in the other three soils. Nitrogen additions had no appreciable effect on phosphorus content of plants in this study. This was unexpected as a reciprocal relationship between the anion $H_2PO_4^-$ and NO_3^- is often noted. Manure additions increased phosphorus content of plants in the Geary and Ladysmith soils but not in the other two. The Geary and Ladysmith soils were the lowest in phosphorus and it could be that additions of phosphorus and manure were able to further increase phosphorus content above that obtained with fertilizer above.

The potassium content of the plants was increased by combined additions of potassium and phosphorus fertilizer and by applications of manure. One would expect that additions of potassium would increase the potassium content of the plants under most conditions. However, in the Marshall soil the third increment of potassium (as PK) did not increase potassium content above the level produced on the second rate of PK. In the Richfield soil the second PK level (which contained no potassium) increased potassium content of the corn. This may have been an interaction between phosphorus additions and potassium content of the plants, but cannot be determined satisfactorily because in the three soils, other than Richfield, the levels of potassium and phosphorus applications were increased simultaneously. On the Marshall and Richfield soils nitrogen applications had no apparent effect on potassium content of the plants. On the Geary soil N_2 level increased and N_3 level decreased the potassium content of the corn, and on the Ladysmith the potassium content was reduced by the addition of the second and third levels of nitrogen. The potassium content of the crop was always higher on topsoil than on subsoil, in spite of the fact that in the Ladysmith the potassium content of the subsoil was higher than that of the topsoil, and in the Richfield, soil test data showed both topsoil and subsoil to have in excess of 560 kg of potassium per hectare. Particularly, at the higher level of nitrogen fertilization there was a tendency for PK additions to reduce the differences between potassium content of plants on topsoil and on subsoil; however, in the case of the Marshall soil, the differences in potassium content of plants on topsoil and on subsoil were lower at the lowest rate of PK fertilization than at the higher levels of PK. Smallest differences in plant potassium content between topsoil and subsoil were always found on the manure treatment.

CONCLUSIONS

1. This study showed that the lower fertility status of subsoil is an important cause of reduced crop growth on four Kansas soils from which surface material was removed. In the case of the Marshall and the Ladysmith soils this apparently was the major cause of reduced productivity as measured in the greenhouse. With the Richfield and the Geary soils the fertility treatments employed did not overcome the detrimental effect of topsoil removal.

2. Factors, other than fertility, may have caused reduced crop growth on the subsoils tested. The influence of other factors should be assessed. However, further study needs to be conducted in the field rather than in the greenhouse and laboratory, because the effect of physical factors, such as infiltration rates and percolation rates, cannot be studied adequately in greenhouse pots.

LITERATURE CITED

1. Alway, F. J., G. R. McDole, and C. O. Rost. 1917. The loess soils of the Nebraska portion of the transition region. VI. The relative "rawness" of the subsoils. Soil Sci. 3:9-36.

2. Association of Official Agricultural Chemists. 1950. Methods of Analyses, Seventh Edition. p. 32.

3. Bachtell, M. A., C. J. Willard, and G. S. Taylor. 1956. Building fertility in exposed subsoil. Ohio Agr. Exp. Sta. Res. Bull. 782.

4. Carlson, C. W., and D. L. Grumes. 1958. Effect of fertilization on yields and nutrient content of barley. Soil Sci. Soc. Amer. Proc. 22:140-145.

5. Carlson, C. W., D. L. Grumes, J. Alessi, and G. A. Reichman. 1961. Corn growth on Gardena surface and subsoil as effected by applications of fertilizers and manure. Soil Sci. Soc. Amer. Proc. 25:44-47.

6. Eck, H. V., and R. H. Ford. 1962. Restoring productivity on exposed subsoils. J. Soil and Water Conserv. 17:274-275.

7. Eck, H. V., R. H. Ford, and C. D. Fanning. 1967. Productivities of horizons of seven benchmark soils of the southern Great Plains. USDA Cons. Res. Rep. 11.

8. Eck, H. V., V. L. Hauser, and R. H. Ford. 1965. Fertilizer needs for restoring productivity on Pullman silty clay loam after various degrees of soil removal. Soil Sci. Soc. Amer. Proc. 29:209-213.

9. Engelstad, O. P., and W. D. Shrader. 1961. The effect of surface soil thickness on corn yields: II. As determined by an experiment using normal surface soil and artificially-exposed subsoil. Soil Sci. Soc. Amer. Proc. 29:497-499.

10. Gardner, R. 1941. Why is subsoil unproductive? Colorado Agr. Exp. Sta. Bull. 464.

11. Harmer, P. M. 1918. The relative "rawness" of some humid subsoils. Soil Sci. 5:393-403.

12. Heilman, M. D., and J. R. Thomas. 1961. Land Leveling can adversely affect soil fertility. J. Soil and Water Conserv. 16:71-72.

13. Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Inc. Englewood Cliffs, N.J. pp. 151-153.

14. Latham, E. E. 1940. Relative productivity of the A horizon of Cecil sandy loam and the B and C horizons exposed by erosion. Jour. Amer. Soc. Agron. 32:950-954.

15. McMiller, P. R. 1919. Some notes on the cause of the unproductivity of "raw" subsoils in humid regions. Soil Sci. 7:233-236.

16. Reuss, J. O., and R. E. Campbell. 1961. Restoring productivity to leveled land. Soil Sci. Soc. Amer. Proc. 25:302-304.

17. Smith, R. M., and G. G. Pohlman. 1951. Comparison of subsoils and surface soils in the greenhouse as an aid in understanding and reclaiming eroded soils. Agron. J. 43:259-264.

18. Whitney, R. S., R. Gardner, and D. W. Robertson. 1950. The effectiveness of manure and commercial fertilizers in restoring the productivity of subsoils exposed by leveling. Agron. J. 42:239-245.

19. Winters, E. and R. W. Simonson. 1951. The subsoil. In A. G. Norman (ed.) Advances in Agronomy, Academic Press, Inc., New York. 3:1-92.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. J. A. Hobbs for his guidance and aid during the experimental phase of the study and in the preparation of the manuscript.

Thanks go also to the graduate students J. L. Estrada and E. D. Grauerholz for their help in running some of the plant analyses.

APPENDIX

Table 51. Effect of fertilization on dry weight of corn (g/pot) on topsoil (T) and "subsoil" (S) on Marshall silt loam.

Treatments	Replications I T	I S	II T	II S	III T	III S	IV T	IV S	V T	V S	VI T	VI S
$N_1(PK)_1$	5.25	2.86	5.85	7.18	5.04	3.04	5.15	2.90	5.94	3.05	5.12	2.85
$N_2(PK)_1$	4.32	2.84	5.82	3.16	5.11	3.31	4.54	2.97	6.39	3.63	4.43	3.16
$N_3(PK)_1$	5.89	2.98	4.54	3.43	6.54	2.68	5.84	3.16	5.67	2.99	4.13	3.06
$N_1(PK)_2$	4.84	2.85	5.14	3.28	4.15	3.44	5.58	3.32	4.16	2.95	6.13	4.04
$N_2(PK)_2$	4.50	3.54	6.24	3.62	6.29	3.76	6.06	4.52	5.55	3.61	4.64	4.02
$N_3(PK)_2$	4.87	4.08	5.39	4.34	6.09	3.76	5.86	4.42	5.86	4.20	5.54	4.25
$N_1(PK)_3$	4.04	3.84	6.04	4.47	4.31	4.25	4.83	3.39	4.33	4.66	4.97	4.59
$N_2(PK)_3$	5.43	4.54	5.20	4.04	6.04	4.61	5.37	5.04	6.22	4.80	6.44	5.24
$N_3(PK)_3$	6.35	4.94	6.30	5.47	6.30	5.04	5.66	5.25	6.49	5.94	5.26	5.02
$N_3(PK)_3$+M	6.29	5.52	5.90	5.54	6.49	6.99	6.27	6.07	6.39	5.82	6.79	6.13

Table 52. Analysis of variance summary of the effect of fertilization on dry weight of corn on Marshall silt loam soil.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	50.0622	5.5625	13.13	**
Topsoil-Subsoil	1	55.6513	55.6513	131.38	**
Replications	5	3.5403	0.7081	1.67	ns
Treatments x Topsoil-Subsoil	9	11.5322	1.2814	3.03	**
Error	95	40.2390	0.4236		
Total	119	161.0250			

** Significant at the 0.01 level
* Significant at the 0.05 level
ns Not significant

Table 53. Effect of fertilization on nitrogen content of corn plants (%) grown on topsoil (T) and on "subsoil" (S) on Marshall silt loam.

	Replications					
	I + II		III + IV		V + VI	
Treatments	T	S	T	S	T	S
$N_1(PK)_1$	3.23	2.66	3.18	2.57	3.14	2.45
$N_2(PK)_1$	3.30	2.77	3.22	2.80	3.19	2.73
$N_3(PK)_1$	3.56	3.31	3.51	3.42	3.37	3.07
$N_1(PK)_2$	2.74	2.33	2.56	2.23	2.63	2.27
$N_2(PK)_2$	3.20	2.75	3.12	2.61	3.05	2.56
$N_3(PK)_2$	3.69	3.40	3.35	3.05	3.32	3.16
$N_1(PK)_3$	2.82	2.34	2.59	2.04	2.52	1.98
$N_2(PK)_1$	2.89	2.61	2.85	2.61	3.03	2.58
$N_3(PK)_3$	3.18	3.22	3.15	3.11	3.26	2.96
$N_3(PK)_3$+M	3.27	2.96	3.19	2.80	3.21	2.94

Table 54. Analysis of variance summary of the effect of fertilization on nitrogen content of corn plants on Marshall silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	5.8810	0.6534	83.77	**
Topsoil-Subsoil	1	2.0277	2.0277	259.96	**
Replications	2	0.2223	0.1112	14.26	**
Treatments x Topsoil-Subsoil	9	0.3400	0.0378	4.85	**
Error	38	0.2985	0.0078		
Total	59	8.7695			

Table 55. Effect of fertilization on phosphorus content of corn plants (%) grown on topsoil (T) and on "subsoil" (S) on Marshall silt loam.

Treatments	Replications I + II T	I + II S	III + IV T	III + IV S	V + VI T	V + VI S
$N_1(PK)_1$	.312	.176	.288	.159	.288	.141
$N_2(PK)_1$	.278	.178	.276	.171	.263	.156
$N_3(PK)_1$	.266	.179	.293	.158	.204	.135
$N_1(PK)_2$	.250	.179	.214	.158	.248	.159
$N_2(PK)_2$	.278	.173	.286	.171	.245	.163
$N_3(PK)_2$	.266	.196	.217	.184	.206	.196
$N_1(PK)_3$	.299	.214	.232	.217	.263	.210
$N_2(PK)_3$	.271	.214	.238	.227	.279	.212
$N_3(PK)_3$	.247	.219	.266	.230	.245	.202
$N_3(PK)_3$+M	.291	.232	.243	.235	.261	.243

Table 56. Analysis of variance summary of the effect of fertilization on phosphorus content of corn plants on Marshall silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	0.0143	0.00159	5.13	**
Topsoil-Subsoil	1	0.0753	0.00753	242.90	**
Replications	2	0.0041	0.00205	6.61	**
Treatments x Topsoil-Subsoil	9	0.0185	0.00206	6.64	**
Error	38	0.0119	0.00031		
Total	59	0.1241			

Table 57. Effect of fertilization on potassium content of corn plants (%) grown on topsoil (T) and on "subsoil" (S) on Marshall silt loam.

Treatments	Replications I + II T	S	III + IV T	S	V + VI T	S
$N_1(PK)_1$	5.55	4.85	5.55	4.30	5.05	4.15
$N_2(PK)_1$	5.90	4.30	5.25	4.30	5.70	3.95
$N_3(PK)_1$	5.90	4.40	5.05	4.15	5.90	3.70
$N_1(PK)_2$	6.50	4.75	5.80	4.85	5.35	4.30
$N_2(PK)_2$	6.35	4.50	5.70	4.30	5.90	4.40
$N_3(PK)_2$	6.35	4.30	6.00	3.95	6.05	4.50
$N_1(PK)_3$	6.00	4.85	5.70	4.60	5.15	4.60
$N_2(PK)_3$	6.35	4.50	5.70	4.50	5.90	4.30
$N_3(PK)_3$	6.60	3.95	5.35	4.05	5.60	3.95
$N_3(PK)_3$+M	6.00	5.25	6.60	5.15	5.60	5.05

Table 58. Analysis of variance summary of the effect of fertilization on potassium content of corn plants.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	2.9040	0.3227	4.00	**
Topsoil-Subsoil	1	28.9815	28.9815	359.57	**
Replications	2	1.7926	0.8963	11.12	**
Treatments x Topsoil-Subsoil	9	1.8027	0.2003	2.48	*
Error	38	3.0640	0.0806		
Total	59	38.5448			

Table 59. Effect of fertilization on dry weight of corn (g/pot) on topsoil (T) and subsoil (S) on Richfield silt loam.

Treatments	Replications I		II		III		IV		V		VI	
	T	S	T	S	T	S	T	S	T	S	T	S
$N_1(PK)_1$	4.12	2.15	4.64	2.36	3.54	2.19	4.94	2.25	4.42	2.36	4.41	2.94
$N_2(PK)_1$	4.22	2.79	4.66	2.27	4.92	2.84	5.38	2.55	4.46	2.44	5.09	2.82
$N_3(PK)_1$	5.44	2.20	5.65	2.32	5.46	1.74	5.99	2.31	6.04	1.93	5.93	2.64
$N_1(PK)_2$	4.73	1.82	4.04	3.15	5.15	2.49	4.21	2.92	5.49	2.52	5.29	2.05
$N_2(PK)_2$	4.64	3.49	5.84	3.14	5.52	3.65	5.48	2.86	5.97	2.29	6.10	3.07
$N_3(PK)_2$	5.84	2.79	5.82	3.24	6.26	3.19	5.63	3.02	6.36	3.20	6.12	3.51
$N_1(PK)_3$	4.96	2.99	5.09	1.84	5.16	2.09	5.14	2.27	5.95	3.92	4.15	2.27
$N_2(PK)_3$	5.71	2.64	4.70	4.02	5.00	2.23	4.58	2.49	5.56	2.92	5.29	3.12
$N_3(PK)_3$	5.55	1.96	6.10	3.22	6.13	3.29	6.59	3.38	6.59	4.17	6.54	3.92
$N_3(PK)_3$+M	5.80	4.65	6.29	4.79	6.65	4.89	6.85	5.16	5.96	5.76	7.27	6.50

Table 60. Analysis of variance summary of the effect of fertilization on dry weight of corn on Richfield silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	57.7350	6.4150	28.30	**
Topsoil-Subsoil	1	176.2248	176.2248	777.35	**
Replications	5	3.8588	0.7718	3.40	**
Treatments x Topsoil-Subsoil	9	10.8218	1.2024	5.30	**
Error	95	21.5379	0.2267		
Total	119	270.1783			

Table 61. Effect of fertilization on nitrogen content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Richfield silt loam.

Treatments	I + II		Replications II + III		V + VI	
	T	S	T	S	T	S
$N_1(PK)_1$	2.30	2.15	2.43	2.27	2.32	2.04
$N_2(PK)_1$	2.88	2.46	2.78	2.37	2.78	2.33
$N_3(PK)_1$	2.90	2.84	2.85	2.68	2.89	2.42
$N_1(PK)_2$	2.69	2.67	2.38	2.87	2.17	2.85
$N_2(PK)_2$	2.81	2.90	2.48	2.77	2.75	2.88
$N_3(PK)_2$	3.23	2.96	2.95	3.22	3.09	3.20
$N_1(PK)_3$	2.21	3.06	2.11	3.15	2.34	3.05
$N_2(PK)_3$	2.87	3.14	2.78	3.25	2.91	3.29
$N_3(PK)_3$	3.04	3.15	3.06	3.27	3.14	3.15
$N_3(PK)$ +M	3.18	2.66	2.90	3.06	2.94	2.87

Table 62. Analysis of variance summary of the effect of fertilization on nitrogen content of corn plants on Richfield silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	4.1031	0.4559	27.14	**
Topsoil-Subsoil	1	0.1325	0.1325	7.89	**
Replications	2	0.0125	0.0062	0.37	ns
Treatments x Topsoil-Subsoil	9	1.9307	0.2145	12.77	**
Error	38	0.6391	0.0168		
Total	59	6.8179			

Table 63. Effect of fertilization on phosphorus content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Richfield silt loam.

Treatments	Replications I + II T	S	III + IV T	S	V + VI T	S
$N_1(PK)_1$	.218	.108	.217	.119	.223	.115
$N_2(PK)_1$	.243	.120	.213	.120	.218	.119
$N_3(PK)_1$	.203	.122	.213	.110	.211	.108
$N_1(PK)_2$	.247	.200	.268	.288	.248	.288
$N_2(PK)_2$	.250	.228	.243	.213	.244	.209
$N_3(PK)_2$	.317	.243	.258	.291	.279	.246
$N_1(PK)_3$	.278	.313	.282	.298	.300	.347
$N_2(PK)_3$	.315	.308	.353	.336	.332	.349
$N_3(PK)_3$	.313	.325	.323	.346	.349	.298
$N_3(PK)_3$+M	.303	.297	.268	.283	.305	.244

Table 64. Analysis of variance summary of the effect of fertilization on phosphorus content of corn plants on Richfield silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	0.2291	0.02546	57.86	**
Topsoil-Subsoil	1	0.0181	0.01810	41.14	**
Replications	2	0.0003	0.00015	0.34	ns
Treatments x Topsoil-Subsoil	9	0.0331	0.00368	8.36	**
Error	38	0.0168	0.00044		
Total	59	0.2974			

Table 65. Effect of fertilization on potassium content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Richfield silt loam.

Treatments	Replications I + II T	I + II S	III + IV T	III + IV S	V + VI T	V + VI S
$N_1(PK)_1$	5.80	5.60	6.05	5.90	6.25	5.35
$N_2(PK)_1$	5.90	5.55	6.00	5.60	6.60	5.25
$N_3(PK)_1$	6.70	5.15	6.45	5.05	6.35	5.35
$N_1(PK)_2$	6.25	6.05	6.05	6.15	6.05	5.35
$N_2(PK)_2$	6.45	5.90	6.35	5.80	6.45	5.45
$N_3(PK)_2$	6.45	5.45	6.45	5.80	6.60	5.70
$N_1(PK)_3$	6.80	5.90	6.45	6.15	6.50	6.25
$N_2(PK)_3$	6.35	6.00	6.45	5.80	6.45	6.25
$N_3(PK)_3$	6.95	5.60	6.45	6.35	6.60	6.05
$N_3(PK)_3$+M	7.25	6.45	6.25	6.90	6.80	6.35

Table 66. Analysis of variance summary of the effect of fertilizer on potassium content of corn plants on Richfield silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	4.0966	0.4552	6.51	**
Topsoil-Subsoil	1	5.4000	5.4000	77.25	**
Replications	2	0.0085	0.0042	0.06	ns
Treatments x Topsoil-Subsoil	9	1.4383	0.1598	2.29	*
Error	38	2.6549	0.0699		
Total	59	13.5983			

Table 67. Effect of fertilization on dry weight of corn (g/pot) on topsoil (T) and subsoil (S) on Geary silt loam.

Treatments	Replications I T	I S	II T	II S	III T	III S	IV T	IV S	V T	V S	VI T	VI S
$N_1(PK)_1$	5.35	4.32	6.14	3.72	5.63	3.85	5.32	3.64	5.25	4.36	5.24	4.75
$N_2(PK)_1$	5.55	4.46	5.98	3.84	5.83	4.46	4.66	4.53	5.63	4.36	5.32	4.51
$N_3(PK)_1$	5.17	4.66	5.36	4.41	5.06	3.75	6.52	4.64	6.11	4.35	5.92	4.20
$N_1(PK)_2$	6.24	4.79	5.47	5.33	5.45	4.42	6.15	4.89	5.53	5.05	5.12	4.86
$N_2(PK)_2$	6.52	5.98	5.62	5.85	5.79	5.18	7.19	5.45	6.74	4.44	7.13	5.39
$N_3(PK)_2$	6.94	5.84	7.06	5.52	5.98	6.25	6.57	5.58	6.21	5.43	5.93	5.32
$N_1(PK)_3$	6.02	4.32	6.72	4.91	6.15	5.48	5.83	4.75	6.45	4.34	6.23	4.66
$N_2(PK)_3$	5.91	6.12	6.93	5.36	6.70	4.93	5.84	4.91	6.85	5.48	5.76	5.48
$N_3(PK)_3$	6.34	4.67	7.32	5.45	7.03	5.97	5.96	6.08	7.41	5.92	6.79	4.96
$N_3(PK)_3$+M	6.91	7.21	6.84	7.00	6.70	5.51	6.47	6.08	7.14	5.42	7.35	6.59

Table 68. Analysis of variance summary of the effect of fertilization on dry weight of corn on Geary silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	39.1104	4.3456	18.75	**
Topsoil-Subsoil	1	35.5885	35.5885	153.53	**
Replications	5	0.7172	0.1434	0.62	ns
Treatments x Topsoil-Subsoil	9	2.4383	0.2709	1.17	ns
Error	95	22.0182	0.2318		
Total	119	99.8726			

Table 69. Effect of fertilization on nitrogen content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Geary silt loam.

Treatments	Replications I + II T	I + II S	III + IV T	III + IV S	V + VI T	V + VI S
$N_1(PK)_1$	1.79	1.88	1.86	1.93	1.93	1.77
$N_2(PK)_1$	2.85	2.77	2.84	2.73	2.72	2.51
$N_3(PK)_1$	3.45	3.32	3.60	3.31	3.34	3.40
$N_1(PK)_2$	2.03	1.62	1.80	1.84	1.90	1.54
$N_2(PK)_2$	2.80	2.52	2.67	2.50	2.80	2.62
$N_3(PK)_2$	3.57	3.17	3.42	3.53	3.42	3.29
$N_1(PK)_3$	1.85	1.68	1.87	1.56	1.81	1.50
$N_2(PK)_3$	2.77	2.46	2.68	2.57	2.73	2.64
$N_3(PK)_3$	3.42	3.38	3.37	3.27	3.49	3.33
$N_3(PK)_3$+M	3.47	3.26	3.39	3.46	3.28	3.27

Table 70. Analysis of variance summary of the effect of fertilization on nitrogen content of corn plants on Geary silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	26.3498	2.9278	308.19	**
Topsoil-Subsoil	1	0.3067	0.3067	32.38	**
Replications	2	0.0240	0.0120	1.26	ns
Treatments x Topsoil-Subsoil	9	0.0921	0.0102	1.07	ns
Error	38	0.3605	0.0095		
Total	59	27.1331			

Table 71. Effect of fertilization on phosphorus content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Geary silt loam.

Treatments	Replications I + II T	I + II S	III + IV T	III + IV S	V + VI T	V + VI S
$N_1(PK)_1$	.187	.137	.145	.170	.197	.156
$N_2(PK)_1$	.206	.135	.193	.156	.206	.150
$N_3(PK)_1$	.185	.141	.193	.152	.197	.135
$N_1(PK)_2$	.214	.202	.224	.249	.226	.228
$N_2(PK)_2$	.249	.208	.237	.206	.243	.197
$N_3(PK)_2$	.245	.206	.239	.224	.247	.228
$N_1(PK)_3$	.284	.297	.280	.312	.299	.307
$N_2(PK)_3$	.303	.310	.293	.282	.305	.274
$N_3(PK)_3$	.295	.316	.307	.324	.301	.291
$N_3(PK)_3$+M	.353	.284	.341	.312	.334	.314

Table 72. Analysis of variance summary of the effect of fertilization on phosphorus content of corn plants on Geary silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	0.1990	0.02211	130.05	**
Topsoil-Subsoil	1	0.0065	0.00650	38.24	**
Replications	2	0.0002	0.00010	0.59	ns
Treatments x Topsoil-Subsoil	9	0.0087	0.00096	5.65	**
Error	38	0.0066	0.00017		
Total	59	0.2210			

Table 73. Effect of fertilization on potassium content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Geary silt loam.

Treatments	Replications I + II T	I + II S	III + IV T	III + IV S	V + VI T	V + VI S
$N_1(PK)_1$	3.95	2.65	4.50	2.90	4.30	3.00
$N_2(PK)_1$	4.15	2.55	4.15	2.55	4.30	2.55
$N_3(PK)_1$	3.95	2.40	4.30	2.55	4.30	2.45
$N_1(PK)_2$	4.75	3.00	5.05	3.30	5.05	3.45
$N_2(PK)_2$	4.75	2.80	4.75	3.60	4.75	3.45
$N_3(PK)_2$	4.50	3.00	4.60	3.35	4.85	3.25
$N_1(PK)_3$	5.25	4.50	5.15	4.50	5.35	4.60
$N_2(PK)_3$	5.25	4.05	5.25	4.30	5.55	4.40
$N_3(PK)_3$	4.75	4.40	5.15	4.30	5.15	4.40
$N_3(PK)_3$+M	5.70	5.70	6.15	6.00	6.00	5.55

Table 74. Analysis of variance summary of the effect of fertilization on potassium content of corn plants on Geary silt loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	34.5784	3.8420	186.50	**
Topsoil-Subsoil	1	21.7804	21.7804	1057.30	**
Replications	2	0.6772	0.3386	16.44	**
Treatments x Topsoil-Subsoil	9	3.6584	0.4065	19.73	**
Error	38	0.7827	0.0206		
Total	59	61.4771			

Table 75. Effect of fertilization on dry weight of corn (g/pot) on topsoil (T) and subsoil (S) on Ladysmith silty clay loam.

Treatments	Replications I T	I S	II T	II S	III T	III S	IV T	IV S	V T	V S	VI T	VI S
$N_1(PK)_1$	5.65	3.66	6.04	4.33	5.94	3.68	5.73	4.23	6.11	4.26	5.56	3.91
$N_2(PK)_1$	6.32	4.43	6.62	4.00	6.64	4.76	6.42	4.28	7.76	4.78	6.32	3.97
$N_3(PK)_1$	6.33	4.60	6.36	3.98	6.15	4.94	7.38	4.03	6.06	5.09	7.15	4.63
$N_1(PK)_2$	6.36	4.59	6.27	5.06	7.04	4.89	6.12	4.68	7.35	5.38	5.91	4.84
$N_2(PK)_2$	6.94	5.36	6.44	5.24	6.98	5.58	7.31	5.84	7.06	6.59	6.58	6.64
$N_3(PK)_2$	6.95	5.21	8.14	5.37	7.35	5.42	7.53	5.26	7.80	5.24	7.39	6.06
$N_1(PK)_3$	6.46	4.15	7.02	6.08	6.84	5.62	6.34	5.77	7.36	6.54	6.89	6.07
$N_2(PK)_3$	6.65	6.92	7.16	6.36	7.47	7.21	8.02	6.06	8.06	6.71	7.84	5.92
$N_3(PK)_3$	7.14	6.54	7.65	6.76	7.84	6.74	8.04	6.61	7.09	8.11	8.60	7.12
$N_3(PK)_3$+M	8.22	6.92	8.24	7.84	8.34	8.06	6.90	7.34	7.64	7.38	8.66	7.42

Table 76. Analysis of variance summary of the effect of fertilization on dry weight of corn on Ladysmith silty clay loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	86.0284	9.5587	46.63	**
Topsoil-Subsoil	1	60.8760	60.8760	296.96	**
Replications	5	4.7026	0.9405	4.59	**
Treatments x Topsoil-Subsoil	9	10.6321	1.1813	5.76	**
Error	95	19.4734	0.2050		
Total	119	181.7125			

Table 77. Effect of fertilization on nitrogen content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Ladysmith silty clay loam.

Treatments	Replications I + II T	I + II S	III + IV T	III + IV S	V + VI T	V + VI S
$N_1(PK)_1$	2.03	2.02	2.13	2.21	2.18	2.21
$N_2(PK)_1$	2.90	3.15	3.05	3.14	2.84	3.01
$N_3(PK)_1$	3.30	3.43	3.51	3.44	3.23	3.37
$N_1(PK)_2$	1.77	1.77	1.94	1.99	1.75	1.78
$N_2(PK)_2$	2.85	2.55	2.80	2.75	2.77	2.45
$N_3(PK)_2$	3.13	3.28	3.32	3.36	3.24	3.32
$N_1(PK)_3$	1.61	1.68	2.04	1.60	1.75	1.68
$N_2(PK)_3$	2.86	2.39	2.59	2.26	2.59	2.31
$N_3(PK)_3$	3.28	3.25	3.22	3.11	3.47	2.94
$N_3(PK)_3$+M	3.26	3.12	3.37	2.97	3.31	2.83

Table 78. Analysis of variance summary of the effect of fertilization on nitrogen content of corn plants on Ladysmith silty clay loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	20.4517	2.2724	181.79	**
Topsoil-Subsoil	1	0.1233	0.1233	9.86	**
Replications	2	0.1887	0.0944	7.55	**
Treatments x Topsoil-Subsoil	9	0.4913	0.0546	4.37	**
Error	38	0.4752	0.0125		
Total	59	21.7302			

Table 79. Effect of fertilization on phosphorus content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Ladysmith silty clay loam.

Treatments	Replications I + II T	S	III + IV T	S	V + VI T	S
$N_1(PK)_1$	.239	.193	.229	.211	.218	.201
$N_2(PK)_1$	.228	.213	.223	.210	.211	.211
$N_3(PK)_1$	.213	.196	.205	.183	.211	.164
$N_1(PK)_2$	.259	.198	.267	.195	.229	.198
$N_2(PK)_2$	.259	.239	.249	.214	.229	.208
$N_3(PK)_2$	.242	.195	.252	.183	.231	.214
$N_1(PK)_3$	.322	.265	.327	.239	.309	.232
$N_2(PK)_3$	.344	.242	.352	.246	.327	.232
$N_3(PK)_3$	.327	.231	.370	.231	.327	.216
$N_3(PK)_3$+M	.349	.260	.336	.264	.360	.247

Table 80. Analysis of variance summary of the effect of fertilization on phosphorus content of corn plants on Ladysmith silty clay loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	0.0822	0.00913	70.23	**
Topsoil-Subsoil	1	0.0489	0.04890	376.15	**
Replications	2	0.0017	0.00085	6.54	**
Treatments x Topsoil-Subsoil	9	0.0179	0.00199	15.31	**
Error	38	0.0050	0.00013		
Total	59				

Table 81. Effect of fertilization on potassium content of corn plants (%) grown on topsoil (T) and on subsoil (S) on Ladysmith silty clay loam.

Treatments	Replications I + II T	S	III + IV T	S	V + VI T	S
$N_1(PK)_1$	4.30	1.85	4.40	1.85	4.15	2.10
$N_2(PK)_1$	4.05	1.60	4.30	1.75	3.70	1.60
$N_3(PK)_1$	4.05	1.75	3.95	1.85	3.70	1.75
$N_1(PK)_2$	4.85	2.55	4.80	2.80	4.30	2.55
$N_2(PK)_2$	4.60	2.45	4.60	2.45	4.40	2.45
$N_3(PK)_2$	4.30	2.65	4.40	2.80	4.50	2.80
$N_1(PK)_3$	5.05	3.45	5.15	3.25	4.95	3.70
$N_2(PK)_3$	4.85	2.90	4.95	2.90	4.60	2.90
$N_3(PK)_3$	4.40	2.90	4.60	3.00	4.60	2.80
$N_3(PK)_3$+M	4.95	3.35	4.60	3.60	5.15	3.70

Table 82. Analysis of variance summary of the effect of fertilization on potassium content of corn plants on Ladysmith silty clay loam.

Source	D.F.	S.S.	M.S.	F	Significance
Treatments	9	13.7869	1.5319	57.37	**
Topsoil-Subsoil	1	54.4354	54.4354	2038.78	**
Replications	2	0.0681	0.0340	1.27	ns
Treatment x Topsoil-Subsoil	9	1.5758	0.1751	6.56	**
Error	38	1.0153	0.0267		
Total	59	70.8815			

EFFECT OF TOPSOIL REMOVAL ON SOIL FERTILITY

by

ALBERTO d'HIRIART

Ing. Agr., Universidad Nacional de Cuyo,
Argentina, 1963

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1969

As the surface layers are generally the soil layers of highest fertility, when these are totally or partially removed, because of soil erosion, land leveling or some other cause, a considerable reduction in crop yield is often observed. Under these conditions, it is important to determine if it is possible to bring subsoil productivity up to that of the original topsoil. Therefore, the purpose of this study was to establish whether or not the productivity of the subsoil could be efficiently restored by the use of inorganic fertilizers and manure.

In successive greenhouse experiments, studies were conducted on four different Kansas soils, Marshall silt loam, Richfield silt loam, Geary silt loam, and Ladysmith silty clay loam. Two depths were sampled from each soil, the first 20-cm sample was called "topsoil" and the second 20-cm increment was called "subsoil." Both topsoil and subsoil were studied under ten fertilizer treatments, which consisted of combinations of three levels of nitrogen and three levels of phosphorus and potassium, plus a treatment including the addition of manure to the highest combination of nitrogen, phosphorus, and potassium.

Corn was used as the test crop, and it was harvested when the biggest plants were about 60 cm in height. After harvest plants were ovendried at 70° C, weighed, and analyzed for nitrogen, phosphorus, and potassium.

Results indicated that the lower fertility status of the subsoil layer is an important cause of reduced crop growth on the four soils studied. In the case of the Marshall and the Ladysmith soils this apparently was the major cause of reduced productivity as measured in the greenhouse. With the Richfield and the Geary soils the fertility treatments employed did not overcome the detrimental effect of topsoil removal.

Factors other than fertility may have caused reduced crop growth on the subsoil tested. The influence of other factors should be assessed. However, further study needs to be conducted in the field rather than in the greenhouse and laboratory, because the effect of physical factors such as infiltration rates and percolation rates cannot be studied adequately in greenhouse pots.