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Use of Green-Manure Amendments and Tillage to Improve Minesoil Productivity

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USE OF GREEN-MANURE AMENDMENTS AND TILLAGE TO IMPROVE MINESOIL PRODUCTIVITY

by

Timothy Opeka and Ronald Morse
Virginia Polytechnic Institute & State University
Blacksburg, Virginia 24061

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Program Coordinator

Eilif V. Miller
Mineland Reclamation Research Program
Science and Education Administration - Cooperative Research
U. S. Department of Agriculture
Washington, DC 20250

Project Officer

Ronald D. Hill
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory-Cincinnati
Cincinnati, Ohio 45268

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INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report is a product of the EPA planned and coordinated Interagency Energy/Environment Research and Development Program in cooperation with the United States Department of Agriculture. Surface mining of coal results in the denuding of the ground surface. Without the rapid development of a vegetative cover, accelerated erosion will occur. The report describes research to develop better reclamation methods and to better understand the physical and chemical changes occurring in the minesoil. Persons concerned with mine land reclamation should find this report of interest. For further information contact the authors or the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

During two years the effects of various green manure crops and tillage regimes on an acid coal minesoil and a calcareous coal minesoil were analyzed with respect to a number of their physical, chemical, and biological properties. Prior to initiation of the experiments, the acid minesoil had a poor cover of sericea lespedeza and KY-31 fescue whereas the calcareous minesoil had an excellent cover. Increased depth of tillage and incorporation of lime plus green manure crops tended to improve the minesoil productivity by improving some of the physical and chemical characteristics. It appears that the rate of water infiltration was, directly and/or indirectly, the most influential factor affecting improvements in plant growth and minesoil properties.

In terms of crop growth and yields, normal and deep tillage treatments did the best on the calcareous minesoil whereas on the acid minesoil the minimum and normal tillage treatments produced the best. The differences were probably moisture related in that normal and deep tillage plots on the calcareous minesoil tended to have higher moisture levels. They also had the highest water infiltration rates. On the acid minesoil, minimum tillage plots tended to have a higher moisture content throughout their profiles than the other treatments.

This report was submitted in filfillment of Grant No. 684-15-26 by Dr. Ronald Morse (Virginia Polytechnic Institute and State University) under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 21, 1976 to September 30, 1978 and the work was completed as of December 31, 1978.

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ACKNOWLEDGMENTS

The cooperation and generosity of Mr. Denver "Bud" Osborne and the Virginia Energy Company for allowing us to have free access to their land and facilities are gratefully acknowledged. The authors are indebted to Mr. David Bender and Mrs. Jean Morris, who diligently labored on the statistical analysis and the typing of this report. Sincere gratitude is expressed to Dr. Gerald McCart and Dr. Gregory Boardman for their technical assistance and cooperation throughout the entire two-year project and particularly for their review and constructive criticism of the report.

Finally, appreciation is extended to Dr. Oran Little (Southern Regional Director/CR) and Dr. Eilif Miller (Science and Education Administrator/CR/USDA), who coordinated the research, and to the Interagency Energy-Environment Research and Development Program of the U.S. Environmental Protection Agency for the financial assistance, without which the project would not have been possible.

SECTION 1

CONCLUSIONS

Increased depth of tillage and incorporation of green manure crops plus lime additions (acid minesoil) tended to enhance minesoil productivity by improving some of the physical and chemical characteristics of these reclaimed surface-mined areas. It appeared that water infiltration was, directly or indirectly, the most influential factor affecting plant growth and minesoil properties. Increased infiltration rates as a result of the treatments tended to promote the following: reduce runoff (not measured but visually apparent); increase moisture content of the profiles; reduce soluble salt concentrations in the major rooting zones by moving them deeper into the profile; reduce minesoil temperature; increase actual amount of water available to plants; enhance rock weathering by increasing water and parent material contact; increase crop yield; add more organic matter and NO_3; and reduce soluble Zn.

Germination and seedling establishment of the cover and vegetable crops used in this study were successful. Austrian winter pea, however, on the acid minesoil displayed excellent germination and establishment in the fall but failed to survive the winter.

At Buchanan (calcareous minesoil) all crop yields were inversely correlated with soluble salt levels. Squash yields were correlated with K leaf tissue concentrations and inversely correlated with Mn, Al, and Zn leaf tissue concentrations. Bean yields were inversely correlated with Al and Sr leaf tissue concentrations and minesoil Zn levels.

At Wise (acid minesoil) bean and squash yields correlated well with K leaf tissue concentrations and were inversely correlated with Mn leaf tissue concentrations. Bean yields were correlated with minesoil moisture levels.

In terms of crop growth and yields, normal and deep tillage plots did the best at Buchanan whereas at Wise the minimum and normal tillage plots produced the best. The differences were probably moisture related in that normal and deep tillage plots at Buchanan tended to have higher minesoil moisture levels, particularly at the 15-30 cm depth as well as throughout the 0-67.5 cm profile sampled. The normal and deep tillage plots at Buchanan also had the highest infiltration rates.

At Wise, minimum tillage plots tended to have a higher moisture content at the 0-15 cm depth. The minimum, normal, and deep tillage plots all had higher amounts of moisture than the control plots at the 15-30 cm depth. It appears that minimum tillage plots may have maintained an overall higher moisture content in the 0-67.5 cm profile sampled. Minimum tillage did not result in overall higher infiltration rates; however, apparently it did lower rates of moisture loss.

At Wise, minimum tillage plots yielded more than the other plots. These yields were not pH dependent because pH values at 15-30 cm of the minimum tillage plots were lower than the other treatments. Even though the fourth replication had a high pH subsoil, minimum tillage still resulted in highest yields. Minesoil moisture content appeared to be the key factor in plant growth at Wise.

In general, deeper plowing operations enhanced rock weathering, uniformity of the plow layer (reducing low pH spots), and infiltration rates. This was probably due to the shattering of rock fragments, roughening up of the surface, creation of macropores, and mixing of minesoil material. The normal tillage treatments are probably the optimum treatment except when the minesoils are extremely droughty and have not had a lot of organic matter incorporated into them. In the latter case, a minimum tillage treatment (disking 0-8 cm deep or deeper) which creates a kind of stubble mulch after each subsequent crop, breaks up the surface crust and roughs up the surface thus enhancing moisture retention and infiltration and providing a good seed bed, is probably best.

It is assumed that areas are "properly" reclaimed in the first place; i.e., soil size materials and nonobstructive sized rocks on the surface, toxic materials deeply buried, and an appropriate revegetation crop(s) has been chosen to deal with each specific site. While generalities are often desirable, it must be realized that most chemical and physical properties of minesoil are site specific. Each site must be sampled and evaluated to determine appropriate treatments and post-mining uses. In the situation of this research, the better the minesoil conditons to begin with (Buchanan - calcareous minesoil) the better normal and deep tillage treatments did, probably as a result of increased rooting depth and removal of undesirable salts. At Wise, moisture was apparently a more limiting factor. The minimum tillage treatments which tended to conserve the greatest amount of water, therefore, did the best.

Barring highly toxic elements or concentrations of elements, and given the ability to raise the pH above 5.0, any treatments that would increase water infiltration and improve minesoil moisture relationships should be employed and should improve minesoil productivity.

SECTION 2

RECOMMENDATIONS

Minesoils at each mine site should be evaluated with respect to their ability to support plant growth for revegetation as well as post reclamation use. Many minesoils in southwest Virginia are superior to native soils in both depth of soil size material and nutrient status.

Careful evaluation of macronutrient levels, especially nitrogen, phosphorus, and potassium, plus textural characteristics, are important in determining reclamation procedures. Neither site in this study displayed phosphorus deficiencies; however, potassium did appear to limit plant growth.

The major factors limiting plant growth at both sites were associated with physical properties--i.e., lack of adequate water infiltration and minesoil moisture. Therefore any treatment, amendment, or procedure which enhances minesoil moisture relations is highly desirable--i.e., rough surfaces, organic matter additions and incorporation, mulches, etc. Rock weathering and minesoil improvement are hastened when moisture is available in sufficient quantities to support plant growth. Moisture increases plant growth, thus increasing organic matter in the minesoil, reduces soluble salt levels, and accelerates rock weathering.

Increased organic matter content can improve soil chemical, physical, and biological properties, especially in the formation of soil surface structure.

Collaborative efforts by interdisciplinary teams of professionals are highly recommended to further assess the total ecological effects of various experiments and natural successions. Since minesoils are complex interactive bodies of physical, chemical, and biological components it is logical to have teams of agronomists, horticulturalists, microbiologists, geologists, mining engineers, and others working together. There are numerous areas of minesoil research that appear to need additional study and/or basic exploratory study. A few of the possible areas of future research are suggested below.

(1) Enhancement of minesoil moisture relations including water infiltration, moisture movement within the profile, anti-surface crusting treatments, mulches, and new reclamation methods to reduce minesoil compaction and improve textural characteristics of the surface layers.

(2) Plant leaf tissue chemical composition studies including correlations between leaf and minesoil elemental content, evaluation of toxicity and deficiency symptoms when present, and methods of reducing availability of undesirable elements.

(3) Studies on the diversity and distribution of soil fauna and flora including soil microorganisms and soil animals to monitor the natural succession as well as the effects of various treatments, plus the effects of the fauna and flora on minesoil improvement and productivity.

(4) Minesoil profile studies to determine how, what, when, and where eluviation and illuviation are taking place in the process of soil formation. This could be coupled with plant rooting depth studies which are also needed.

(5) Development of reliable methods for organic matter determinations which eliminate interferences from coal, carbonaceous shales and possibly other substances. Determination of total N may prove to be a more useful test.

(6) Development of a procedure to determine the most effective phosphorus or potassium soil test methods for different minesoils.

Experiments and/or monitoring of reclaimed surface-mined areas must be carried out for a sufficient length of time so as to adequately and reliably assess the changes that occur. This is referring to a minimum time period of 2 years and perhaps an optimum of from 4 to 10 years or longer.

SECTION 3

INTRODUCTION

Surface mining in Virginia began in the late 1800's and has grown into an extremely important economic industry at present. Intensive surface mining in southwestern Virginia disturbs approximately 10,000 acres each year in the six counties of Buchanan, Dickenson, Wise, Tazewell, Lee, and Russell. This has possibilities for both positive and negative effects.

The Appalachian mountain region is typified by shallow soils, steep slopes, and narrow valleys which are unsuited for most agricultural, industrial, and urban uses. The scarcity of arable soil in this region has resulted in a situation where practically all of the fruits and vegetables are imported into the area. In addition, there are few sites for industry to locate and cities are literally crammed into the narrow valleys and flood plains for lack of flat areas on which to expand and build. Throughout the Appalachian region new, potentially arable land is being created as a result of stripmining operations that literally level mountain tops and carve out wide terraces (benches) on the slopes. Many of the flat areas created by stripmining are large enough to be considered for many agricultural, industrial, and urban uses as well as being modified for specific wildlife habitats.

The agricultural potential of these areas is the focus of this research. With favorable economic and climatic conditions, the production of certain horticultural and agronomic crops appears to offer excellent opportunities to increase food production and provide an additional source of revenue for the Appalachian stripmining region.

Fresh minesoils[1], however, do not provide an adequate rooting environment to produce economic yields of most crops. Therefore, research is needed to develop methods of expediting the improvement of minesoil that would provide the necessary environment to support vigorous plant growth. This assumes that if one can develop minesoil to the point where it can support vegetable

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[1] The term "minesoil" is used throughout this report in agreement with the modern definition of soil--i.e., "the collection of natural bodies of the earth's surface, in places modified or even made by man of earthy materials containing living matter and supporting or capable of supporting plants out-of-doors" (Smith and Sobek, 1978). The commonly used term "spoil" means waste material and is an inaccurate description of the potential use of overburden materials. Minesoil in this report refers to overburden materials derived from stripmining of coal, and clearly current data show that it is capable of supporting plant growth.

crops, then minesoil can be used for a variety of urban, recreational, industrial, and wildlife purposes, as well as agricultural.

Very little research has been done on minesoil modification for crop production using tillage regimes and green manure crops as a means to accelerate rock weathering and minesoil improvement. The objectives of this study were to determine the value of soil amendments, tillage regimes and their interactions on minesoil properties and crop yields. This research specifically studies minesoil with respect to:

(1) Changes in the physical properties of the minesoil including aggregation, moisture infiltration and retention, particle size, and temperature;

(2) Chemical changes in minesoil pH, organic matter, Ca, P, K, NO_3, Mg, Mn, Zn, and soluble salts;

(3) Crop yield response;

(4) Leaf tissue chemical analyses for P, K, Ca, Mg, Mn, Fe, Al, B, Cu, Zn, Sr, Ba, and Na;

(5) Selected interactions of the above factors.

SECTION 4

MATERIALS AND METHODS

Field experiments were established to determine the effects of (1) green manure cover crops as soil amendments, and (2) tillage regimes on plant growth and soil properties on surface-mined areas.

Field Experiments

The research activities were conducted at two locations, Buchanan and Wise Counties in Virginia. In 1976 research was initiated on three (Buchanan) and four (Wise) year old minesoil which had not received any special treatment other than the normal reclamation procedure of fertilizing with 17-28-15 (392 kg/ha) and seeding with a standard mixture of sericea lespedeza and Kentucky-31 fescue. The research sites were both relatively flat with no serious soil erosion problems. The Wise County site had an initial pH of 4.4 (October 1976) on the average which was common for the area. The Buchanan County site is a naturally calcareous area with an average initial pH of 6.5 (October 1976). The Buchanan County site also had a much better stand of sericea lespedeza and Kentucky-31 fescue than the site at Wise. Aside from differences in pH and amount of ground cover, both sites had similar initial chemical and physical soil analysis results.

The Buchanan County site was located on a surface-mined bench area with a western exposure and the highwall to the east. The site at Wise was on a mountain top removal area with full exposure on all sides. Wise had a slight slope to the south and Buchanan sloped to the north.

Beginning October 1976, when the field experiments were initiated, both sites were treated exactly the same with respect to experimental plot layout, seeding and fertilizer rates, and tillage regimes. Wise, with a pH of 4.4, was limed; however, Buchanan was not in 1976 or 1977, but required liming by 1978 in order to equalize pH values throughout the experimental area.

The plots were 4 X 10 m in size (40 m^2) and treatments were applied in a randomized complete block design with four replications at each site. Only the center 3 X 9 m (27 m^2) of each plot was sampled allowing a border 0.5 m wide on all sides of each plot.

The treatments consisted of three depths of tillage with soil amendments and one undisturbed control plot. A summary of tillage regimes and minesoil amendments follows in Tables 1 and 2. All seed, lime, fertilizer, and straw were broadcast for the green manure crops. The herbicide paraquat was used to kill the rye cover crop prior to plowing in May 1977. The soybean cover crop was mowed prior to plowing and planting of the winter cover crop in

September 1977. No weed control was necessary during any of the crops' growth periods.

All yield data were taken by hand (Table 29). For the green manure cover crops a composite of ten 20 X 20 cm subplots (4000 cm^2) were taken per plot for dry matter yield determinations. Dry matter yields were taken in order to quantify the amount of organic matter input into all treatment plots. Vegetables were harvested weekly and weighed. The vegetables were sprayed weekly for insect and disease control with combinations of the following chemicals: sevin, lannate, methoxychlor, thiodan, benlate, bravo, and manzate.

TABLE 1. TILLAGE TREATMENTS

Treatment	Description of treatment
A (T_A)	Control - undisturbed, standard reclamation treatment.
B (T_B)	Minimum Tillage - plowed 15-30 cm depth Fall 1976 when rye was planted, thereafter only light disking prior to fertilization sowing of seed.
C (T_C)	Conventional Tillage - plowed 15-20 cm depth and disked prior to each crop planting.
D (T_D)	Deep Tillage - plowed 30-35 cm depth and disked prior to each crop planting. At Wise, plots were chiseled to the 45 cm depth prior to the start of the experiment in October 1976.

The data in this study pertain to the time period starting October 1976 and terminating September 1978. The plots were sampled numerous times during the two year period, but not all properties were analyzed on each date. The dates of sampling and agricultural practices are shown in Table 2 and noted on each data table.

Minesoil Material

The minesoil material on the experimental areas was variable at both sites. The initial plowing operations, Fall 1976, exposed bands of gray, brown, and blackish material including large numbers of rocks from 15 to 60 cm in length and 10 to 30 cm in width (Figure 1). The rocks were primarily sandstones, siltstones, and shales. The rocks did pose a minor problem at times in the initial plowing operations. It appeared that at Wise an effort was made to place a layer of brown material on the surface of the mined area because it resembled top soil, whereas at Buchanan approximately 2 meters of "uniform" material covered the surface.

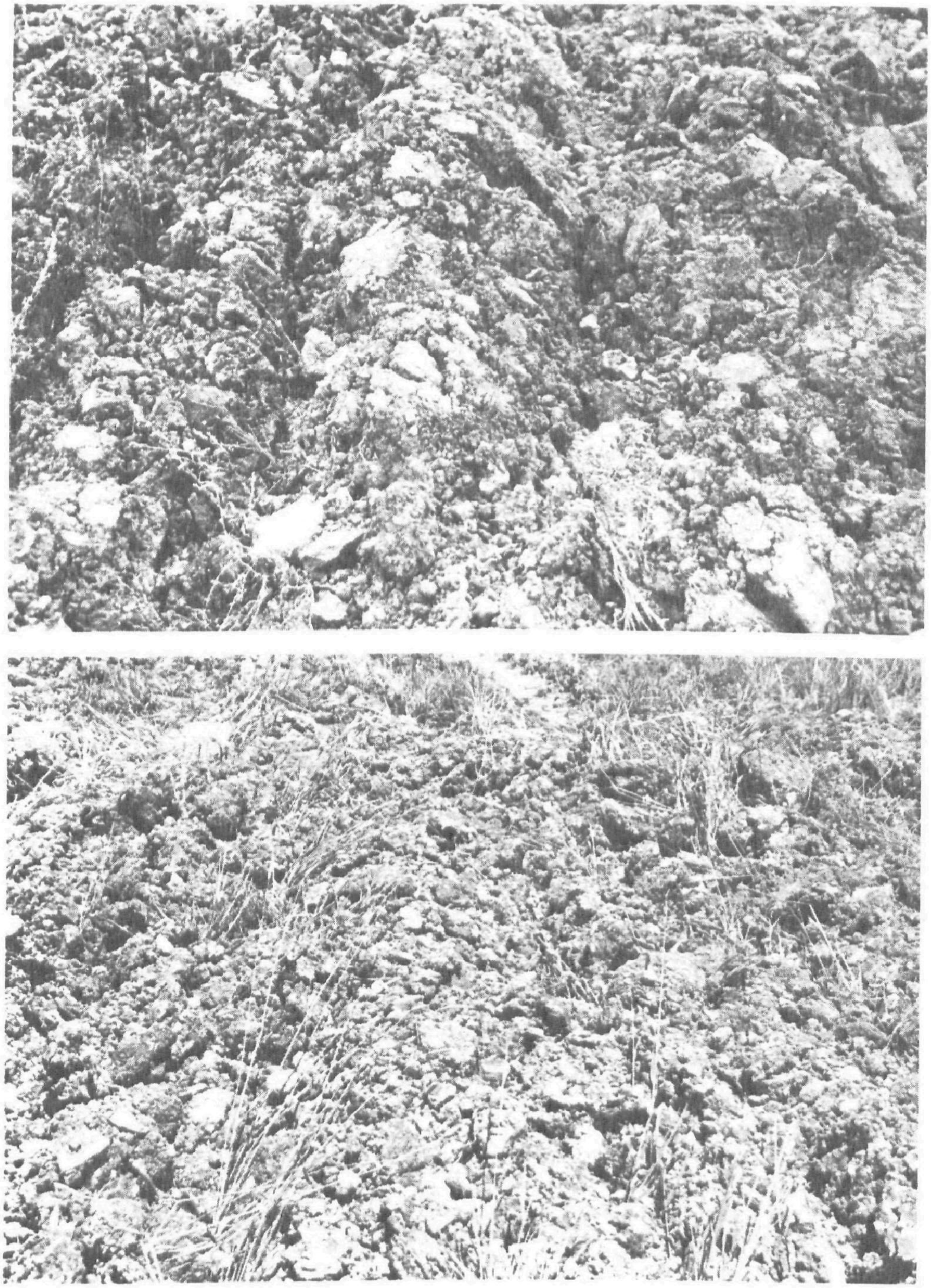


FIGURE 1. Initial (top) and final (bottom) plowing exposes bands of gray, brown, and blackish material.

TABLE 2. MINESOIL AMENDMENTS USED AND VEGETABLE CROPS GROWN[w], 10/16/76-7/7/78

Crop	Date[z]	Seeding rate	Fertilizer rate	Liming rate	Straw mulch
Rye (Secale cereale) var. Abruzzi	10/16/76 10/30/76	125 kg/ha	1000 kg/ha 10-10-10	10,000 kg/ha Wise only	168 bales/ ha
Soybean (Glycine max) var. York	6/4/77 5/31/77	269 kg/ha (27 kg/bu)	560 kg/ha 10-10-10	1680 kg/ha Wise only	
Austrian Winter Pea (Pisum arvense)	9/20/77 9/21/77	67 kg/ha	560 kg/ha 10-20-20		
Rye[x] (Secale cereale) var. Abruzzi	10/28/77	63 kg/ha 25 kg/bu			
Rye-Austrian Winter Pea	3/27/78		Topdress N 45 kg/ha		
Snap Beans (Phaseolus vulgaris) var. Bush Blue Lake Summer Squash (Cucurbita pepo) var. Seneca Prolific	5/11/78			Liming to obtain pH 6.2 in all plots[y]	
Snap Beans	6/1/78 5/30/78	349,657 plants/ha	1120 kg/ha 10-10-10		
Summer Squash	6/1/78 5/30/78	19,985 plants/ha	1120 kg/ha 10-10-10		
Summer Squash and Snap Beans	7/7/78		Sidedress N kg kg/ha		

[w] For both sites, Wise and Buchanan Counties.

[x] Rye was over seeded into the Austrian Winter Pea stand.

[y] Applied immediately prior to plowing in preparation for vegetable crops.

[z] Wise County date is given first and Buchanan County second when the two dates are not the same.

Geologic Description

The following information is based on research done at the Buchanan County site by Howard (1976abc) and Howard and Amos (1977). The Wise County site appears to have the same approximate weathering sequence as the Buchanan County site; however, Wise is NOT a calcareous area and no direct geologic comparisons can be made using only data obtained at the Buchanan County site.

The overburden at the Buchanan site was derived from the Pennsylvania Wise Formation, a calcareous Fe-rich, heterogeneous group of strata characterized by abrupt lithologic and geochemical facies changes involving sandstone, siltstones, shales, mudstones, conglomerates, and coals. The underlying Norton Formation is apparently not calcareous. The dolomitic sandstones and siltstones are uniform in mineralogic composition except for the irregular distribution of calcite and geothite, which are locally abundant cementing agents. The clay and silt mineralogies are also uniform. In general, the rocks are weakly cemented by silica and are decomposed relatively easily by blasting and physical weathering. Those rocks with abundant Fe-oxide rather than carbonate cements are more resistant physically and chemically to weathering under oxidizing conditions. Reducing conditions, however, would more favor Fe-oxide weathering. The more thoroughly silica cemented rocks are most resistant.

Field observation suggests the following weathering sequence: shales > siltstones > sandstones. This is due to the degree of bedding, particle size and type of cementation. Shales with their bedding planes and argillaceous cements degrade most readily. Siltstones with bedding and lamination disintegrate readily, but more slowly than shales because of particle size (surface area) and the presence of additional, more resistant cements. Massive sandstones are most resistant although bedded sandstones disintegrate more readily. Bedding is a major factor contributing to physical disintegration of the strata. The rocks consist mostly of quartz, muscovite, and rock fragments of slate or shale (Table 3). The data in Table 4 apply for fresh rock and spoil up to three years in age. Note a prevalence of muscovite and an obvious absence of illite, mixed layer and intergrade minerals.

In terms of blending rock types to improve minesoil, a 60:30:10 ratio of sandstone:siltstone:shale would generate a sandy loam perhaps best suited to the site in terms of availability of raw materials and adequacy as a medium for plant growth. However, siltstones disintegrate more readily than sandstones which would accelerate soil formation, but silty soils tend to be poorly drained and to crust and heave. Silty soils are being formed at both sites (Wise and Buchanan Counties) as noted by field observations and particle size analysis data on minesoil samples.

A comparison was made between the nutrient status of fresh rocks and minesoils and the native soils of the area. The minesoils were superior to the native soils in nutrient status and pH. In the fresh rock and minesoil, exchangeable acidity levels were low and available Ca, Mg, and P high. Available K was low. The native soils were low to very low in pH and available Ca, P, and K and medium to high in Mg. It should be noted that the soil test results for P indicate a higher amount of available P than may be the

TABLE 3. PETROGRAPHIC ANALYSIS, MINERALOGIC COMPOSITION OF SANDSTONE, SILTSTONE, AND CONGLOMERATE[y,z]

Mineral Species	%	Mineral Species	%
quartz	70-80	dolomite	1-10
rock fragments	5-15	calcite	0-20
muscovite	2-10	geothite	2-10
chlorite	2-10	hematite	0-10
albite-oligoclase	1-5	zircon	1
K-spar	1-2	epidote	1
chert	1-2	tourmaline	1

[y] Howard and Amos (1977).

[z] Buchanan County Site.

case. Fixation of K by vermiculite and illite and P-fixation by geothite appear formidable. Since coal bearing rocks are characteristically ferrogenous on a world-wide basis, P-fixation may prove to be a severe limitation on the use of minesoils. It is fortunate that the minesoils are high in available nutrients since, in the steeply sloping terrain at the mine sites, native soils are too thin to be stockpiled for regrading.

Minesoil Chemical Properties

Composite samples of minesoil were taken from each plot on seven (Buchanan County) and eight (Wise County) sampling dates. Each composite sample consisted of a minimum of ten cores taken with a soil probe of 1.9 cm inside diameter. Samples were taken from the 0-15 cm depth during the period Fall 1976 to Fall 1977 and 0-15 cm and 15-30 cm depth during 1978. The samples were placed in standard half pint soil boxes. The samples were transported to the VPI & SU soil testing laboratory where they were air dried, ground, and analyzed for pH (1:1 soil to water ratio); weak acid extractable P and K; oxidizable carbon (expressed at % organic matter); Ca, Mg, Zn, and Mn by atomic absorption spectrophotometer; and water soluble nitrates and soluble salts (Donahue and Martin, 1976; Rich, 1955).

Minesoil Physical Properties

The moisture content of the minesoil was determined gravimetrically with oven drying at 105° C (Gardner, 1965). The moisture percentages at 0.33 and 15 bars were determined to show the "available" moisture of the

TABLE 4. COMPARISON OF CLAY MINERALOGIES - FRESH ROCK AND MINESOIL, COLLUVIAL, AND RESIDUAL SOILS[y][z]

Mineral species	Fresh rock and minesoil	75 cm below surface colluvium	Residual soil B horizon
	%		
muscovite	40	20	10
kaolinite	30	--	15
vermiculite	15	30	40
chlorite	10	--	--
montmorillonite	3	--	--
quartz	0	10	5
illite	0	10	15
albite	2	30	15

[y] Howard and Amos (1977).

[z] Buchanan County Site.

minesoil. Soil thermometers were used in Summer 1977 to determine the soil temperature at the 5 cm depth. During the 1978 growing season, thermocouples were implanted in the minesoil and used to determine the soil temperature at the 5 cm depth.

Infiltration rate was determined on the July 1977, April 1978, and August 1978 sampling dates by applying water to the soil surface in two concentric metal rings according to the procedure outlined by Bertrand (1965). Infiltration rate was also determined on treatments A and D at Wise County in June 1977. The amount of water infiltration was recorded at 0, 10, 30, 60, and 90 minute time intervals. From these data, infiltration rates were determined for each treatment.

In October 1976 and August 1978, particle size analysis was performed on samples from both experimental sites according to the pipette method outlined by Day (1965).

Samples were taken from the upper 8-10 cm of minesoil with a shovel on Septebmer 1977, April 1978, and August 1978. The moist minesoil was gently placed in plastic bags to retain its moist condition for aggregate analysis. The percentage of water-stable aggregates of the minesoil was determined by wet sieving (Yoder, 1936) using six nests of sieves. The percent aggregate stability was calculated using the following equation (Kemper, 1965):

$$\% \text{ Aggregate Stability} = \frac{100 \text{ (weight of aggregates + sand)} - \text{(weight of soil)}}{\text{oven dry weight of sample - weight of sand}}$$

Leaf Tissue Chemical Analysis

Bean and squash leaves were analyzed spectrographically by atomic absorption for P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, Sr, Ba, Mo, Na, and Al. Sampling instructions prepared by Donahue and Hawkins (1977) were used.

Statistical Analysis

The data were analyzed using the IBM computer facilities at VPI & SU and the Statistical Analysis System (SAS) programs prepared by Barr, Goodnight, Sall, and Helwig (1976).

The field experiment was a randomized complete block design with respect to the treatments listed in Table 1. Means are discussed as being significantly different if the probability of a greater test statistic is 0.05 or smaller. When the F test in an analysis of variance was significant at the 0.05 level, Duncan's multiple range test was used to compare more than two means. Total and partial correlations were also investigated between and among selected factors (Snedecor and Cochran, 1967; Little and Hills, 1972).

SECTION V

RESULTS AND DISCUSSION

This research investigates changes in physical and chemical properties of minesoils and subsequent vegetable crop yields, resulting from two years of green manure crops and tillage regimes. The results will be presented and discussed in that order although attempts will be made to interrelate the three areas throughout. The Buchanan County site (calcareous minesoil) will be discussed first, then the Wise County site (acid minesoil). In the following pages these abbreviations will be used: T_A - control; T_B - minimum tillage; T_C - normal tillage; and T_D - deep tillage.

PHYSICAL PROPERTIES

Minesoil Moisture

The minesoil moisture data for Buchanan are presented in Table 5. Apparently T_C and T_D enhanced moisture levels at the 15-30 cm depth. At the 0-15 cm depth, T_B, T_C, and T_D plots generally all had higher or equal moisture contents than T_A except for early spring when the control was significantly wetter. This was probably due to poor drainage characteristics in T_A. The control plots frequently had standing water on their surfaces but were dry within a few centimeters of the surface due to inadequate infiltration. Since the plots of T_B, T_C, and T_D had a drier surface layer in the spring, they had the potential advantage of being plowed earlier in the season if desired.

Minesoil moisture profile data are presented in Table 6 and Figures 2a and 2b. T_B, T_C, and T_D all improved the overall moisture content of the profile, above that of the control. This was particularly apparent in the major rooting zone, the 0-45 cm depth. Enhancement of moisture content is very important given the normally droughty nature of silty minesoils.

At Wise there was a tendency for T_B plots to be the wettest at the 0-15 cm depth and the plots of T_B, T_C, and T_D to be wetter than the control at the 15-30 cm depth (Table 7). Enhanced infiltration rate in the tilled plots was probably the reason. Moisture relationships near the surface were probably better for T_B plots due to the organic matter being mixed in a shallower (0-7 cm) depth of minesoil. The organic matter probably maintained openings in the surface and increased aggregate and crumb formation in the surface horizon, leading to increased water infiltration and decreased erosion potentials. The mulch effects reduced water evaporation and dampened temperature and moisture fluctuations.

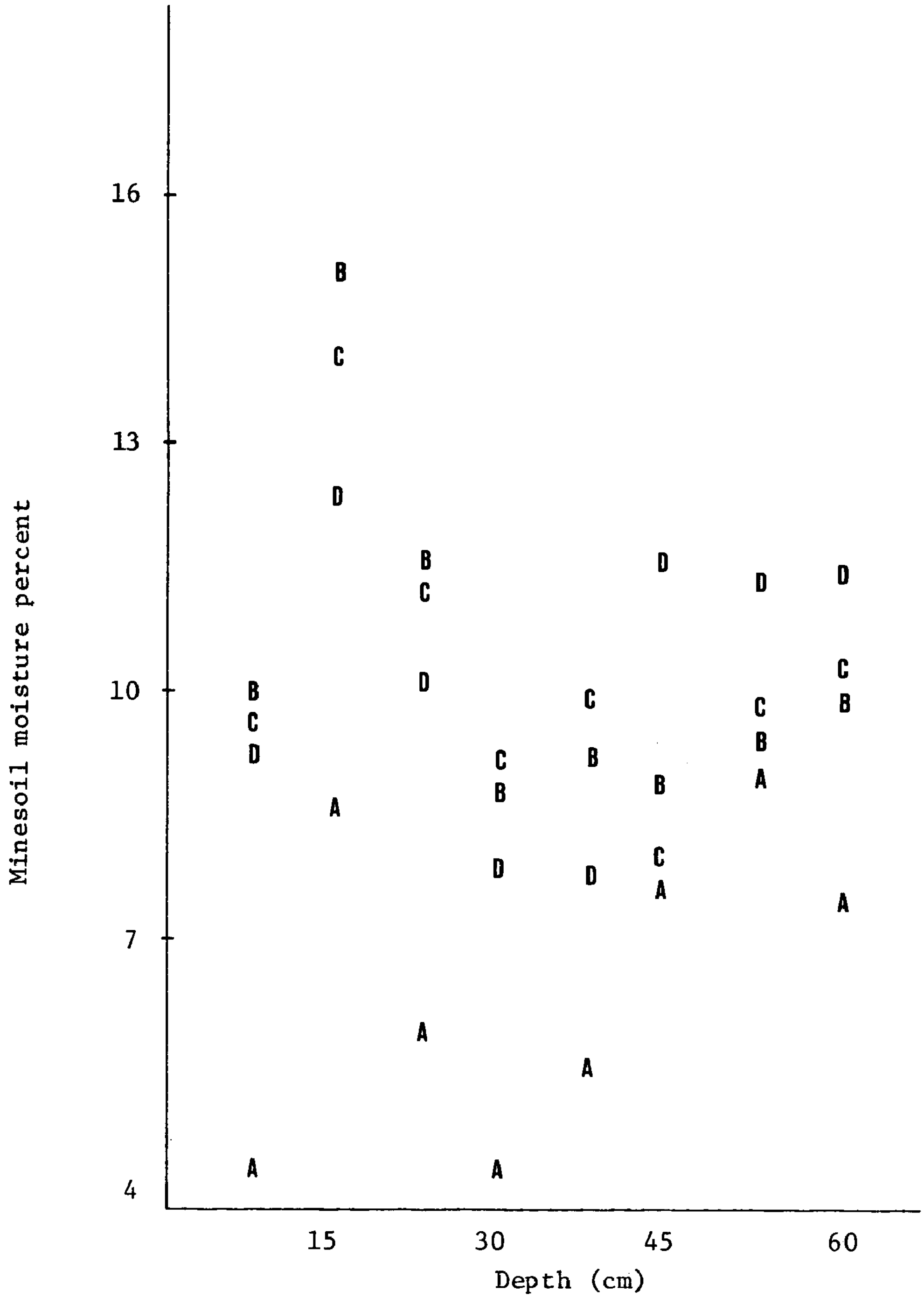


Figure 2a. Minesoil moisture profile - Buchanan County, June 29, 1977.

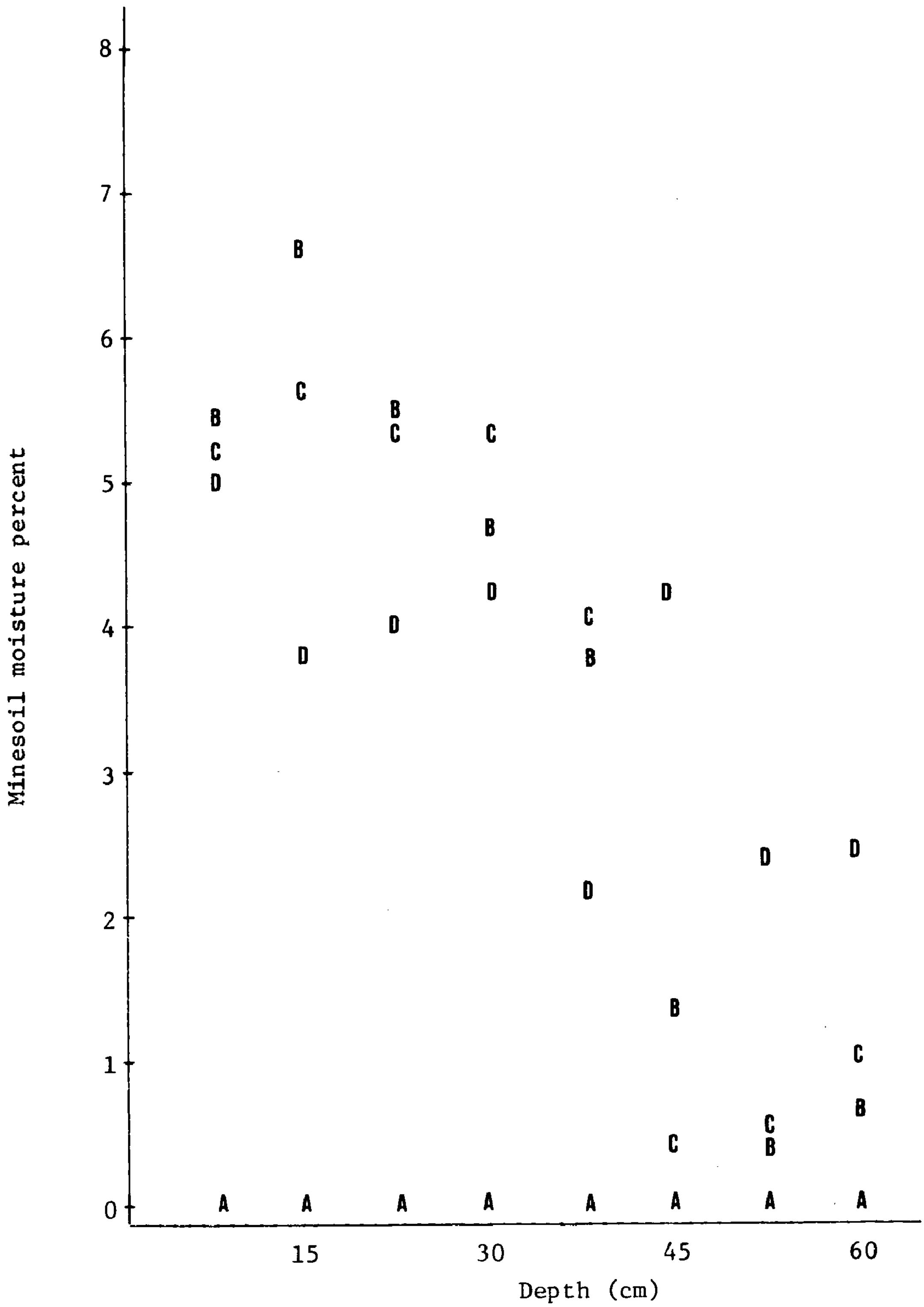


Figure 2b. Minesoil moisture profile values adjusted to show actual differences between treatments - Buchanan County, June 29, 1977.

TABLE 5. MINESOIL MOISTURE CONTENT - BUCHANAN COUNTY[z]

Treat-ment	Depth (cm)	Sampling dates					Mean
		6/22/77	9/13/77	4/12/78	6/21/78	8/15/78	
		%					
A	0-15	8.0	5.8	13.0	9.6	17.4	10.8
B		13.2	7.4	8.8	9.4	17.7	11.3
C		11.4	7.0	9.5	10.8	17.5	11.2
D		11.3	7.1	9.2	10.2	16.4	10.8
A	15-30	--	--	8.8	8.6	--	8.7
B		--	--	8.5	9.7	--	9.1
C		--	--	9.3	11.9	--	10.6
D		--	--	9.8	11.4	--	10.6

[z] Means of 4 composite samples.

T_B plots displayed the highest moisture content throughout the profile (Table 8 and Figures 3a and 3b). T_B, T_C, and T_D all increased moisture content over that of the control below the 15 cm depth.

Available Moisture

Samples from the 0-10 cm depth of each treatment were dried in a pressure plant apparatus at 0.33 and 15.0 bars. The respective moisture percentages are given in Tables 9 and 10.

At Buchanan T_D plots had the highest "available" moisture percentages, although the differences among treatments were not great. No real trends were apparent at Wise, although for the last four sampling dates, plots of T_B, T_C, and T_D tended to hold slightly more water than did the control. Although the amount of available moisture may not have increased much, the amount of moisture that the plants actually used probably increased.

Minesoil Temperature

Presented in Table 11 are the limited amount of data collected on minesoil temperature at each site. Each mean represents the average of temperature readings from 12 soil thermometers in 1977 and 8 thermocouples in 1978 placed approximately two meters apart throughout the plots. The control and

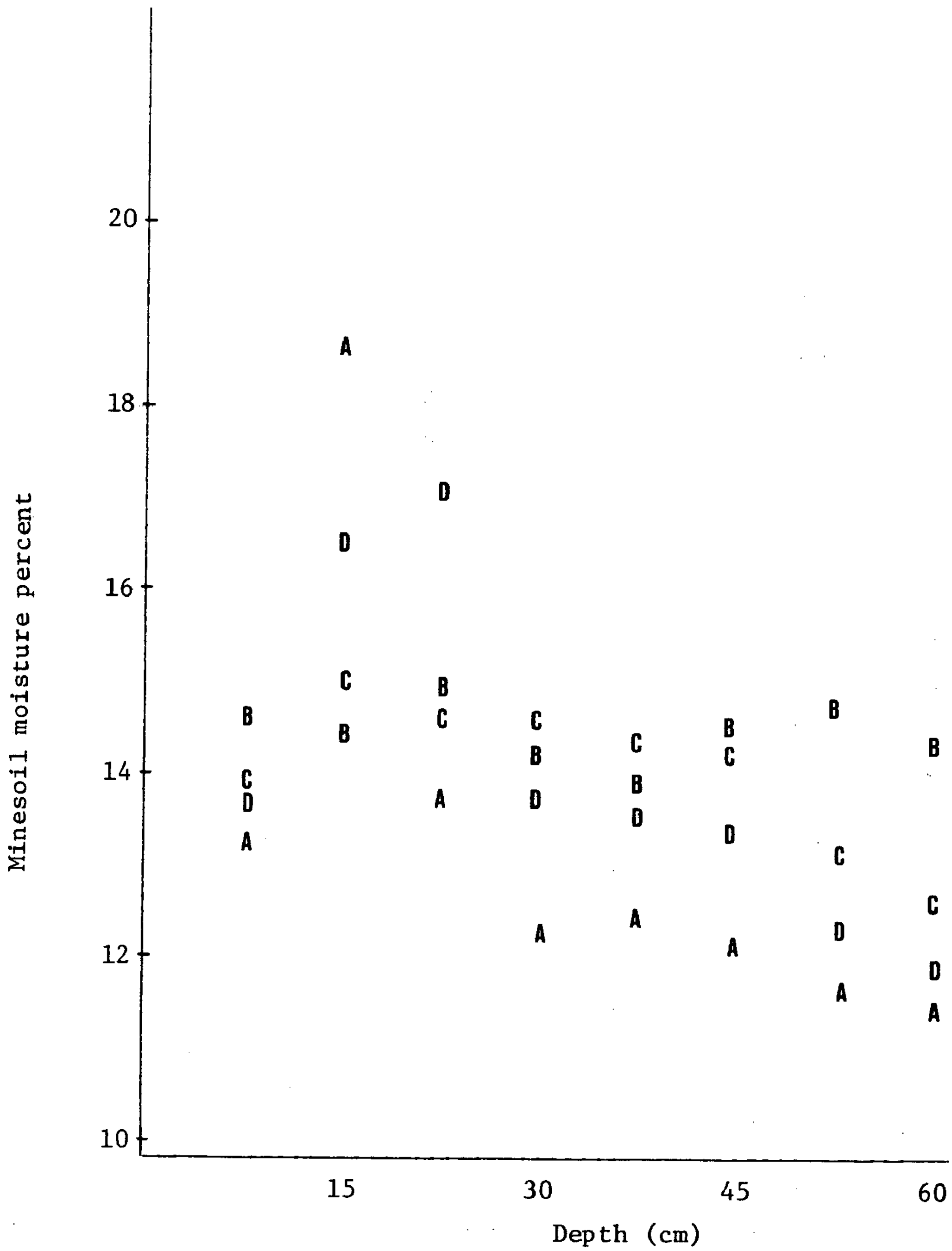


Figure 3a. Minesoil moisture profile - Wise County, July 7, 1977.

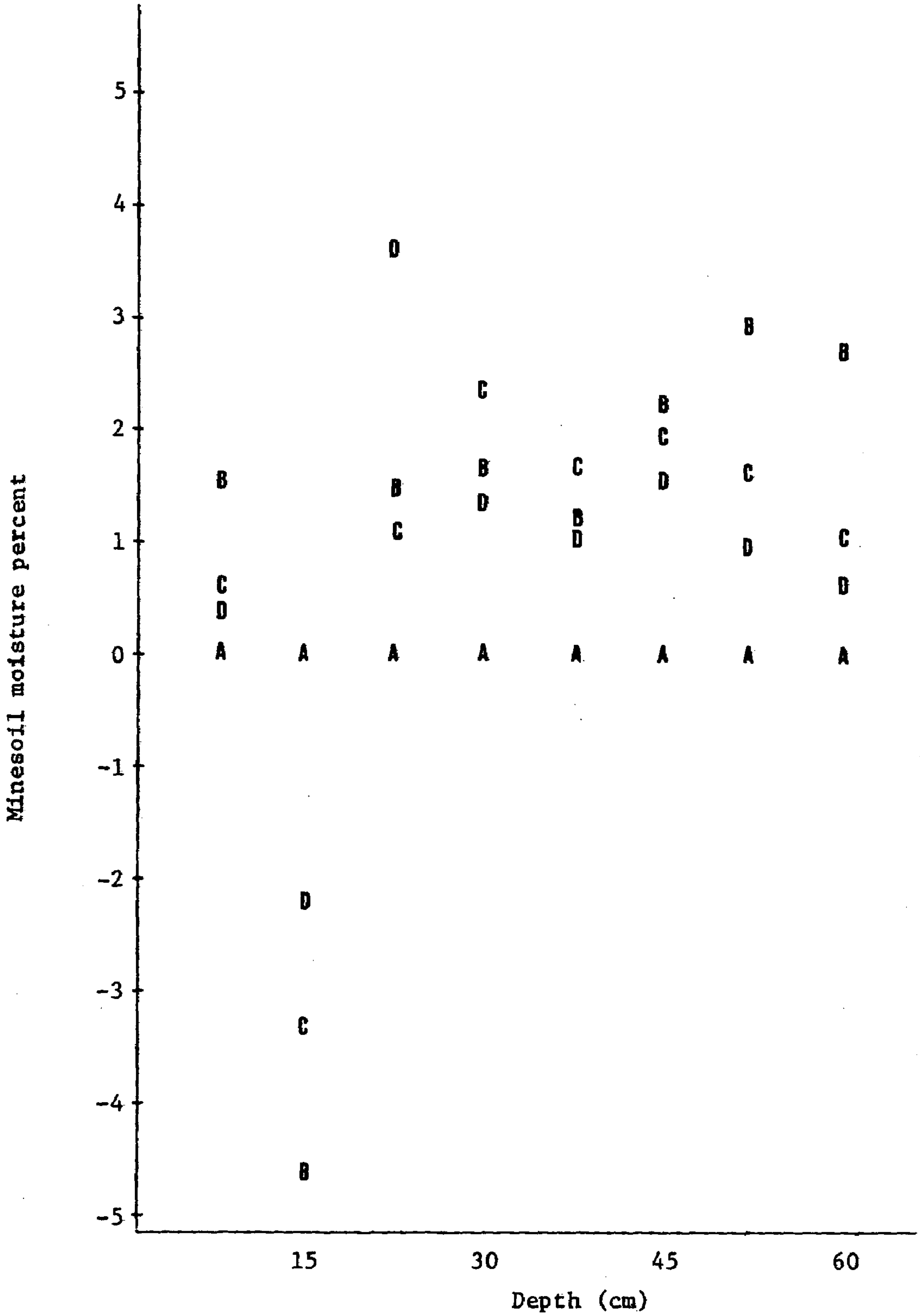


Figure 3b. Minesoil moisture profile values adjusted to show actual differences between treatments - Wise County, July 7, 1977.

TABLE 6. MOISTURE CONTENT AT VARIOUS MINESOIL DEPTHS - BUCHANAN COUNTY, JUNE 29, 1977[z]

Depth (cm)	Treatments				Means
	A	B	C	D	
	%				
0-7.5	4.51	9.89	9.84	9.53	8.19
7.5-15.0	8.51	15.24	14.16	12.30	12.58
15.0-22.5	5.95	11.33	11.28	9.97	9.63
22.5-30.0	4.30	8.99	9.56	8.62	7.87
30.0-37.5	5.74	9.35	9.91	7.87	8.22
37.5-45.0	7.39	8.72	7.86	11.67	9.82
45.0-52.5	8.97	9.40	9.51	11.39	9.82
52.5-60.0	8.89	9.67	10.03	11.39	10.00
60.0-67.5	9.77	9.18	11.49	13.07	10.88
67.5-75.0	--	--	10.87	12.66	--
75.0-82.5	--	--	10.65	13.57	--
Treatment Means 0-67.5	7.12	10.20	10.40	10.53	

[z] Means represent two composite samples.

minimum tillage plots were the warmest in the morning; all treatments were equal in the afternoon; and the minimum tillage plots were coolest in the evening. The data are mainly a function of minesoil moisture content, with minimum tillage being the wettest, and therefore, warmer at night and cooler during the day. The controls being warmer during the day and night is probably due to lower moisture content, increased compaction, and higher solar radiation since these plots generally had much less ground cover than did the T_B, T_C, and T_D plots. In general, the recorded high temperatures were thought to have caused no detrimental effects at either site, although yields of beans and squash were inversely correlated with temperature readings at Buchanan and Wise (Tables A-6 and A-13).

Aggregate Stability

Lutz (1934) discussed the importance of very stable, large aggregates in inhibiting soil erosion by resisting raindrop impact and enhancing infiltration. Plant growth (Baver, et al., 1972) and soil arthropods (Haarlov, 1955)

TABLE 7. MINESOIL MOISTURE CONTENT - WISE COUNTY[z]

Treatment	Depth (cm)	Sampling dates					Mean
		6/21/77	9/12/77	4/5/78	6/20/78	8/12/78	
		%					
A	0-15	16.5	12.5	15.5	15.9	18.7	15.8
B		21.4	13.4	16.1	17.1	18.5	17.3
C		17.7	12.4	14.6	15.9	16.2	15.4
D		16.4	11.8	15.1	15.8	15.7	15.0
A	15-30	--	--	14.4	13.7	13.5	13.9
B		--	--	15.9	17.6	16.0	16.5
C		-	--	16.0	18.0	14.7	16.2
D		--	--	16.3	17.8	14.9	16.3

[z] Means of 4 composite samples.

are also enhanced by good aggregation due to increases in macropores. Baver, et al. (1972) concluded that in fine textured soils organic matter primarily affected larger aggregates and that fresh organic materials do not affect soil structure until they are decomposed through biological action. Fresh organic matter can, however, influence soil properties--i.e., aeration, infiltration, moisture and temperature--by physically separating soil particles (Bender and Opeka, 1977).

The percent water stable aggregates is presented in Tables 12a and 12b. Apparently the treatments had minor impact on increasing the percentage of stable aggregates. Possibly this was due to the two-year time constraint of this project. In general, soil physical properties take a long time to develop and two years is not long enough. There was a tendency for T_C plots to have the highest percentage of stable aggregates, probably as a result of its high green manure crop yields and good mixing of the organic matter in the plow layer. T_D plots yielded less organic matter and it was mixed in a greater volume of minesoil material. The organic matter in the T_B plots was not incorporated.

The Buchanan County site averaged twice the percent aggregation as did the site at Wise County. This was probably a function of the different revegetation cover present at both locations. Wise had a poor stand of sericea lespedeza and Kentucky-31 fescue prior to the experiment and Buchanan

TABLE 8. MOISTURE CONTENT AT VARIOUS MINESOIL DEPTHS - WISE COUNTY, JULY 7, 1977[z]

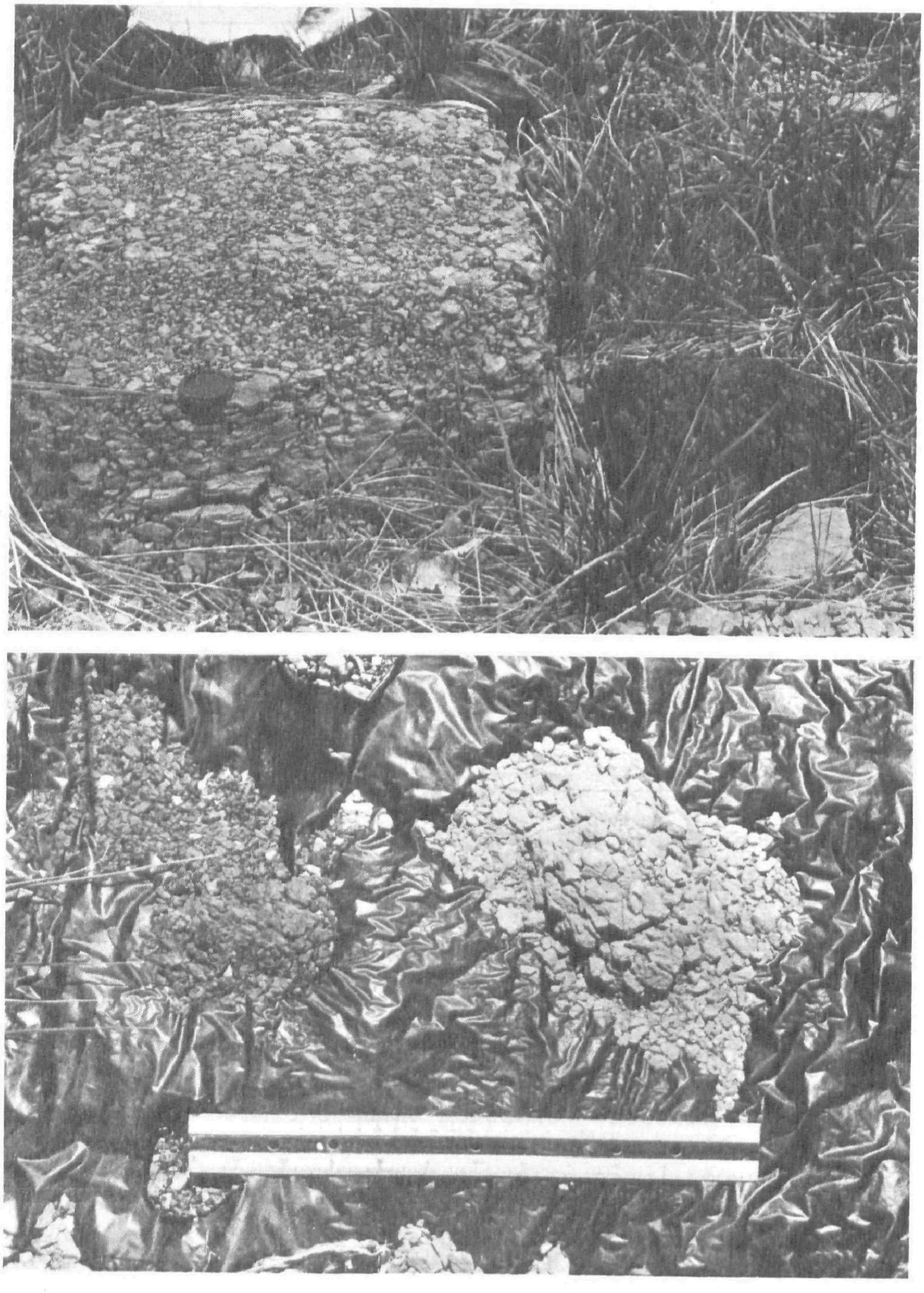
Depth (cm)	Treatments				Mean for depth
	A	B	C	D	
	%				
0-7.5	13.24	14.63	13.89	13.76	13.88
7.5-15.0	18.70	14.30	15.32	16.55	16.22
15.0-22.5	13.86	15.22	14.94	17.26	15.32
22.5-30.0	12.48	14.10	14.96	13.82	13.84
30.0-37.5	12.66	13.95	14.57	13.80	13.74
37.5-45.0	12.21	14.58	14.30	13.52	13.65
45.0-52.5	11.60	14.87	13.12	12.34	12.98
52.5-60.0	11.52	14.29	12.72	11.93	12.62
60.0-67.5	11.76	13.40	12.90	11.61	12.42
Treatment Means	13.11	14.37	14.08	13.84	

[z] Means represent 4 observations.

had a thick stand. The percent aggregation was highest in the spring, at the peak of the winter cover crop growth, with T_B and T_C being substantially higher than the control.

Rock Weathering

Improvements in minesoil condition have continued throughout the length of the experiment. The tillage and cover crop treatments have enhanced rock weathering and minesoil improvement to the point that in May 1978 when all plots were plowed, the control plots could be visually picked out. The control plots had more and larger rocks than the other treatments. The tillage regimes (T_B, T_C, and T_D) increased rock weathering probably due to mechanical fracturing and increased exposure of the rocks to the weather plus increased water content through improvements in water infiltration rates. Weathering of rocks (shales, siltstones, and some sandstones) was incredibly rapid as depicted in Figures 4a and 4b. In Figure 4a, solid and intact rocks are shown that were removed from plots in October 1976 and weathered to this condition by April 1977. Other rocks placed on top of black plastic to keep it from blowing away in June 1977 weathered dramatically over the 10 months ending April 1978 (Figure 4b).



FIGURES 4a (top) and 4b (bottom). Rock weathering.

TABLE 9. MINESOIL MOISTURE RETENTION AT TWO POINTS AS AN ESTIMATE OF AVAILABLE MOISTURE AT THE 0-10 CM DEPTH - BUCHANAN COUNTY[z]

Sampling date	Treatment	Bars soil moisture tension		
		0.33	15.0	Available
		%		
October 29, 1976	A	21.0	11.6	9.4
	B	20.4	10.4	10.0
	C	21.3	11.1	10.2
	D	21.1	10.3	10.8
	Mean	20.9	10.8	10.1
April 12, 1978	A	23.3	11.6	11.7
	B	23.2	11.6	11.6
	C	22.4	11.2	11.2
	D	23.1	11.2	11.9
	Mean	23.0	11.4	11.6
August 15, 1978	A	21.1	10.8	10.3
	B	20.8	11.8	9.0
	C	23.4	12.1	11.3
	D	22.3	10.5	11.8
	Mean	21.9	11.3	10.6
Overall Means	A	21.8	11.3	10.5
	B	21.5	11.3	10.2
	C	22.4	11.5	10.9
	D	22.2	10.7	11.5

[z] Means of 8 observations.

TABLE 10. MINESOIL MOISTURE RETENTION AT TWO POINTS AS AN ESTIMATE OF AVAILABLE MOISTURE AT THE 0-10 CM DEPTH - WISE COUNTY[z]

Sampling date	Treatment	Bars soil moisture tension		
		0.33	15.0	Available
			%	
October 15, 1976	A	25.7	10.6	15.1
	B	25.0	11.7	13.3
	C	25.9	12.0	13.9
	D	26.6	12.7	13.9
	Mean	25.8	11.8	14.0
September 12, 1977	A	23.2	11.6	11.6
	B	26.4	12.4	14.0
	C	25.3	12.2	13.1
	D	25.0	12.2	12.8
	Mean	25.0	12.1	12.9
April 8, 1978	A	18.0	9.0	9.0
	B	19.4	9.7	9.7
	C	19.2	9.6	9.6
	D	19.8	9.9	9.9
	Mean	19.1	9.5	9.6
August 12, 1978	A	25.9	12.5	13.4
	B	26.7	13.0	13.7
	C	25.5	10.8	14.7
	D	24.5	12.0	12.5
	Mean	25.7	12.1	13.6
Overall Mean	A	23.2	10.9	12.3
	B	24.4	11.7	12.7
	C	24.1	11.2	12.9
	D	23.9	11.7	12.2

[z] Means of 8 observations.

TABLE 11. MINESOIL TEMPERATURES AT THE 5 CM DEPTH[z]

Site	Time and date	Treatments			
		A	B	C	D
		°C			
Wise County	8 a.m. June 20, 1977	19.9	19.1	18.7	18.7
	3 p.m. June 20, 1977	28.2	24.8	25.7	25.7
	3 p.m. June 21, 1977	27.0	25.0	26.5	26.1
	8 a.m. June 20, 1978	18.6	18.7	18.6	18.8
	3 p.m. June 20, 1978	26.6	27.0	27.3	27.2
Buchanan County	8 a.m. June 21, 1977	19.1	18.6	17.6	17.7
	3 p.m. June 21, 1977	22.9	22.6	23.3	23.1
	9 p.m. June 21, 1977	24.9	23.8	25.3	25.0
	3 p.m. June 21, 1978	29.9	29.2	29.1	29.8

[z] Means represent 12 observations in 1977 and 8 observations in 1978.

The texture was predominantly silty at Buchanan and Wise. At both sites the percentage of silt appears to be decreasing, with sand increasing (Table 13). The time frame was too short to be certain, although if the trends continue, an increase in sand content would benefit aeration and water relationships, thus further promoting both minesoil condition and plant growth.

Infiltration Rates

An increased infiltration rate is critical in improving moisture relationships which, in turn, would favor soil organisms and plant growth. Greater infiltration also reduces surface runoff, thus lowering the threat of erosion. It is readily apparent that all tillage regimes (T_B, T_C, and T_D) increased infiltration for both initial and saturated flows (Tables 14 and 15). For T_B the higher readings in July 1977 than April 1978 were probably due to the residual effects of initial plowing in October 1976. By April 1978 those effects were diminishing.

Normal and deep tillage treatments had the greatest beneficial effects. This was probably a function of the physical effects of tillage--i.e., disruption of surface crusts, creation of more macropores, greater incorporation of crop residues and general mixing of the minesoil material, thus creating a more uniform plow layer. Infiltration rates were found to be correlated with depth of tillage for both Buchanan and Wise (Tables A-14 and

TABLE 12a. THE EFFECT OF TREATMENTS ON AGGREGATE STABILITY - BUCHANAN COUNTY[xyz]

Treatment	Sampling dates 4/12/78	8/15/78	Overall treatment mean
A	36.4	24.3	30.4
B	41.5	21.7	31.6
C	43.6	24.7	34.2
D	40.6	22.0	31.3
Date mean	40.5	23.2	31.9

TABLE 12b. THE EFFECT OF TREATMENTS ON AGGREGATE STABILITY - WISE COUNTY[xyz]

Treatment	Sampling dates 9/12/77	4/8/77	8/12/78	Overall treatment mean
A	13.1	19.4	14.0	15.5
B	15.5	18.2	14.2	16.0
C	16.2	24.3	14.0	18.2
D	14.5	21.2	13.9	16.5
Date mean	14.8	20.8	14.0	16.5

[x] Means of 8 observations.

[y] Samples taken from the 0-10 cm depth.

[z] x and y apply to 12a and 12b.

TABLE 13. INITIAL AND FINAL PARTICLE SIZE ANALYSIS DATA[z]

Site	Sampling date	Treatments	Sand	Silt	Clay
			%		
Buchanan County	10/29/76	A	20.1	60.8	19.1
		B	22.1	58.1	19.8
		C	19.6	60.8	19.6
		D	21.3	57.6	21.1
		Mean	20.8	59.3	19.9
	8/15/78	A	20.5	58.3	21.2
		B	23.5	56.7	19.8
		C	20.5	58.3	21.2
		D	20.2	58.5	21.2
		Mean	21.2	58.0	20.8
Wise County	10/15/76	A	13.7	64.1	22.2
		B	13.6	61.7	24.6
		C	12.3	64.5	23.2
		D	14.8	59.2	26.0
		Mean	13.6	62.4	24.0
	8/12/78	A	18.3	57.0	24.6
		B	17.0	61.0	22.0
		C	16.8	60.4	22.8
		D	15.9	61.1	23.0
		Mean	17.0	59.9	23.1

[z] Means of 8 observations.

A-15). The Buchanan site had greater infiltration rates than did Wise; however, the overall trends for treatments were the same.

CHEMICAL PROPERTIES

Soil test values for organic matter, pH, CaO, P_2O_5, K_2O, MgO, and Mn are presented in Tables 16, 17, 18, and 19. There were no major differences in these components between treatments in October 1976 and August 1978. This was the desired outcome except for organic matter levels. It was thought that the treatments would raise the levels of organic matter in the minesoil, but it appears that the more organic matter incorporated into each plot, the lower the corresponding soil test organic matter readings. Organic matter values therefore appear to be inversely correlated with cover crop yields (organic matter additions). Various types of interferences are thought to obscure the true organic matter values. Problems with soil organic matter

TABLE 14. INFILTRATION RATES - BUCHANAN COUNTY[y]

Sampling dates	Elapsed time in minutes	Treatments			
		A	B	C	D
		cms of H_2O			
July 1977	10	0.52	1.12	1.55	1.80
	30	0.80	2.42	4.08	3.52
	60	1.02	4.20	6.98	5.25
	90	1.20	5.42	9.38	6.69
April 1978	10	0.42	0.95	5.10	5.55
	30	0.70	1.38	8.78	10.25
	60	0.90	1.75	13.50	15.45
	90	1.02	2.00	17.42	20.28
August 1978	10	5.05	7.72	19.23	20.18
	30	10.35	25[z]	50[z]	50[z]
	60	20[z]	--	--	--
	90	--	--	--	--

[y] Means of 8 observations; all values represent the cummulative amount of water infiltrated up to that time.

[z] Rough estimates of values; actual values are $\leq$ those reported.

determination on surface-mined areas have been reported by other researchers and are not unique to southwest Virginia. As a result, three minor studies on organic matter were conducted and are discussed in the Appendix.

High phosphorus levels were found at both sites. The use of the dilute double acid extraction method probably elevated the actual available phosphorus readings; hence the Bray #1 method should have been investigated (Bray and Kurtz, 1945; Berg and May, 1969; Berg, 1973; Smith and Sobek, 1978). It should be noted that phosphorus was not found to be limiting in this study and therefore the high available P readings might be valid.

A number of favorable trends have surfaced as a result of the treatments. Tillage regimes, crop yields, and infiltration rates are correlated with a number of variables, including pH, Zn, NO_3, and soluble salts (Tables A-6, A-12, A-13, A-14, and A-15). These and other relationships will be discussed in the following pages.

Soluble Salts

Soluble salts and Zn levels tended to drop with increased aggregate stability, infiltration rate, moisture content, depth of tillage, and crop

TABLE 15. INFILTRATION RATES - WISE COUNTY[z]

Sampling dates	Elapsed time in minutes	Treatments			
		A	B	C	D
		cms of H_2O			
July 1977	10	0.82	2.02	1.25	2.10
	30	1.20	4.18	1.95	3.12
	60	1.68	6.15	2.52	3.88
	90	2.12	7.95	2.92	4.48
Spril 1978	10	0.65	1.30	1.30	1.30
	30	0.92	2.12	1.98	2.22
	60	1.08	2.98	2.68	3.18
	90	1.22	3.80	3.22	3.88
August 1978	10	0.90	1.72	1.90	3.75
	30	1.25	2.80	3.12	6.92
	60	1.68	4.08	4.15	9.05
	90	1.95	5.05	4.98	10.40

[z] Means of 8 observations; all values represent the cummulative amount of water infiltrated up to that time.

yields, while NO_3 levels were enhanced. Increased depth of tillage had a tendency to reduce the soluble salt concentration at the 15-30 cm depth at both sites (Tables 20 and 21). This decrease appears to follow higher water infiltration rates (Figures 5 and 6). Soluble salt concentrations tended to be lowest in the spring following the leaching by winter and spring rains. Profile samples indicate horizons of eluviation and illuviation (Tables 22, 23, and 24). The zone of illuviation for Wise was approximately the 15-45 cm depth; whereas at Buchanan, the younger site with greater infiltration rates, it was the 30-60 cm depth. Therefore, soluble salts are being moved deeper into the profile and farther away from the major rooting zone at Buchanan. High levels of soluble salts are detrimental to plants because they increase the soil moisture tension (osmotic pressure effect) and decrease the availability of water to the plants. High soluble salt levels frequently include high percentages of Mn and Al at lower pHs. The leaf tissue concentrations for Mn and Al at Wise were both higher than those at Buchanan and are discussed later in this paper (Tables 30 and 31).

Aggregate stability was inversely correlated with soluble salt levels and correlated with pH at Wise (Tables A-10 and A-15). Buchanan soil pH values are probably more favorable to aggregate formation than those at Wise. In some calcareous soils calcium carbonate can be a stabilizing agent enhancing soil structure (Russell, 1973).

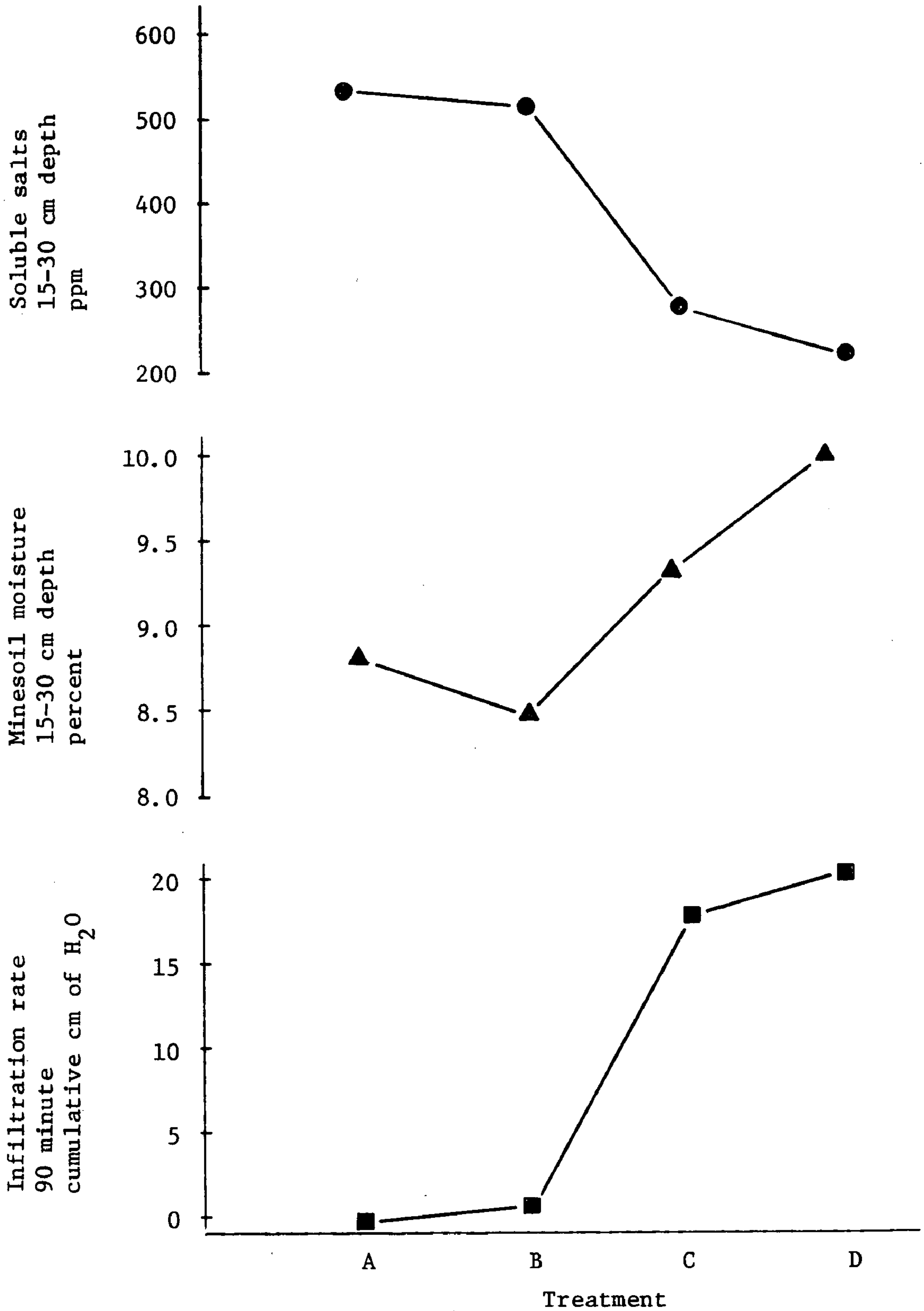


Figure 5. Relationship between infiltration rates, minesoil moisture, and soluble salts - Buchanan County, April 1978.

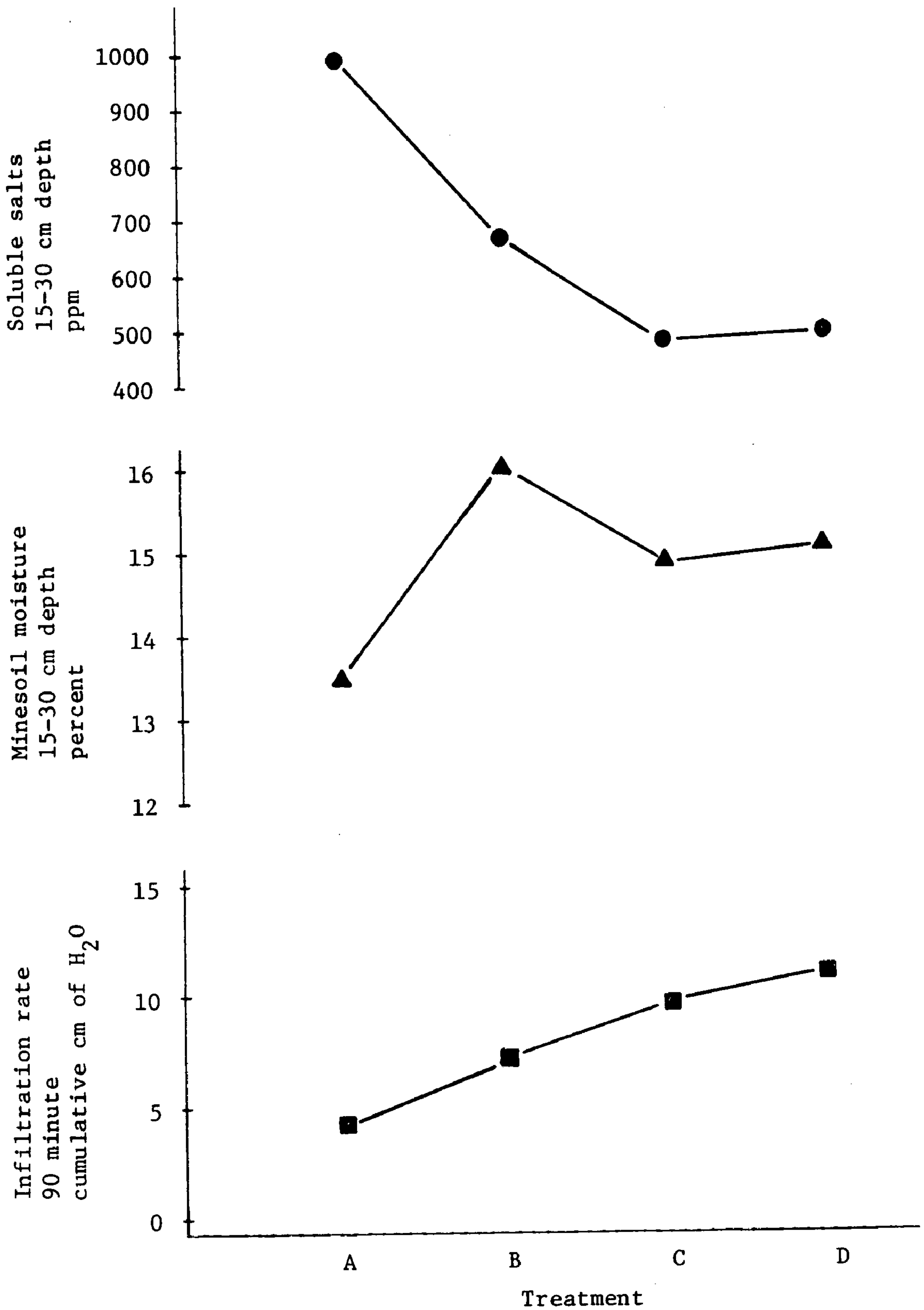


Figure 6. Relationship between infiltration rates, minesoil moisture, and soluble salts - Wise County, August, 1978.

TABLE 16. SOIL TEST ORGANIC MATTER VALUES FOR VARIOUS DATES AND DEPTHS - BUCHANAN COUNTY[z]

Sampling dates	Depth (cm)	Treatments				
		A	B	C	D	Mean
		%				
October 29, 1976	0-15	1.9	1.9	1.9	2.0	1.9
April 30, 1977	0-15	1.2	1.4	1.5	1.3	1.4
June 22, 1977	0-15	1.6	1.7	1.7	1.8	1.7
September 13, 1977	0-15	1.6	1.7	1.8	2.0	1.8
Spril 12, 1978	0-15	1.6	1.5	1.6	2.1	1.7
	15-30	2.4	2.0	2.2	2.1	2.2
June 21, 1978	0-15	1.8	1.6	1.4	1.7	1.6
	15-30	2.1	1.8	1.6	2.0	1.9
August 15, 1978	0-15	1.9	1.4	1.5	1.8	1.6
Overall means	0-15	1.6	1.6	1.6	1.8	1.7
	15-30	2.2	1.9	1.9	2.0	2.0

[z] Means of 4 composite samples.

pH

Soil pH is a major factor influencing nutrient availability and toxicity. It appears that pH of the minesoil increased with depth at both sites (refers to unlimed situations). This is highly favorable at Wise (Tables 22, 23, 24, 25, and 26), but at Buchanan the high pH levels were apparently above optimum since they were inversely correlated with yields of rye, soybean, bean, and squash (Tables A-12 and A-14). This does not imply that higher pHs dramatically reduced yields at Buchanan. Obviously the yields of these crops were very good and much better than those at Wise. At Wise, pH was correlated with rye-Austrian winter pea and bean yields, possibly due in part to increased K and P availability (Tables A-7, A-8, and A-11). It should be noted that T_B plots at Wise had lower pHs at the 15-30 cm depth than the T_C and T_D plots, yet T_B plots had higher yields.

The effect of tillage on pH at the 15-30 cm depth was an example of the effects of incorporating lime at various depths (Table 26). In April 1978 at Wise, the pH differences between the 0-15 cm and 15-30 cm depths were: T_B, 0.8; T_C, 0.4; and T_D. 0.2 of a pH point, respectively. Adequate incorporation of lime is necessary to facilitate pH increases in the profile.

TABLE 17. SOIL TEST ORGANIC MATTER VALUES FOR VARIOUS DATES AND DEPTHS - WISE COUNTY[z]

Sampling dates	Depth (cm)	Treatments				
		A	B	C	D	Mean
		%				
October 15, 1976	0-15	2.4	3.0	3.1	2.3	2.7
April 27, 1977	0-15	2.6	2.5	2.8	2.6	2.6
June 20, 1977	0-15	3.0	2.4	2.6	2.2	2.6
September 12, 1977	0-15	3.2	2.6	2.6	2.3	2.7
November 20, 1977	0-15	2.9	3.2	3.2	2.8	3.0
April 5, 1978	0-15	2.8	2.9	2.6	2.4	2.7
	15-30	1.7	3.1	2.4	2.1	2.3
June 20, 1978	0-15	2.7	2.5	2.4	2.2	2.4
	15-30	2.6	2.3	2.6	2.1	2.4
August 12, 1978	0-15	2.7	2.6	2.4	2.2	2.5
	15-30	1.7	2.4	2.4	2.0	2.3
Overall means	0-15	2.8	2.7	2.7	2.4	2.6
	15-30	2.0	2.6	2.5	2.1	2.3

[z] Means of 4 composite samples.

Manganese

There was an inverse correlation between Mn leaf tissue levels and vegetable yields at both sites (Tables A-5 and A-6). Minesoil Mn levels were all reported as greater than 16+ ppm because that was the lab's standard recording procedure for Mn levels above 16 ppm. The actual values have ranged from 30 to over 80 ppm at both sites. Correlations between minesoil Mn levels and yields are therefore not possible. Symptoms resembling Mn toxicity were displayed by bean plants at both sites and occasionally by squash at Wise. These symptoms faded away as the season progressed, possibly as a result of minesoil Mn complexing with organic matter (Beckwith, 1955) from the plowed down cover crop and/or higher pH values after liming. Both of these factors would tend to reduce the levels of available Mn in the minesoil. Although the visual symptoms disappeared, yields of both vegetable crops were inversely correlated with leaf tissue Mn levels. Plants vary in tolerance to Mn levels. Ouellette (1950) showed that for good growth soluble Mn concentration in soil must be less than 3 ppm for soybeans, 2 ppm for

TABLE 18. SELECTED SOIL TEST VALUES FROM EACH TREATMENT AND DEPTH SAMPLED - BUCHANAN COUNTY[x,z]

Soil test	Sampling date	Depth (cm)	Treatment A	Treatment B	Treatment C	Treatment D
			kg/ha			
CaO	10/29/76	0-15	3216*[y]	2933*	2745	3027*
	4/30/77	0-15	2088	2369	2463	2463
	6/22/77	0-15	2933*	1805*	2275*	3121*
	9/13/77	0-15	2463*	2557	2557	3216*
	4/12/78	0-15	3839*	2557	2463	3216*
		15-30	3761*	3498*	3404*	3216*
	6/21/78	0-15	2745*	2839*	2651	3216*
		15-30	3761*	3027*	3404*	3404*
	8/15/78	0-15	3027	3027*	2839*	3310*
Overall means		0-15	2759	2584	2570	3081
		15-30	3761	3262	3404	3310
P_2O_5	10/29/76	0-15	294	294	263	294
	4/30/77	0-15	288	294	294	301
	6/22/77	0-15	245	308	294	308
	9/13/77	0-15	263	308	301	301
	4/12/78	0-15	288	308	308	308
		15-30	308	308	308	308
	6/21/78	0-15	281	308	308	308
		15-30	308	308	308	308
	8/15/78	0-15	308	308	308	308
Overall means		0-15	281	304	296	304
		15-30	308	308	308	308

(continued)

TABLE 18. CONTINUED

Soil test	Sampling date	Depth (cm)	Treatment A	B	C	D
			kg/ha			
K_2O	10/29/76	0-15	158	133	133	121
	4/30/77	0-15	113	113	133	113
	6/22/77	0-15	146	195	146	158
	9/13/77	0-15	133	170	133	158
	4/12/78	0-15	146	170	158	170
		15-30	170	146	170	158
	6/21/78	0-15	182	221	195	221
		15-30	170	158	170	158
	8/15/78	0-15	146	146	146	158
Overall means		0-15	146	164	149	157
		15-30	170	152	170	158

[x] Means of 4 composite samples.

[y] Means marked by "*" contain values which represent the upper limit of sensitivity of the particular test and thus, the actual mean is ≥ that reported here. The greatest values to which the tests are sensitive are CaO = 3761, P_2O_5 = 308, MgO = 446, K_2O = 421, and Mn = 16.

[z] MgO readings were 446+ kg/ha and Mn readings were 16+ ppm for all dates and depths sampled.

TABLE 19. SELECTED SOIL TEST VALUES FROM EACH TREATMENT AND DEPTH SAMPLED - WISE COUNTY[wz]

Soil test	Sampling date	Depth (cm)	Treatment			
			A	B	C	D
			kg/ha			
CaO	10/15/76	0-15	1147	959	1241	1241
	4/27/77	0-15	1147	1523	2088	1617
	6/20/77	0-15	1147	2839*	2745	2369
	9/12/77	0-15	1147	2275	2463	2275
	11/20/77	0-15	1429	2467	2933	2557
	4/05/78	0-15	1241	2557	2275	2088
		15-30	2088	1617	1994	2275
	6/20/78	0-15	3498*[x]	3310*	3404*	3121*
		15-30	2181*	2088*	2745*	2933*
	8/12/78	0-15	3498*	3216*	2933*	2745
		15-30	2933*	2557*	2463*	2557
Overall means		0-15	1782*	2393*	2510*	2252*
		15-30	2401*	2987*	2401*	2588*
P_2O_5*	10/15/76	0-15	294	195	294	281
	4/27/77	0-15	263	235[y]	288	281
	6/20/77	0-15	281	294	301	301
	9/12/77	0-15	245	301	301	301
	11/20/77	0-15	263	294	301	294
	4/05/78	0-15	263	301	301	288
		15-30	294	288	281	301
	6/20/78	0-15	281	308	301	301
		15-30	294	281	294	301
	8/12/78	0-15	228	308	281	294
		15-30	288	294	294	288
Overall means		0-15	265	281	296	293
		15-30	292	288	290	297

(continued)

TABLE 19. CONTINUED

Soil test	Sampling date	Depth (cm)	Treatment			
			A	B	C	D
			kg/ha			
K_2O	10/15/76	0-15	105	97	105	113
	4/27/77	0-15	113	146	121	146
	6/20/77	0-15	147	220	195	195
	9/12/77	0-15	147	170	147	170
	11/20/77	0-15	170	207	220	170
	4/05/78	0-15	146	182	182	182
		15-30	146	158	170	170
	6/20/78	0-15	242	280	262	252
		15-30	158	158	182	146
	8/12/78	0-15	182	182	221	195
		15-30	158	170	121	170
Overall means		0-15	156	186	182	178
		15-30	154	162	158	162

[w] Means of 4 composite samples.

[x] Means marked by "*" contain values which represent the upper limit of sensitivity of the particular test and thus, the actual mean is ≥ that reported here. The greatest values to which the tests are sensitive are CaO = 3761, P_2O_5 = 308, K_2O = 421, MgO = 446, and Mn = 16.

[y] This mean does not contain values which represent the upper limit of sensitivity of the test.

[z] MgO readings were 446+ kg/ha and Mn readings were 16+ ppm for all dates and depths sampled.

TABLE 20. SOLUBLE SALT LEVELS AT VARIOUS DATES AND DEPTHS - BUCHANAN COUNTY[z]

Sampling dates	Depth (cm)	Treatments			
		A	B	C	D
		ppm			
October 29, 1976	0-15	504	531	348	427
April 30, 1977	0-15	224	359	212	222
September 13, 1977	0-15	283	323	352	339
April 12, 1978	0-15	227	333	195	214
	15-30	528	522	298	230
June 21, 1978	0-15	324	703	531	547
	15-30	453	403	280	196
August 15, 1978	0-15	478	486	416	372
Overall means	0-15	340	456	342	354
	15-30	490	462	289	213

[z] Means of 4 replications.

lespedeza, 1.5 ppm for clover, and 1 ppm for potatoes. Obviously, the available Mn levels in the minesoil were much higher than these values for both Buchanan and Wise. Toxicity symptoms are displayed by the leaves of following plants at levels of: 1000 ppm beans; 550 ppm peas; and 200 ppm barley (White, 1970). Therefore, at Wise the rye-Austrian winter pea cover crop possibly did poorly due to high available Mn levels in the minesoil as a result of the lower pHs and wet winter weather.

Zinc

Zinc availability decreases with increases in pH with most deficiencies occurring between pH 6.0 and 8.0. At Wise, Zn was inversely correlated with pH and Ca. Deficiencies may also show up on high P soils due to a Zn-P interaction where high levels of one element may reduce uptake of the other (Tisdale and Nelson, 1975). Zn can form insoluble phosphates as well. This could be a problem where minesoil P levels are low and Zn levels are high. In fact, at both Buchanan and Wise, inverse correlations were found between Zn and P (Tables A-14 and A-15). Excess Zn can substantially reduce the

TABLE 21. SOLUBLE SALT LEVELS AT VARIOUS DATES AND DEPTHS - WISE COUNTY[z]

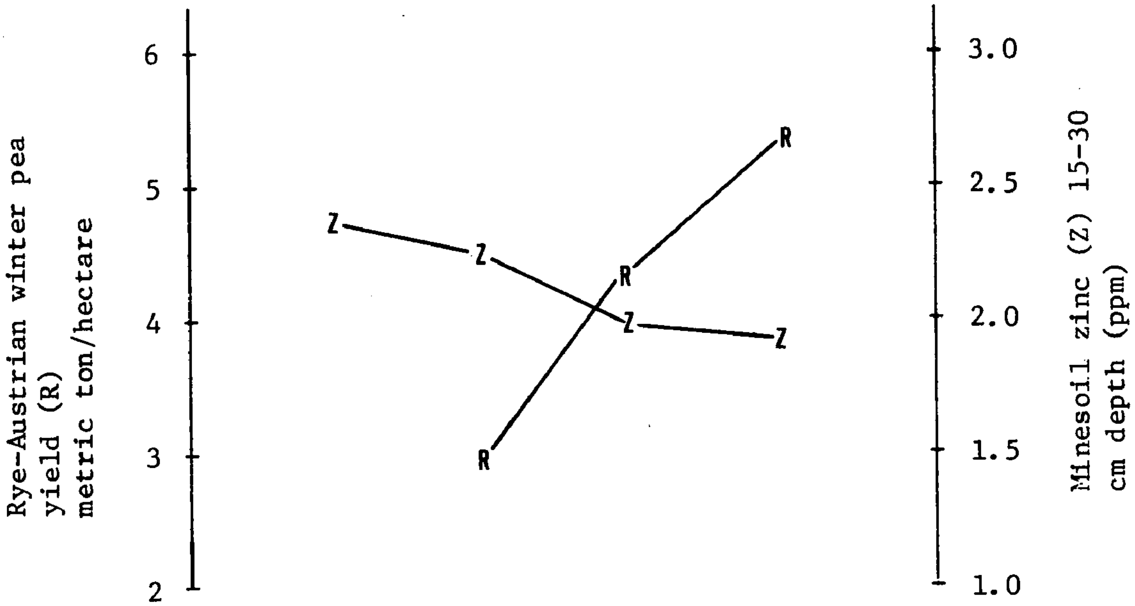
Sampling dates	Depth (cm)	Treatments			
		A	B	C	D
		ppm			
October 15, 1976	0-15	714	573	748	694
April 27, 1977	0-15	467	362	374	358
September 12, 1977	0-15	682	570	810	726
April 5, 1978	0-15	570	605	451	512
	15-30	1162	576	451	630
June 20, 1978	0-15	675	614	589	650
	15-30	688	366	362	388
August 12, 1978	0-15	1062	707	672	643
	15-30	1008	672	477	490
Overall means	0-15	695	572	607	597
	15-30	953	538	430	503

[z] Means of 4 replications.

concentration of leaf tissue P and Fe--i.e., Zn interferes with the capacity of the roots to reduce Fe^{3+} to Fe^{2+} (Bidwell, 1974). Minesoil Zn at Buchanan was inversely correlated with rye-Austrian winter pea yield, leaf tissue P and bean yield, and leaf tissue Zn levels were inversely correlated with squash yields (Tables A-6 and A-14, Figures 7 and 8).

Zinc levels were lower in the 0-15 cm depth than the 15-30 cm depth and appeared to diminish with increased depth of tillage (Tables 27, 28, A-14, and A-15). Increases in infiltration appeared to reduce Zn levels at Wise. Zn can be immobilized by organic matter and adsorbed by carbonates of Ca and Mg. This supports the inverse correlation found between Ca and Zn at Wise (Table A-15). Soil test organic matter readings cannot be used quantitatively, but in general the higher the organic matter (cover crop yields), the greater the Zn immobilization potential.

Figure 7. Relationship between rye-Austrian winter pea yield and zinc - Buchanan County, April 1978.



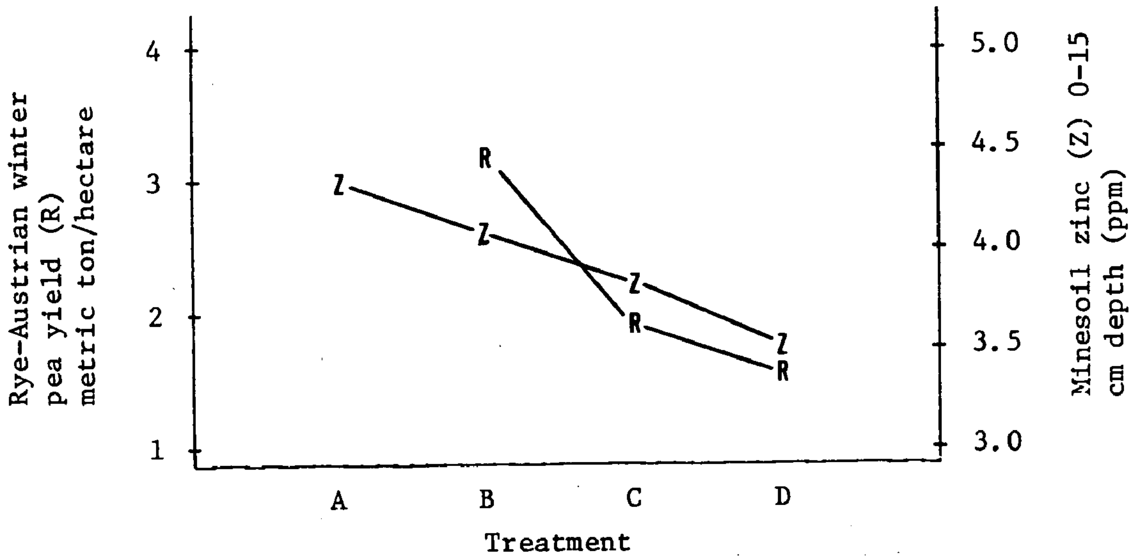


Figure 8. Relationship between rye-Austrian winter pea yield and zinc - Wise County, April 1978.

TABLE 22. SOIL TEST VALUES FOR DEEPLY SAMPLED CONTROL PLOTS (TREATMENT A) - WISE COUNTY, OCTOBER 1976[y,z]

Rep	Depth (cm)	pH	CaO	MgO	P_2O_5	K_2O	Soluble salts	Zn	Mn	NO_3	Organic matter
			kg/ha				ppm				%
I	0-15	4.3	709	446	254	97	282	6+	16+	5	3.4
	15-30	4.4	986	446	180	84	947	4.0	16+	5	1.1
	30-45	4.5	801	446	38	75	1152	1.7	16+	5	0.3
	45-60	5.6	3389	446	308	97	1766	2.1	16+	5	2.0
II	0-15	4.2	1448	446	308	108	1254	6+	16+	5	2.9
	15-30	3.6	2249	446	308	62	1900	5.5	16+	5	1.6
	30-45	5.0	2588	446	308	100	1766	3.1	16+	5	2.4
	45-60	3.9	2219	446	308	90	1664	6+	16+	5	2.3
III	0-15	4.5	1325	446	308	116	563	6+	16+	5	4.0
	15-30	4.5	3328	446	308	157	2176	5.9	16+	5	1.8
	30-45	4.5	2557	446	308	130	1818	4.5	16+	5	2.0
	45-60	4.5	1941	446	308	121	1203	6+	16+	5	1.5
IV	0-15	4.5	493	231	149	84	166	5.1	16+	5	1.1
	15-30	4.9	1355	446	308	92	307	4.1	16+	5	0.9
	30-45	6.6	2249	446	308	124	640	3.2	16+	5	1.3
	45-60	6.8	2803	446	308	146	794	4.5	16+	5	1.7
Overall means											
	0-15	4.4	994	392	255	101	566	5.8	16+	5	2.8
	15-30	4.4	1980	446	276	99	1332	4.9	16+	5	1.4
	30-45	5.2	2049	446	240	107	1344	3.1	16+	5	1.5
	45-60	5.2	2588	446	308	114	1357	4.6	16+	5	1.9

[y] Means represent one composite sample of two observations.

[z] The greatest values to which the tests are sensitive are CaO = 3761, P_2O_5 = 308, MgO = 446, K_2O = 421, Zn = 6, Mn = 16, and organic matter = 15. The lowest value to which the test is sensitive is NO_3 = 5.

TABLE 23. SOIL TEST VALUES FOR DEEPLY SAMPLED TREATMENT PLOTS - BUCHANAN COUNTY, JUNE 29, 1977[y,z]

Treatment	Depth (cm)	pH	CaO	MgO	P_2O_5	K_2O	Soluble salts	Organic matter
		kg/ha					ppm	%
A	7.5–15.0	6.6	3730	446	308	167	256	1.5
	15.0–22.5	7.5	3761	446	308	180	218	2.3
	22.5–30.0	7.6	3761	446	308	213	307	2.6
	30.0–37.5	6.7	3761	446	308	230	998	3.2
	37.5–45.0	5.3	1974	446	293	259	640	2.7
	45.0–52.5	4.3	2977	446	230	237	1216	6.5
	52.5–60.0	3.7	2789	446	152	153	1438	12.5
B	7.5–15.0	5.1	1661	446	189	153	141	1.0
	15.0–22.5	--	--	--	--	--	--	--
	22.5–30.0	6.7	3102	446	308	138	448	1.4
	30.0–37.5	5.5	2475	446	308	143	806	1.9
	37.5–45.0	3.6	1974	446	214	176	1728	4.4
	45.0–52.5	6.1	2914	446	308	148	307	1.4
	52.5–60.0	7.0	3761	446	308	197	333	1.6
	60.0–67.5	5.6	1724	446	308	251	371	2.5
C	7.5–15.0	4.2	1755	446	308	243	678	3.8
	15.0–22.5	--	--	--	--	--	--	--
	22.5–30.0	3.8	2632	446	264	237	1306	3.4
	30.0–37.5	--	--	--	--	--	--	--
	37.5–45.0	3.8	2414	446	238	266	1690	4.2
	45.0–52.5	4.5	3071	446	308	230	1472	3.5
	52.5–60.0	5.5	2601	446	308	170	960	3.0
	60.0–67.5	5.9	2632	446	308	170	973	2.7
	67.5–75.0	5.8	2506	446	308	167	909	2.1
	75.0–82.5	5.8	2037	446	308	176	896	2.0

(continued)

TABLE 23. CONTINUED

Treatment	Depth (cm)	pH	CaO	MgO	P_2O_5	K_2O	Soluble salts	Organic matter
			kg/ha				ppm	%
D	7.5-15.0	7.3	3761	446	308	176	218	2.4
	15.0-22.5	7.8	3761	446	308	180	218	2.4
	22.5-30.0	7.9	3761	446	308	197	209	2.3
	30.0-37.5	7.8	3761	446	308	216	230	2.6
	37.5-45.0	7.8	3761	446	308	170	346	2.5
	45.0-52.5	7.6	3761	446	308	199	320	2.3
	52.5-60.0	7.4	3761	446	308	205	320	3.8
	60.0-67.5	5.7	2131	446	148	146	243	13.3
	67.5-75.0	4.7	1002	446	52	138	209	14.1
	75.0-82.5	4.4	971	446	52	121	230	13.3
Overall means								
	7.5-15.0	5.8	2727	446	278	185	323	2.2
	15.0-22.5	7.6	3761	446	308	180	218	2.4
	22.5-30.0	6.5	3314	446	297	196	568	2.4
	30.0-37.5	5.0	3332	446	308	196	678	2.6
	37.5-45.0	5.1	2531	446	263	218	1101	3.4
	45.0-52.5	5.6	3181	446	288	204	829	3.4
	52.5-60.0	5.9	3228	446	269	181	763	5.2
	60.0-67.5	5.7	2162	446	255	189	529	6.2
	67.5-75.0	5.2	1754	446	180	152	559	8.1
	75.0-82.5	5.1	1504	446	180	148	563	7.6

[y] Means represent 2 observations per treatment.

[z] The greatest values to which the tests are sensitive are CaO = 3761, P_2O_5 = 308, MgO = 446, K_2O = 421, and organic matter = 15.

TABLE 24. SOIL TEST VALUES FOR DEEPLY SAMPLED TREATMENT PLOTS - WISE COUNTY, JULY 7, 1977[yz]

Treatment	Depth (cm)	pH	CaO	MgO	P_2O_5	K_2O	Soluble salts
			—	kg/ha	—	—	— ppm —
A	0-7.5	3.65	846	446	167	119	2035
	7.5-15.0	3.80	2350	446	213	143	2016
	15.0-22.5	3.65	3761	446	308	119	2816
	22.5-30.0	4.45	3698	446	308	133	2368
	30.0-37.5	5.05	3761	446	308	137	2304
	37.5-45.0	4.80	3761	446	308	144	2867
	45.0-52.5	4.80	1959	446	263	166	582
	52.5-60.0	5.05	2022	446	254	141	563
	60.0-67.5	5.00	1975	446	308	146	544
B	0-7.5	4.95	1567	446	271	167	480
	7.5-15.0	4.85	1504	446	264	162	468
	15.0-22.5	4.25	1034	446	180	116	717
	22.5-30.0	4.60	1457	446	293	150	851
	30.0-37.5	4.00	1206	446	181	143	1024
	37.5-45.0	4.15	1865	446	308	157	1510
	45.0-52.5	4.60	1818	446	308	170	1446
	52.5-60.0	5.70	3008	446	308	153	1728
	60.0-67.5	5.50	3761	446	234	138	1050
C	0-7.5	4.35	1833	446	306	117	768
	7.5-15.0	4.20	1583	446	296	137	947
	15.0-22.5	3.85	1410	446	256	145	941
	22.5-30.0	3.95	1943	446	285	146	1203
	30.0-37.5	4.65	2586	446	253	99	1689
	37.5-45.0	5.55	2946	446	272	134	1440
	45.0-52.5	5.70	2978	446	303	131	1606
	52.5-60.0	4.35	1458	446	164	128	889
	60.0-67.5	4.05	956	446	173	132	710

(continued)

TABLE 24. CONTINUED

Treatment	Depth (cm)	pH	CaO	MgO	P_2O_5	K_2O	Soluble salts
			kg/ha				ppm
D	0-7.5	4.90	1677	446	308	158	493
	7.5-15.0	4.65	1426	446	209	143	518
	15.0-22.5	5.05	1802	446	308	142	583
	22.5-30.0	5.65	2711	446	308	145	1005
	30.0-37.5	5.90	2883	446	308	156	909
	37.5-45.0	4.80	1692	446	170	167	595
	45.0-52.5	5.30	2868	446	170	164	723
	52.5-60.0	3.95	893	446	138	141	634
	60.0-67.5	5.05	2068	446	261	147	506
Overall means	0-7.5	4.46	1481	446	263	140	944
	7.5-15.0	4.38	1716	446	246	146	987
	15.0-22.5	4.20	2002	446	263	131	1264
	22.5-30.0	4.66	2452	446	299	144	1357
	30.0-37.5	4.90	2609	446	263	134	1482
	37.5-45.0	4.83	2566	446	265	151	1603
	45.0-52.5	5.10	2406	446	261	150	1089
	52.5-60.0	4.76	1845	446	216	141	954
	60.0-67.5	4.90	2190	446	244	141	703

[y] Means represent 2 observations per treatment.

[z] The greatest values to which the tests are sensitive are CaO = 3761, P_2O_5 = 308, MgO = 446, and K_2O = 421.

TABLE 25. SOIL TEST PH VALUES FOR VARIOUS DATES AND DEPTHS - BUCHANAN COUNTY[z]

Sampling dates	Depth (cm)	Treatments				
		A	B	C	D	Mean for date
October 29, 1976	0-15	6.6	6.6	6.3	6.7	6.6
April 29, 1977	0-15	6.0	6.3	6.5	6.3	6.3
June 22, 1977	0-15	5.6	6.0	5.6	6.0	5.8
September 13, 1977	0-15	5.9	6.1	5.8	6.4	6.0
April 12, 1978	0-15	6.4	6.5	6.4	7.0	6.6
	15-30	7.6	7.3	7.0	7.3	7.3
June 21, 1978	0-15	6.2	6.6	6.3	7.0	6.5
	15-30	7.5	7.2	7.0	7.4	7.3
August 15, 1978	0-15	6.7	6.8	6.7	6.9	6.8
Overall means	0-15	6.2	6.4	6.2	6.6	6.4
	15-30	7.6	7.2	7.0	7.4	7.3

[z] Means of 4 composite samples.

Water Soluble Nitrates

Water soluble nitrates were determined on minesoil samples taken in 1978 (Tables 27 and 28). Soil test (water soluble) NO_3 results are not an absolute measure of soil nitrogen content, but they do indicate relative levels in each sample analyzed.

The Buchanan County data are a good example of nitrate levels as affected by the growth, incorporation, and decomposition of a green manure crop (Figure 9). Buchanan had an excellent stand of rye-Austrian winter pea growing as the winter cover crop on the T_B, T_C, and T_D plots. In April, the NO_3 levels on the 0-15 cm depth were low because of the consumption of nitrates by the thick stand of rye. The NO_3 levels at the 0-15 cm depth increased in June due to the release of nitrogen by the Austrian winter pea and rye when they were plowed down. The nitrogen derived from the peas was a net gain to the minesoil. By August, NO_3 levels at the 0-15 cm depth were dropping probably due to immobilization by microorganisms in the process of

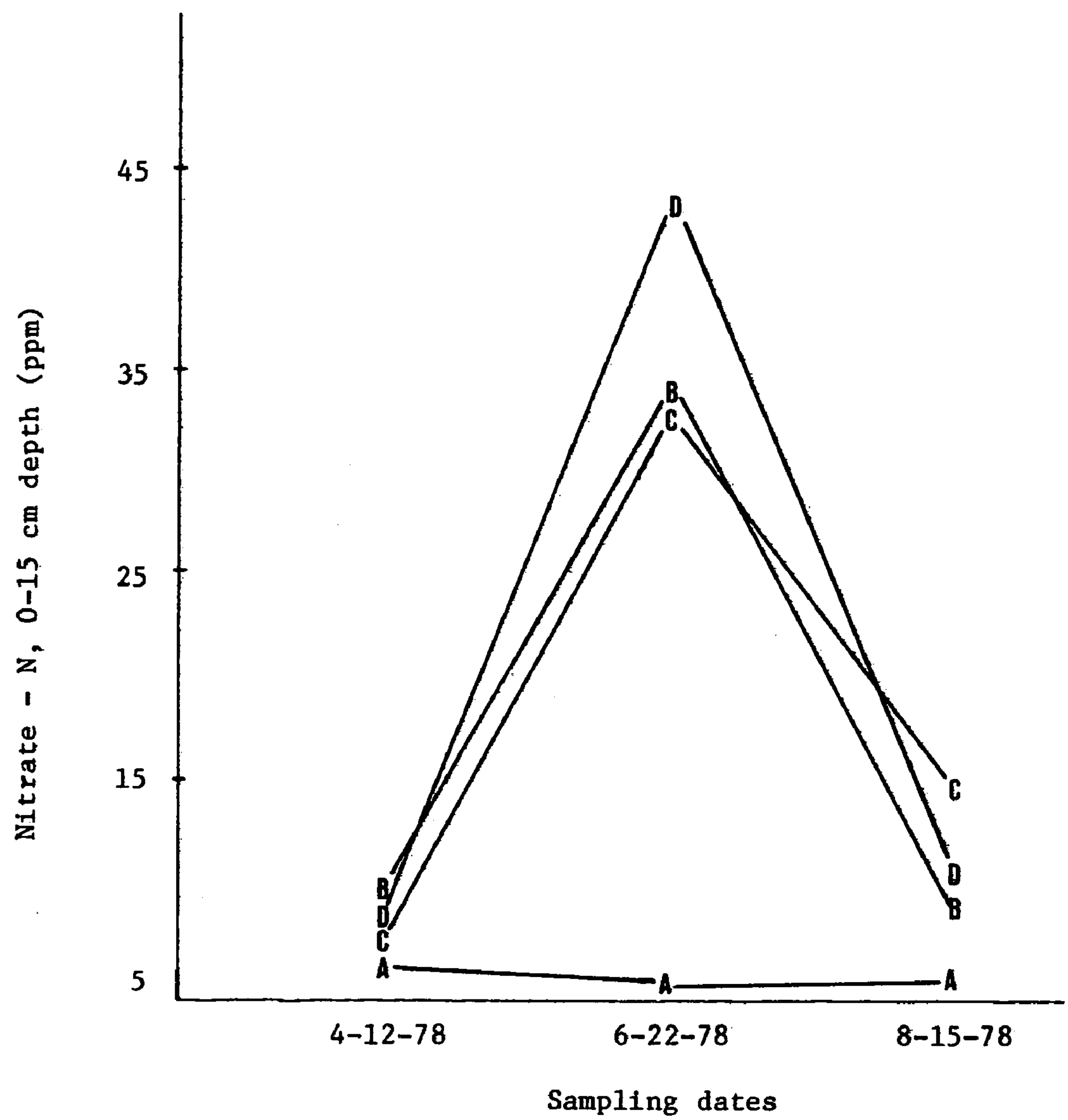


Figure 9. Nitrate levels as affected by cover crop growth, incorporation, and decomposition - Buchanan County, 1978.

TABLE 26. SOIL TEST PH VALUES FOR VARIOUS DATES AND DEPTHS - WISE COUNTY[z]

Sampling dates	Depth (cm)	Treatments				
		A	B	C	D	Means for BCD
October 15, 1976	0-15	4.4	4.3	4.5	4.4	4.4
April 27, 1977	0-15	4.5	5.4	5.2	5.3	5.3
June 20, 1977	0-15	4.4	5.5	5.4	5.6	5.5
September 12, 1977	0-15	4.2	5.4	5.4	5.3	5.4
November 20, 1977	0-15	4.3	5.3	5.6	5.5	5.5
April 5, 1978	0-15	4.4	5.6	5.8	5.6	5.7
	15-30	4.6	4.8	5.4	5.4	5.2
June 20, 1978	0-15	6.0	6.0	6.3	6.2	6.2
	15-30	5.1	5.1	5.9	6.2	5.7
August 12, 1978	0-15	6.2	6.2	5.9	6.0	6.0
	15-30	5.4	5.5	5.5	6.1	5.7
Means for June and August 1978	0-15	6.1	6.1	6.1	6.1	
	15-30	5.2	5.3	5.7	6.2	

[z] Means of 4 composite samples.

organic matter decomposition, use by the vegetable crops and leaching out of the profile as a result of the good infiltration rates. Nitrate levels at the 15-30 cm depth were much lower throughout 1978, probably due to the lower organic matter content of this depth. The NO_3 levels at the 0-15 cm and the 15-30 cm depths appear to reflect the yield of the rye-Austrian winter pea cover crop. T_C and T_D which had the highest yield of rye-Austrian winter pea also had the highest NO_3 levels in August. Control plots had lower NO_3 levels in April, since they did not receive the mineral N applications of the rye-Austrian winter pea plots. NO_3 levels in the T_B, T_C, and T_D plots were higher in June and August than the control, probably as a result of the differences in cover crop yields because mineral fertilizer N applications were the same for all plots.

TABLE 27. SOIL TEST VALUES FOR ZN AND NO_3 AT VARIOUS DATES AND DEPTHS - BUCHANAN COUNTY[y]

Soil test	Depth (cm)	Treat- ment	Sampling dates				
			10/29/76	4/12/78	6/21/78	8/15/78	Overall means
			ppm				
An	0-15	A	2.4	2.0	2.2	2.0	2.2
		B	2.5	2.1	2.1	1.8	2.1
		C	2.6	2.0	1.8	1.8	2.0
		D	2.4	2.0	1.7	1.8	2.0
	15-30	A	--	2.4	2.2	--	2.3
		B	--	2.3	2.1	--	2.2
		C	--	2.0	2.0	--	2.0
		D	--	1.9	2.1	--	2.0
NO_3	0-15	A	--	5.8	5.0*[z]	6.4*	5.7*
		B	--	7.8	33.3	9.2	16.8
		C	--	7.3	32.0	15.2	18.2
		D	--	7.6	43.6	11.6	20.9
	15-30	A	--	5.3*	5.0*	--	5.2*
		B	--	5.8*	5.1*	--	5.4*
		C	--	5.7	6.2	--	6.0
		D	--	6.0	6.9*	--	6.4*

[y] Means of 4 composite samples.

[z] Means marked by "*" contain values of less than 5 for NO_3, therefore, the actual values are equal to or less than for NO_3.

TABLE 29. COVER AND VEGETABLE CROP YIELDS[x,y]

Site	Tillage regime	Cover crop: Rye Winter 76/77	Cover crop: Soybean Summer 77	Cover crop: Rye-Austrian Winter Pea Winter 77/78	Vegetable crop: Bean Summer 78	Vegetable crop: Summer Squash Summer 78
		Metric ton/ha				
Buchanan County	A	--	--	--	13.30b	55.35b
	B	2.59b[z]	2.46a	2.98b	17.74ab	79.05a
	C	3.78a	3.00a	4.48a	22.49a	81.92a
	D	2.76b	3.07a	5.22a	22.15a	93.52a
	Mean	3.04	2.84	4.23	19.93	77.46
Wise County	A	--	--	--	6.34b	6.97b
	B	3.65a	6.00a	3.16a	22.22a	43.21a
	C	3.29ab	6.83a	1.93a	16.98ab	31.40a
	D	2.15b	4.34a	1.61a	13.42ab	22.40ab
	Mean	3.02	5.73	2.24	14.74	25.98

[x] Means of four replications.

[y] Yields represent above ground growth for cover crops expressed as dry weight and fruit fresh weight for vegetable crops.

[z] Means of one column for each county followed by the same letter are not different at the 0.05 level of probability.

cattle approximately 3 weeks after germination. This factor aside, soybean growth at both sites was very much alike. Observations of soybean roots showed that only the darker green plants, which made up less than a quarter of the total stand, had substantial numbers of root nodules. These well nodulated plants, however, showed no sign of being larger, healthier, or faster maturing than the poorly or nonnodulated plants. Therefore, the incidence of nodulation had no apparent effect on the growth of soybeans.

Rye-Austrian Winter Pea--Winter 1977-78--

Germination rates were excellent for both the rye and Austrian winter pea components of the winter cover crop. Excellent stands were observed at both sites in December of 1977; however, the Austrian winter pea did not survive the winter at Wise. In fact, even the rye component of the cover did not grow as well as it did the previous winter at Wise (Figure 10a). In contrast, Buchanan produced a thick and healthy stand of rye and Austrian winter pea (Figure 10b). Observations of Austrian winter pea roots showed that they all were well nodulated. Yields were inversely correlated with soluble salt levels at Buchanan (Table A-14). It is interesting that the two treatments which enhanced the yields the most (T_C and T_D) also had the lowest soluble salt concentration, probably as a result of their higher infiltration rates.

At Wise, yields were correlated with infiltration rates, pH, Ca, and P and inversely correlated with Zn (Table A-15). Zn levels decreased with increased depth of tillage and infiltration.

Vegetable Crops

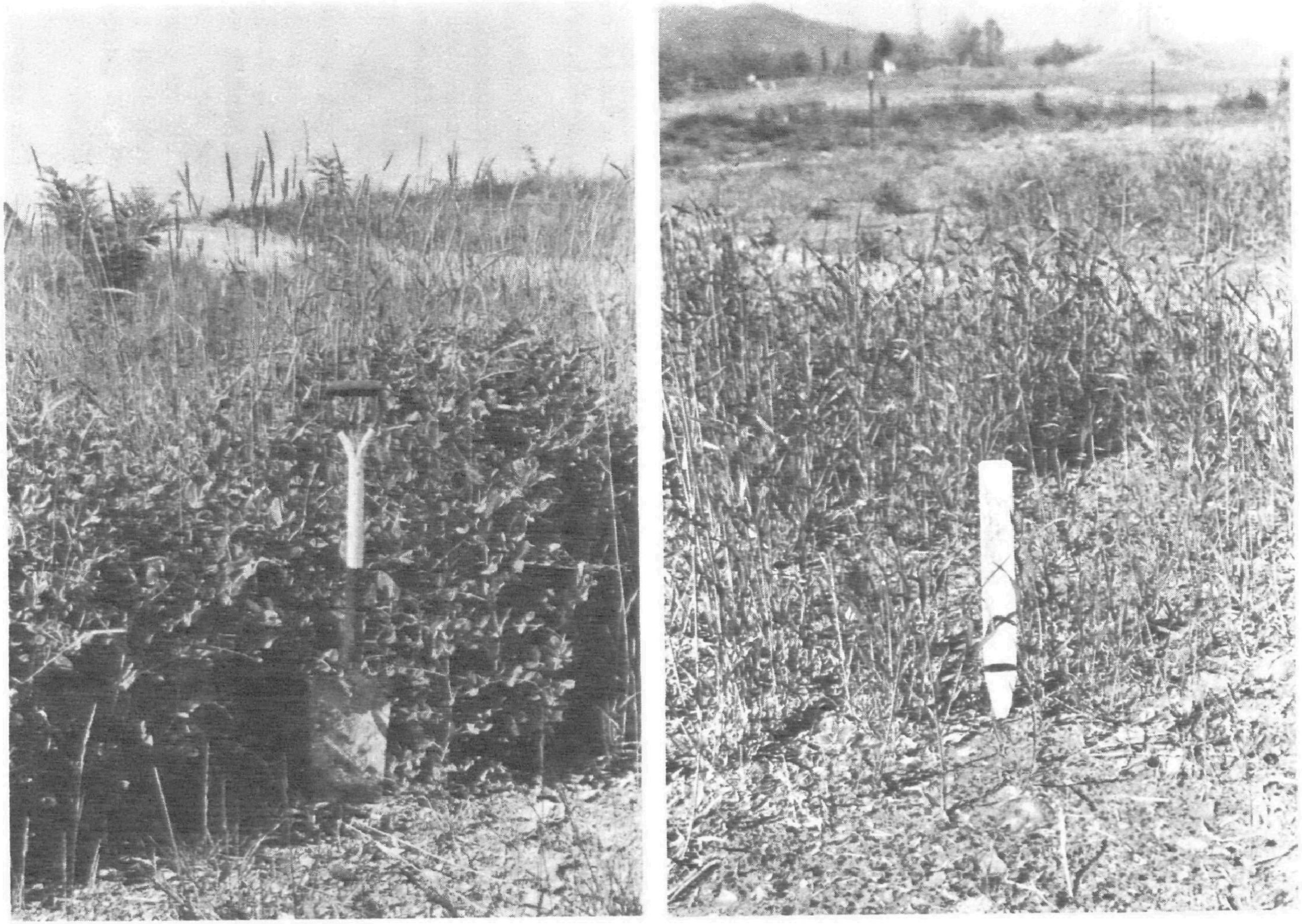
The plots at Buchanan had good stands of beans and squash with T_B, T_C, and T_D having the best growth, production, and quality. The vegetable plots did much better at Buchanan than at Wise with the control plots at Buchanan producing as well or better than the tillage plots (T_B, T_C, and T_D) at Wise.

Germination throughout the experiment was uniform in terms of stand density and time of seedling emergence. Some bean plants exhibited manganese toxicity symptoms during their early growth stage, but later appeared to "outgrow it". Bean plants on one control plot exhibited marginal chlorosis throughout the growing season; however, this was the only plot to do so. No insect or disease problems were encountered during the growing season for either vegetable, and all plants appeared very healthy (Figure 11).

Germination rates at Wise were also excellent for both vegetable crops. However, with a small percentage of beans, spoil crusting resulted in rupture of the hypocotyls.

The minimum tillage plots all germinated the fastest and produced excellent quality fruit (beans and squash) early in the season and then their quality dropped. Except for the fourth replication and minimum tillage plots, most plots never produced high quality fruits. Essentially those plots that had the fastest germination and initial growth yielded the most. The majority of plots which did not germinate and grow quickly did not do well, whereas the plots that did well early became progressively worse as the season advanced. Minimum tillage and all other plots decreased in quality and quantity as the season progressed, all except those in the fourth replication. The success of the fourth replication was probably due to its high subsoil pH; readings of 6.6 to 6.8 were recorded at the 30 to 60 cm depth in October 1976 (Table 22). The fourth replication continued to produce fruit of good quality throughout the harvest period. The relative yield pattern of treatments was the same for all four replications (Figure 12).

Vegetables at Wise exhibited stress symptoms throughout the growing season. Most squash plants were small and produced harder and darker yellow fruits well below optimum quality. The initial bean harvests produced good quality and quantity fruit with quality dropping as the season progressed. Bean plants displayed signs of manganese toxicity (leaf cupping with marginal chlorosis) during the early stages of growth and then appeared to "outgrow"



FIGURES 10a (left) and 10b (right). A comparison of rye-Austrian winter pea growth at Buchanan (shovel is over 1 meter tall) and Wise (stake is 30 cm tall) Counties, May 1978.

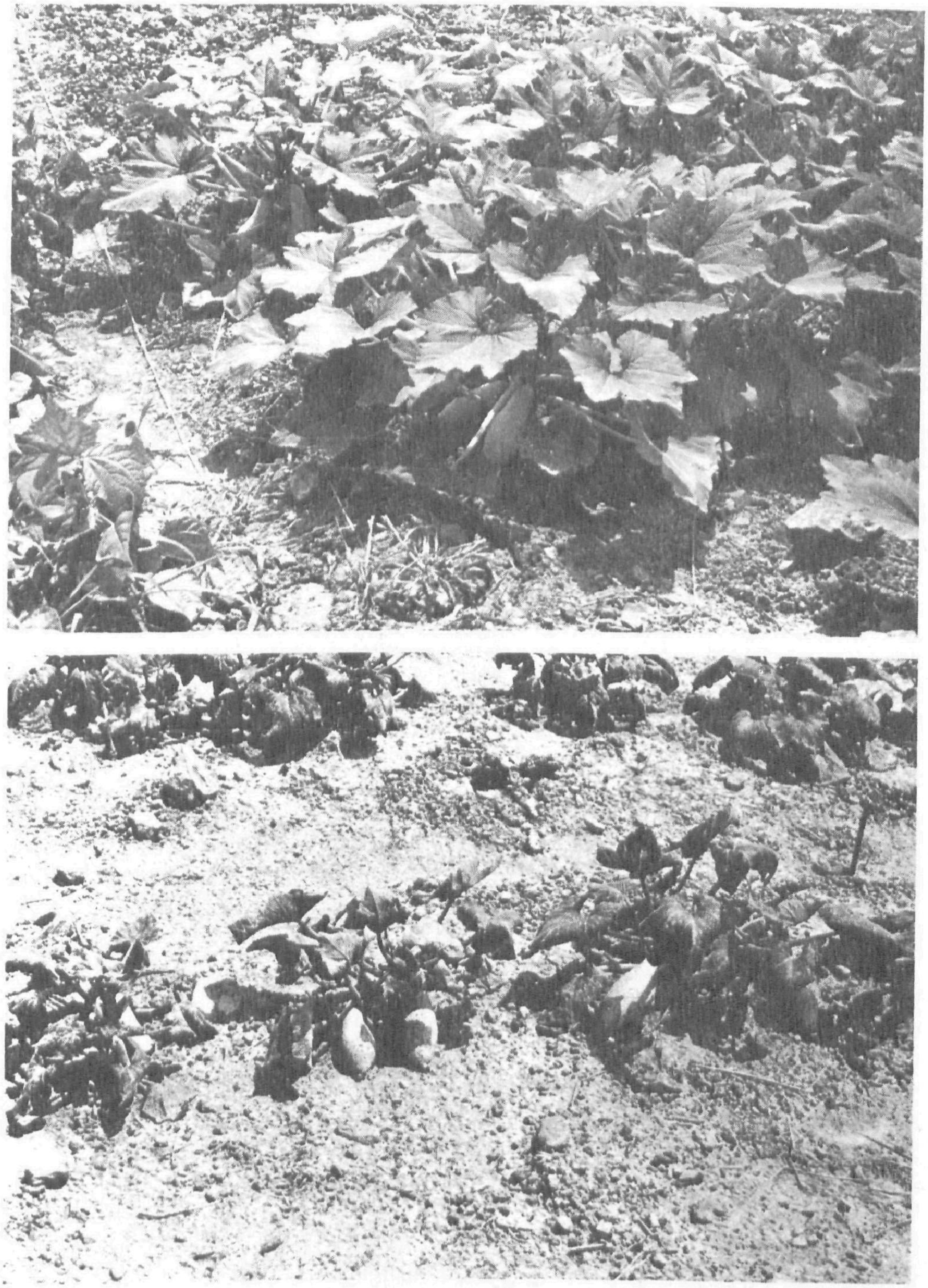


FIGURE 11. A comparison of squash growth at Buchanan and Wise Counties, August 1978.

FIGURE 12. A comparison of treatment effects on squash growth - Wise County, July 6, 1978.

the problem. No insect or disease problems were encountered during the growing season for either vegetable.

Total Correlations Between Vegetable Leaf Tissue Chemical Data and Minesoil Properties

Leaf tissue chemical data were comparable to the data reported by Geraldson, et al. (1973) for plants grown in agricultural soils (Tables 30 and 31). Vegetable yields were, however, adversely affected by various elements and interactions of elements (Tables A-5 and A-6).

Buchanan--

Squash yields were correlated with K and Ba leaf concentrations and inversely correlated with Mn, Al, and Zn leaf levels (Figure 13). Ba and K levels tended to increase with increased depth of tillage, whereas Mn, Al, and Zn levels appeared to decrease. Bean yields were inversely correlated with Al and Sr leaf tissue concentration, both of which appeared to decrease with increased depth of tillage. Al is a primary growth limiting factor, but usually only on acid soils. Al may interfere with a number of plant functions, including cell division, respiration, DNA synthesis and sugar phosphorylation. Al can also bind P to root surfaces, cell walls, and in the free space of roots (Mortvedt, et al., 1972). P leaf tissue concentrations were inversely correlated with leaf tissue levels for Ca, Mg, Mn, Fe, Sr, and minesoil Zn levels, and correlated with 90 minute infiltration rates. P leaf tissue values increased with depth of tillage, whereas Ca, Mg, Mn, Fe, and Sr leaf tissue levels tend to decrease with increased depth of tillage. High Ca and Mg levels tend to precipitate P out of the soil solution. Calcareous soils reduce the available phosphates by converting them into insoluble apatites or precipitating them as insoluble calcium phosphates directly from the soil solution. Leaf tissue levels for Mn and K were inversely correlated with 90 minute infiltration and Zn leaf tissue values, respectively.

Wise--

Leaf tissue K levels are correlated with yields of both vegetables and they were higher in T_B, T_C, and T_D than T_A. Haufler (1976) reported K to be the most influential factor dealing with natural revegetation of orphan mine sites in southwest Virginia. Leaf tissue manganese levels are inversely correlated with yield of vegetables with treatment A having the highest amount (Figure 14). High soil Mn causes crinkle leaf in cotton and these symptoms were visible in both beans and squash. Deeper tillage and increased infiltration rates appear to reduce Cu and increase Mg levels in the leaves.

In general, it appears that an increase in tillage depth with its accompanying increase in soil aeration, moisture, and infiltration rates tends to enhance elements favorable to increased plant growth and decrease those elements that are present in adverse quantities at both Buchanan and Wise.

TABLE 30. LEAF TISSUE CHEMICAL ANALYSIS FOR BEANS AND SQUASH - BUCHANAN COUNTY, JULY 1978[y,z]

Treatments	Elements			
	P	K	Ca	Mg
	%			
A	0.60	3.10	1.33	0.99
B	0.76	3.24	1.06	0.75
C	0.78	3.24	0.92	0.79
D	0.77	3.33	1.05	0.77
	B	Cu	Zn	Ba
	ppm			
A	10.69	13.28	43.36	4.75
B	12.24	13.12	41.58	4.97
C	16.12	14.28	42.94	6.28
D	16.26	12.95	40.17	7.29
	Mn	Fe	Al	Na
	ppm			
A	212.55	427.25	645.75	49.04
B	147.80	331.95	513.35	50.74
C	180.05	316.75	485.10	42.41
D	140.15	321.05	481.15	50.94
	Sr			
	ppm			
A	29.70			
B	20.40			
C	17.42			
D	18.74			

[y] Means represent 8 composite samples.

[z] Means represent beans and squash because they were handled as replication.

TABLE 31. LEAF TISSUE CHEMICAL ANALYSIS FOR BEANS AND SQUASH - WISE COUNTY, JULY 1978[y,z]

Treatments	Elements			
	P	K	Ca	Mg
	%			
A	0.55	3.00	1.14	0.62
B	0.66	3.30	0.78	0.59
C	0.54	3.25	1.09	0.66
D	0.47	3.18	1.39	0.87
	B	Cu	Zn	Ba
	ppm			
A	18.90	14.28	46.92	6.00
B	15.48	12.62	47.22	4.23
C	14.96	12.08	49.40	5.33
D	15.52	11.80	43.34	6.59
	Mn	Fe	Al	Na
	ppm			
A	267.15	448.75	747.20	62.86
B	156.10	353.85	584.20	56.28
C	193.85	381.25	624.75	48.27
D	187.70	570.20	1262.60	73.06
	Sr			
	ppm			
A	12.28			
B	7.38			
C	14.37			
D	16.14			

[y] Means represent 8 composite samples.

[z] Means represent beans and squash because they were handled as replication.

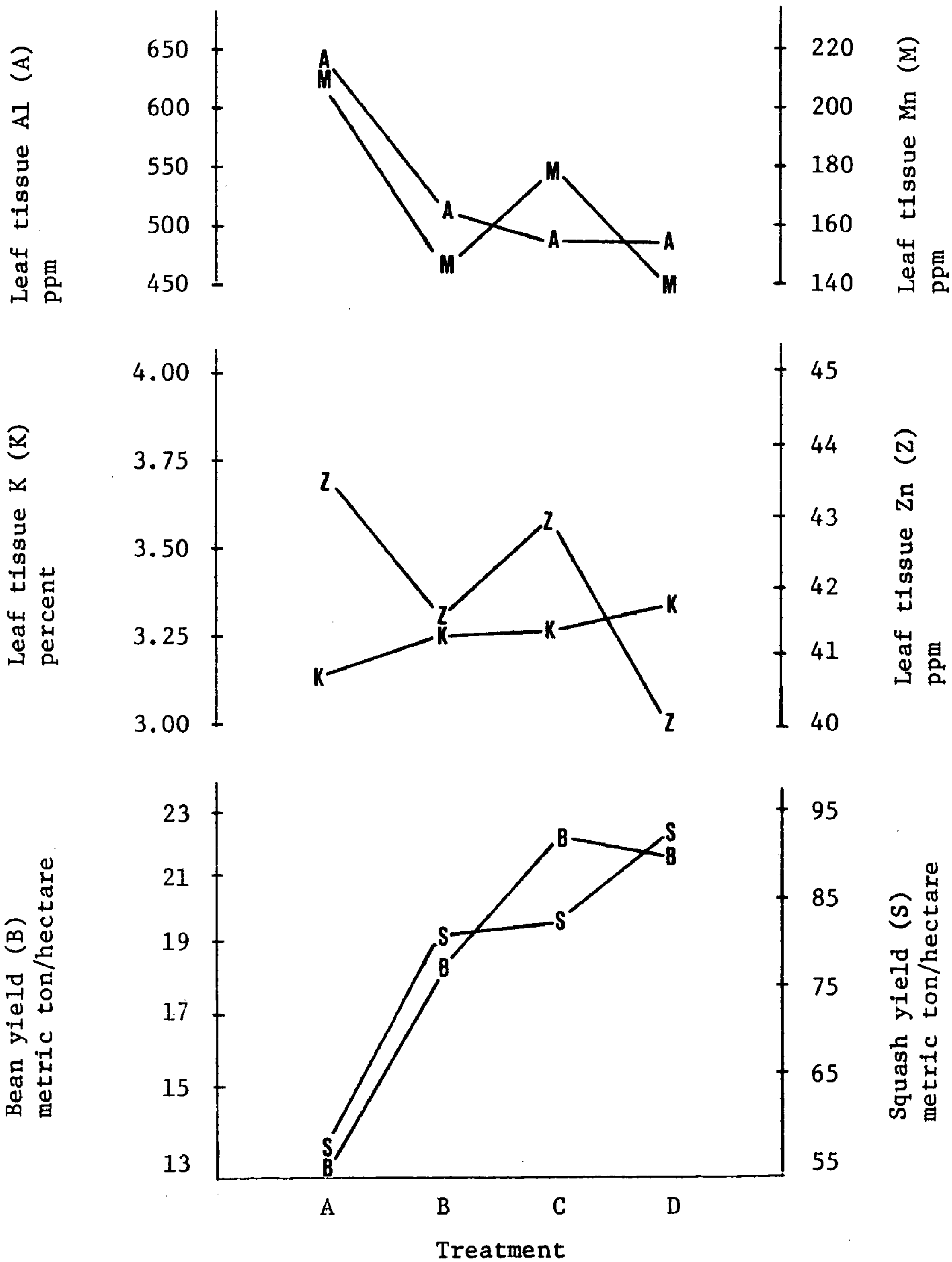


Figure 13. Relationship of bean and squash yield to leaf tissue concentrations of K, Mn, Zn, and Al - Buchanan County, August 1978.

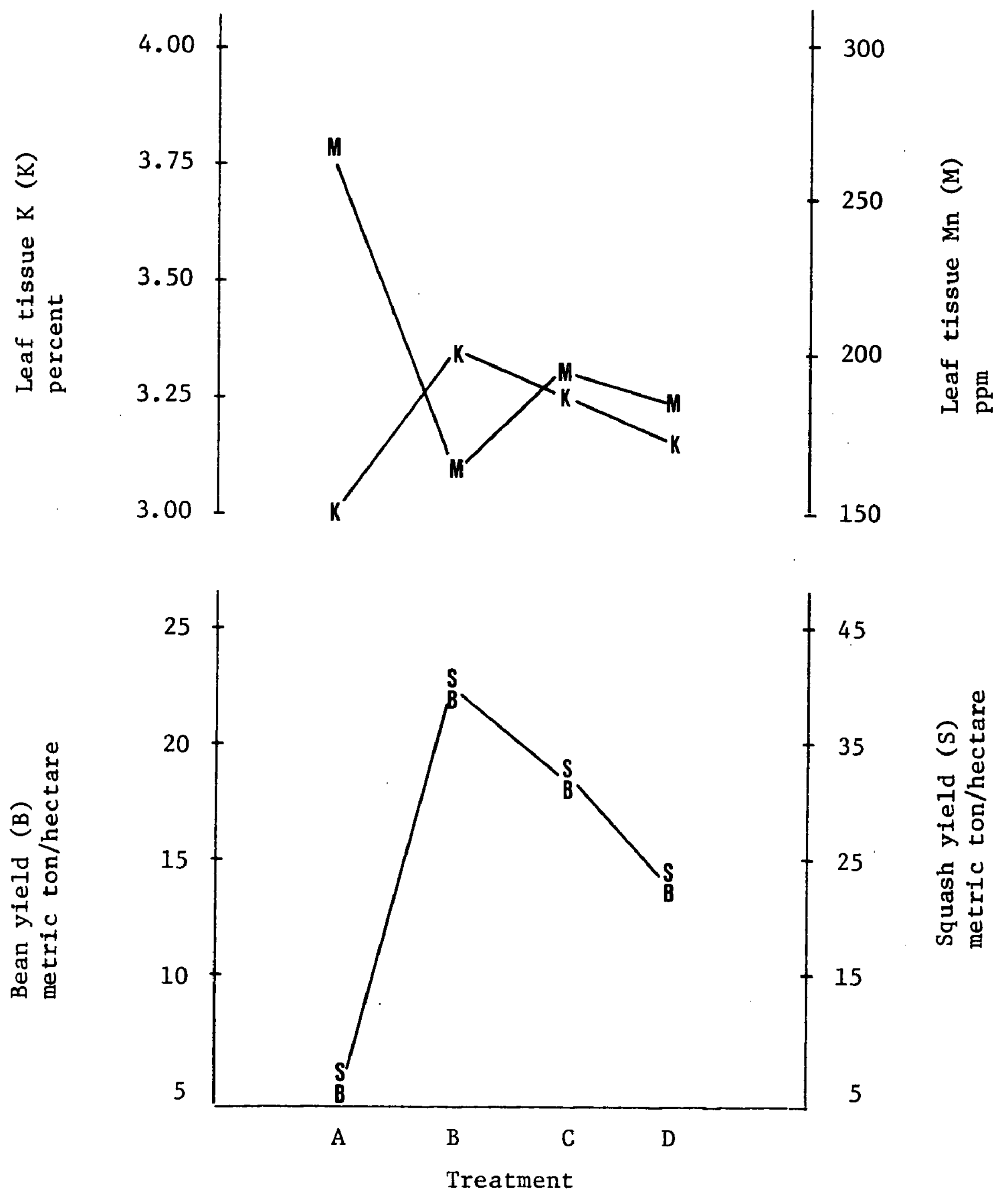


Figure 14. Relationship of bean and squash yield to leaf tissue concentrations of K and Mn - Wise County, August 1978.

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APPENDIX

Minesoil Organic Matter

Problems with minesoil organic matter readings were recognized from the start of this experiment. As a result, three minor substudies on organic matter were investigated. The coal used was all from the same source.

The first study was to remove any doubt that coal did show up as organic matter in the soil test procedure. Four replications of the following samples were analyzed: (1) pure coal; (2) alkaline sand; and (3) a mixture of 20 percent coal and 80 percent sand by volume. It is obvious, given the off scale "15+" readings, that coal does indeed enter into the analysis results (Table A-1). It can also be seen that this particular coal is not a major source of manganese.

TABLE A-1. RESPONSE OF COAL IN MINESOIL ORGANIC MATTER DETERMINATIONS

Sample^{z}	Organic Matter - %	Mn - ppm	pH
Coal	15+	0.8	7.6
Sand	0.1	2.4	8.6
Coal + Sand	4.0	2.6	8.4

^{z} Means represent four replications.

The second study consisted of taking a large composite sample from each experimental plot, mixing it thoroughly and dividing it into two identical subsamples. One subsample was run through the laboratory analysis procedure as usual, the second subsample had as much coal as possible removed visually prior to being analyzed. The visual separation technique employed was ineffective even though substantial amounts of coal were seemingly removed from each sample (Table A-2).

TABLE A-2. EFFECT OF VISUAL COAL REMOVAL ON MINESOIL ORGANIC MATTER DETERMINATIONS

Rep	Treatment	Samples Run as Usual	Coal Visually Removed
		Organic Matter - %	
1	A	3.3	3.5
	B	3.1	2.6
	C	4.2	3.8
	D	3.2	3.1
2	A	3.1	3.6
	B	4.0	3.6
	C	4.8	4.8
	D	3.8	4.0
3	A	4.2	4.4
	B	4.4	4.0
	C	2.5	2.5
	D	2.3	2.5
4	A	1.0	1.2
	B	1.4	1.5
	C	1.3	1.3
	D	1.9	1.8
Overall Means		3.0	3.0

There are two possible conclusions that can be drawn from the data. First, coal may not be present in large enough quantities to greatly influence the minesoil organic matter readings or secondly, the amount of coal removed visually was not enough to affect the test results. Sample pH was unaffected.

The third study consisted of additions of organic matter to minesoil material prior to laboratory analysis. Rye var. abruzzi was added to 2 and 4 percent levels by weight to the samples and thoroughly mixed. In addition, 8 identical control samples of minesoil material were run in order to evaluate the consistency of the laboratory procedure (Table A-3). The laboratory analysis procedure is highly reproducible as was evident by the data

TABLE A-3. REPRODUCIBILITY OF MINESOIL ORGANIC MATTER DETERMINATIONS

Sample Description		Organic Matter	Means
		%	
Controls	1	1.8	
	2	1.9	
	3	1.6	
	4	1.7	
	5	1.8	1.8
	6	1.9	
	7	1.8	
	8	1.8	
2% OM added	1	2.6	2.4
	2	2.3	
4% OM added	1	2.3	2.3
	2	2.3	

of the control samples. Added organic matter (rye hay) raised the test results substantially, although the crudity of the study resulted in equal or higher levels for the 2 percent samples than the 4 percent. Therefore, if enough organic matter is plowed down, it will show up in the soil test results. It is important to realize that soil test organic matter results are merely one aspect of minesoil condition and that the test figures are very likely artificially elevated due to coals, carbonaceous shales, reduced manganese, and other factors.

TABLE A-4. COEFFICIENTS OF CORRELATION (R) AMONG VEGETABLE LEAF TISSUE CHEMICAL DATA - BUCHANAN COUNTY, SUMMER 1978[z]

	P	K	Ca	Mg	Mn	Fe	Al	Ba
P	--	--	-0.96	-0.99	-0.95	-0.99	--	--
	--	--	0.04	0.005	0.05	0.01	--	--
Ca	-0.96	--	--	--	--	0.97	--	--
	0.04	--	--	--	--	0.03	--	--
Mg	-0.99	--	--	--	--	0.97	--	--
	0.005	--	--	--	--	0.03	--	--
Mn	-0.95	--	--	--	--	0.97	0.97	-0.99
	0.05	--	--	--	--	0.03	0.03	0.0006
Fe	-0.99	--	0.97	0.97	0.97	--	0.98	-0.96
	0.01	--	0.03	0.03	0.03	--	0.02	0.04
Al	--	--	--	--	0.97	0.98	--	-0.97
	--	--	--	--	0.03	0.02	--	0.03
Ba	--	--	--	--	-0.99	-0.96	-0.97	--
	--	--	--	--	0.0006	0.04	0.03	--
Zn	--	-0.98	--	--	0.95	--	--	-0.96
	--	0.02	--	--	0.05	--	--	0.04
Sr	-0.95	--	0.98	--	--	0.98	0.98	--
	0.05	--	0.02	--	--	0.02	0.02	--

[z] Total or simple correlations with their corresponding level of significance.

TABLE A-5. COEFFICIENTS OF CORRELATION (R) AMONG LEAF TISSUE CHEMICAL AND YIELD DATA OF VEGETABLES - WISE COUNTY, SUMMER 1978[z]

	B	Ba	Na	Bean yield	Squash yield
Ca	--	0.99	--	--	--
	--	0.01	--	--	--
Mg	--	--	0.95	--	--
	--	--	0.04	--	--
Fe	0.99	0.95	0.98	--	--
	0.01	0.05	0.02	--	--
Al	--	--	0.99	--	--
	--	--	0.002	--	--
K	--	--	--	0.95	0.96
	--	--	--	0.05	0.04
Mn	--	--	--	-0.95	-0.96
	--	--	--	0.05	0.04

[z] Total or simple correlations with their corresponding level of significance.

TABLE A-6. COEFFICIENTS OF CORRELATION (R) AMONG VEGETABLE LEAF TISSUE CHEMICAL DATA, YIELDS, AND MINESOIL PROPERTIES - BUCHANAN COUNTY, SUMMER 1978[y,z]

	Zn	Bean yield	Squash yield	3 p.m. minesoil temperature	90 minute infiltration rate
P*	-0.98	--	--	-0.96	0.99
	0.02	--	--	0.04	0.04
K*	--	--	0.95	--	--
	--	--	0.05	--	--
Ca*	0.99	--	--	--	--
	0.01	--	--	--	--
Mg*	0.96	--	--	--	--
	0.04	--	--	--	--
Mn*	0.95	--	-0.99	0.99	-0.99
	0.05	--	0.006	0.01	0.03
Fe*	0.99	--	--	0.99	--
	0.005	--	--	0.008	--
Al*	0.97	-0.98	-0.97	0.99	--
	0.03	0.03	0.03	0.006	--
Ba*	--	--	0.99	-0.99	--
	--	--	0.003	0.01	--
Zn*	--	--	-0.98	--	--
	--	--	0.03	--	--
Sr*	0.99	-0.97	--	0.97	--
	0.006	0.03	--	0.02	--
3 p.m. mine-	--	-0.96	--	--	--
soil temp.	--	0.04	--	--	--
10 min. infil-	--	0.96	--	--	--
tration rate	--	0.04	--	--	--
90 min. infil-	--	--	0.99	--	--
tration rate	--	--	0.006	--	--
Zn	--	-0.94	--	--	--
	--	0.05	--	--	--

[y] An "*" denotes leaf tissue chemical data.

[z] Total or simple correlations with their corresponding level of significance.

TABLE A-7. COEFFICIENTS OF CORRELATION (R) AMONG SEVERAL SOIL TEST VALUES AT THE 0-15 CM DEPTH, OCTOBER 1976-AUGUST 1978[z]

	pH	Ca	P	K	pH	Ca	P	K
	Buchanan				Wise			
Organic matter	0.48 0.0001	0.50 0.0001	0.24 0.01	0.19 0.04	-0.25 0.005	-- --	-0.28 0.002	-- --
pH	-- --	0.61 0.0001	0.52 0.0001	0.25 0.009	-- --	0.84 0.0001	0.26 0.004	0.65 0.0001
Ca	-- --	-- --	0.42 0.0001	0.19 0.04	-- --	-- --	0.25 0.005	0.69 0.0001
P	-- --	-- --	-- --	0.34 0.0003	-- --	-- --	-- --	0.31 0.0005

[z] Partial correlations with their corresponding level of significance.

TABLE A-8. COEFFICIENTS OF CORRELATION (R) AMONG VARIOUS MINESOIL PROPERTIES - WISE COUNTY - APRIL, JUNE, AND AUGUST 1978[z]

	Depth (cm)	Organic matter	pH	Ca	P	K	Soluble salts
pH	0-15	-0.33	--	--	--	--	--
		0.03	--	--	--	--	--
Ca	0-15	--	0.82	--	--	--	--
		--	0.0001	--	--	--	--
K	0-15	--	0.39	0.50	--	--	--
		--	0.01	0.0007	--	--	--
Soluble salts	0-15	--	0.34	0.42	-0.46	--	--
		--	0.03	0.006	0.001	--	--
Zn	0-15	0.44	--	--	--	--	0.29
		0.004	--	--	--	--	0.05
NO_3	0-15	--	--	--	--	0.43	0.39
		--	--	--	--	0.004	0.009
Moisture	0-15	--	0.38	0.38	--	--	--
		--	0.01	0.01	--	--	--
Ca	15-30	--	0.67	--	--	--	--
		--	0.0001	--	--	--	--
K	15-30	--	0.34	0.34	--	--	--
		--	0.02	0.02	--	--	--
Zn	15-30	0.37	--	--	--	--	--
		0.01	--	--	--	--	--

[z] Partial correlations with their corresponding level of significance.

TABLE A-9. COEFFICIENTS OF CORRELATION (R) AMONG SEVERAL MINESOIL CHARACTERISTICS - BUCHANAN COUNTY - APRIL, JUNE, AND AUGUST 1978[z]

	pH	Ca	P	Soluble salts	Zn	NO_3	Moisture
				0-15 cm			
Organic matter	0.58 0.0001	0.45 0.002	0.30 0.04	-- --	0.40 0.007	-- --	-- --
pH	-- --	0.60 0.0001	0.40 0.007	-- --	-- --	-- --	-- --
Ca	-- --	-- --	0.29 0.05	-- --	-- --	-- --	-- --
P	-- --	-- --	-- --	0.35 0.02	-- --	-- --	-- --
K	-- --	-- --	-- --	0.51 0.0005	-- --	0.64 0.0001	-0.50 0.0007
Soluble salts	-- --	-- --	-- --	-- --	-- --	0.75 0.0001	-- --
Zn	-- --	-- --	-- --	-- --	-- --	-- --	-0.30 0.04
				15-30			
Organic matter	0.56 0.002	0.46 0.01	-- --	-- --	-- --	-- --	-0.56 0.002
pH	-- --	0.51 0.006	-- --	-- --	-- --	-- --	-0.44 0.02
Ca	-- --	-- --	-- --	0.40 0.03	0.56 0.002	-- --	-0.46 0.01
Soluble salts	-- --	-- --	-- --	-- --	0.46 0.01	-- --	-- --

[z] Partial correlations with their corresponding level of significance.

TABLE A-10. COEFFICIENTS OF CORRELATION (R) AMONG SEVERAL MINESOIL CHARACTERISTICS AT THE 0-15 CM DEPTH - BUCHANAN COUNTY, JUNE AND AUGUST 1978[z]

	Organic matter	pH	P	Soluble salts	Zn	NO_3	Moisture
pH	0.68	--	--	--	--	--	--
	0.006	--	--	--	--	--	--
Ca	0.61	0.70	--	--	--	--	--
	0.01	0.005	--	--	--	--	--
P	--	0.54	--	--	--	--	--
	--	0.04	--	--	--	--	--
Soluble salts	--	--	0.62	--	--	--	--
	--	--	0.01	--	--	--	--
Zn	--	--	--	-0.59	--	--	--
	--	--	--	0.02	--	--	--
Moisture	--	--	--	0.68	--	--	--
	--	--	--	0.006	--	--	--
Aggregate stability	--	--	--	-0.88	0.53	-0.52	-0.88
	--	--	--	0.0001	0.05	0.05	0.0001
Available moisture	--	--	--	--	--	0.59	--
	--	--	--	--	--	0.02	--

[z] Partial correlations with their corresponding level of significance.

TABLE A-11. COEFFICIENTS OF CORRELATION (R) AMONG SEVERAL MINESOIL CHARACTERISTICS AT THE 0-15 CM DEPTH - WISE COUNTY, JUNE AND AUGUST 1978[z]

	Ca	K	Soluble salts	NO_3	Moisture	Available moisture
pH	0.87	0.44	0.51	--	0.51	--
	0.0001	0.02	0.007	--	0.006	--
Ca	--	--	0.59	--	0.55	0.51
	--	--	0.001	--	0.003	0.006
P	--	--	-0.55	--	--	--
	--	--	0.003	--	--	--
K	--	--	--	0.39	--	--
	--	--	--	0.04	--	--
Moisture	--	--	--	--	--	0.66
	--	--	--	--	--	0.0002
Aggregate stability	--	--	--	--	--	-0.45
	--	--	--	--	--	0.01

[z] Partial correlations with their corresponding level of significance.

TABLE A-12. COEFFICIENTS OF CORRELATION (R) AMONG YIELD AND SEVERAL MINESOIL CHARACTERISTICS AT THE 0-15 CM DEPTH - BUCHANAN COUNTY, AUGUST 1978[z]

	Moisture	Available moisture	Bean yield	Squash yield	Sand
pH	--	--	-0.70	-0.73	--
	--	--	0.02	0.01	--
K	--	--	--	-0.76	--
	--	--	--	0.01	--
NO_3	-0.66	--	--	--	--
	0.03	--	--	--	--
Moisture	--	0.68	--	--	--
	--	0.02	--	--	--
Available moisture	--	--	--	--	-0.64
	--	--	--	--	0.04
Bean yield	--	--	--	0.85	--
	--	--	--	0.001	--

[z] Partial correlations with their corresponding level of significance.

TABLE A-13. COEFFICIENTS OF CORRELATION (R) AMONG YIELD AND SEVERAL MINE-SOIL CHARACTERISTICS AT THE 0-15 CM DEPTH - WISE COUNTY, AUGUST 1978[z]

	Moisture	Bean yield	8 a.m. mine soil temperature	3 p.m. mine soil temperature	9 p.m. mine soil temperature
Organic matter	-0.75 0.01	-- --	-- --	-- --	0.86 0.002
pH	0.73 0.02	0.73 0.02	-- --	-- --	-- --
K	-- --	0.69 0.03	-0.71 -0.03	-- --	-- --
Moisture	-- --	0.90 0.009	-- --	-- --	-0.79 0.01
Bean yield	-- --	-- --	-0.71 0.02	-- --	-- --
Squash yield	-- --	-- --	-- --	-0.69 0.03	-0.73 0.02

[z] Partial correlation with their corresponding level of significance.

TABLE A-14. COEFFICIENTS OF CORRELATION (R) FOR VARIOUS MINESOIL CHARACTERISTICS - BUCHANAN COUNTY, OCTOBER 1976 THROUGH APRIL 1978

	pH	Ca	P	K	SS	Zn	NO_3	Moisture	Available moisture
Time	.39	.29	.33	--	--	-.44	.40	--	.39
	.0001	.0008	.0001	--	--	.0001	.0008	--	.02
Sampling depth	.59	.44	.29	--	--	--	-.45	--	--
	.0001	.0001	.0007	--	--	--	.0001	--	--
P	--	--	--	.39	.23	-.39	--	--	--
	--	--	--	.0001	.01	.0003	--	--	--
K	--	--	--	--	.36	-.31	.59	--	--
	--	--	--	--	.0001	.005	.0001	--	--
Soluble salts	--	--	--	--	--	--	.61	--	--
	--	--	--	--	--	--	.0001	--	--
Zn	--	--	--	--	--	--	-.30	-.27	--
	--	--	--	--	--	--	.01	.02	--

(continued)

TABLE A-14. CONTINUED

	Rye yield	Soybean yield	Rye-AWP yield	Infiltration Rate 10 (min.)	30	60	90	Treatment
Time	--	--	--	.47	.46	.31	--	--
	--	--	--	.0007	.0017	.05	--	--
P	--	-.82	--	--	--	--	--	.28
	--	.0009	--	--	--	--	--	.001
Soluble salts	-.44	-.56	-.59	--	--	--	--	-.19
	.14	.05	.04	--	--	--	--	.03
Zn	--	--	--	--	--	--	--	-.25
	--	--	--	--	--	--	--	.02
NO_3	--	--	--	--	--	--	--	.27
	--	--	--	--	--	--	--	.02
Temp 1	--	--	--	-.77	-.76	-.70	-.66	-.85
	--	--	--	.0005	.0006	.002	.004	.0001
Rye-AWP yield	--	--	--	--	--	--	--	.71
	--	--	--	--	--	--	--	.008
Infiltration rates (minutes)								
10	--	--	--	--	--	--	--	.32
	--	--	--	--	--	--	--	.02
30	--	--	--	--	--	--	--	.29
	--	--	--	--	--	--	--	.06
60	--	--	--	--	--	--	--	.31
	--	--	--	--	--	--	--	.04
90	--	--	--	--	--	--	--	.42
	--	--	--	--	--	--	--	.01

TABLE A-15. COEFFICIENTS OF CORRELATION (R) FOR VARIOUS MINESOIL CHARACTERISTICS - WISE COUNTY, OCTOBER 1976 THROUGH APRIL 1978

	pH	Ca	P	K	Soluble salts	Zn	NO_3	Moisture
Time	0.47 0.0001	0.53 0.0001	0.19 0.02	0.52 0.0001	-- --	-0.56 0.0001	-- --	-- --
pH	-- --	0.81 0.0001	0.50 0.0001	0.62 0.0001	-0.33 0.0004	-0.63 0.0001	0.43 0.0004	-- --
Ca	-- --	-- --	0.40 0.0001	0.70 0.0001	-- --	-0.44 0.0001	0.31 0.01	-- --
P	-- --	-- --	-- --	0.30 0.0003	-0.26 0.005	-0.51 0.0001	0.26 0.04	-0.25 0.01
K	-- --	-- --	-- --	-- --	-- --	-0.38 0.0005	0.55 0.0001	0.20 0.04
Soluble salts	-- --	-- --	-- --	-- --	-- --	0.35 0.002	-- --	-- --
Zn	-- --	-- --	-- --	-- --	-- --	-- --	-- --	0.50 0.0001

(continued)

TABLE A-15. CONTINUED

	Aggregate stability	Soybean yield	Rye-Austrian winter pea yield	Infiltration rates (min.) 10	30	60	90	Depth of tillage
Time	0.41	--	--	--	--	--	--	--
	0.02	--	--	--	--	--	--	--
pH	0.41	--	0.69	--	--	--	--	--
	0.02	--	0.01	--	--	--	--	--
Ca	--	0.67	0.63	--	--	--	--	0.28
	--	0.01	0.02	--	--	--	--	0.0006
P	--	--	0.68	--	--	--	--	0.21
	--	--	0.01	--	--	--	--	0.01
Soluble	-0.46	0.68	--	--	--	--	--	--
salts	0.008	0.01	--	--	--	--	--	--
Zn	--	--	-0.64	-0.65	-0.59	-0.58	-0.57	-0.22
	--	--	0.02	0.006	0.01	0.01	0.02	0.05
NO_3	--	--	--	--	--	--	--	0.36
	--	--	--	--	--	--	--	0.003
Moisture	--	--	-0.68	--	--	--	--	--
	--	--	0.01	--	--	--	--	--
Aggregate	--	--	--	0.59	0.56	0.54	0.54	--
stability	--	--	--	0.01	0.02	0.03	0.03	--
Rye yield	--	--	--	--	--	--	--	-0.66
	--	--	--	--	--	--	--	0.02
Rye-Austrian winter pea yields	--	--	--	0.76	0.71	0.70	0.72	--
	--	--	--	0.004	0.009	0.01	0.006	--
Infiltration rates (min.)								
10	--	--	--	--	--	--	--	0.34
	--	--	--	--	--	--	--	0.01
30	--	--	--	--	--	--	--	0.33
	--	--	--	--	--	--	--	0.01
60	--	--	--	--	--	--	--	0.31
	--	--	--	--	--	--	--	0.03
90	--	--	--	--	--	--	--	0.28
	--	--	--	--	--	--	--	0.05

GLOSSARY

argillaceous rocks: A group of detrital sedimentary rocks, usually clays, marls, mudstones, and siltstones.

bedding, bedding plane: A bedding plane is a surface parallel to the surface of deposition, i.e., in shales the rock splits along planes which are bedding planes, whereas in sandstones, no plane of preferred splitting occurs, although the bedding planes may be marked by changes in color, grain size, etc.

detrital: Particles of rocks or minerals, which have been derived from pre-existing rock usually by weathering and/or erosion but as a result of stripmining in this case.

facies: The sum total of features like sedimentary rock type, mineral content, sedimentary structures, bedding characteristics, etc. which characterize a sediment as having been deposited in a particular environment.

partial correlation: The relation between two variables when one or more of the remaining variables are held constant.

total or simple correlation: The linear correlation between any pair of variables, disregarding the values of the remaining variables.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

During two years the effects of various green manure crops and tillage regimes on an acid coal minesoil and a calcareous coal minesoil were analylzed with respect to a number of their physical, chemical, and biological properties. Prior to initiation of the experiments, the acid minesoil had a poor cover of sericea lespedeza and KY-31 fescue whereas the calcareous minesoil had an excellent cover.

Increased depth of tillage and incorporation of green manure crops plus lime additions (acid minesoil) tended to enhance minesoil productivity by improving some of the physical and chemical characteristics of these reclaimed surface-mined areas. It appeared that water infiltration was, directly or indirectly, the most influential factor affecting plant growth and minesoil properties. Increased infiltration rates as a result of the treatments tended to promote the following: reduce runoff (not measured but visually apparent); increase moisture content of the profiles; reduce soluble salt concentrations in the major rooting zones by moving them deeper into the profile; reduce minesoil temperature; increase actual amount of water available to plants; enhance rock weathering by increasing water and parent material contact; increase crop yield; add more organic matter and NO_3; and reduce soluble Zn.

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