PLANT EXTRACTION OF PHOSPHORUS AND POTASSIUM FROM RECLAIMED STRIP-MINED SOILS IN KANSAS

by

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INTRODUCTION

The devastation caused by strip-mining renders the land largely useless for agricultural production without extensive restoration. The increasing need for food and fiber coupled with the unsightliness of strip mines makes it imperative that these areas be restored to a productive and/or aesthetic state. The increased need for coal due to the expanding energy requirements and shrinking petroleum reserves means more strip-mine reclamation will be necessary in the future.

Strip-mined land can be detrimental to the environment besides being unproductive. The lack of vegetation allows erosion (28) which impedes the soil forming process and allows sediments and, in some cases, sulfuric acid (33) to enter the waterways. The unproductivity of the area also leads to a devaluation of the land and can seriously deprive local governments of tax revenue.

Recent statistics show that surface mining of coal is increasing and that 3.2 million acres had been disturbed by surface mining as of January 1, 1965 and that two-thirds of this needed "remedial attention" (21).

In Kansas, 45,000 acres of land was stripped for coal prior to January 1, 1969 when the Mined-Land Conservation and Reclamation Act went into effect. This law requires the coal companies to level and revegetate any land stripped after January 1, 1969 (3).

A review of prior work on spoilbank reclamation shows that most of the investigations centered on physical and chemical characteristics detrimental to revegetation. Because it has been fairly well established that most releveled Kansas spoilbanks can be revegetated, it is of primary importance that the potassium and phosphorus release characteristics of these materials be determined under intensive cropping conditions.

A greenhouse study was initiated in the fall of 1972 to determine the P and K availability from the spoil material and to correlate spoil material and soil test results with present interpretation for normal soils of the area. The study was carried out in the greenhouse to eliminate weather and environmental variables.

The investigation was set up with two objectives: 1) to compare spoil material and adjacent native soils for P and K release characteristics under intensive cropping conditions, and 2) to determine if conventional soil test techniques accurately measure the plant-available P and K in the spoil material.

LITERATURE REVIEW

Coal Strip-Mining in the United States and Kansas

Surface mining is a very important source of crude metallic and non-metallic ores in the United States. In 1969, 2.45 billion tons of crude ore was mined from surface mines compared with 165 million tons from underground mines. Surface mining of coal jumped from 38 percent of the total coal mined in 1969 to 44 percent in 1970 and accounted for approximately 41 percent of all strip-mining. Indications are that coal will be of major importance in meeting the nations energy requirements for the next 30 years. Federal officials have taken action to develop an accelerated program of coal gasification. After the year 2000 estimates are that fossil sources of energy will decline in importance (21).

Coal mining in the United States occurs in six coal provinces. Mineable coal in Kansas occurs in the western region of the Interior Coal Province and includes the counties of Labette, Cherokee, Crawford, and Bourbon (32).

The coal in these counties lies in the Cherokee group of sedimentary rocks. The Cherokee group of rocks was formed during the Pennsylvanian period and lies within the Desmoinesian Series (Middle Pennsylvanian) and has two subgroups, the Krebs and Cabaniss. The Cabaniss subgroup lies above the Krebs subgroup and contains most of the mineable coal beds in Kansas (12).

Within the sedimentary rocks are formations which extend from the top of a given coal bed to the top of the next higher coal bed and are cyclic successions. Each of these is made up of lithologic units. There are five of these units common in the Cherokee formation and include, from the base upward: dark shale and dark irregular limestone, gray shale, underlimestone and sandstone, underclay, and bituminous coal (12).

The most predominant clay minerals in the underclays are illite, mixed-later illite-montmorillonite, kaolinite and chlorite. The common nonclay minerals are quartz, calcite, feldspars and pyrite. There are no differences in the mineral assemblages between underclays and the associated lithotypes, but the relative abundance of the individual minerals varies (30).

Strip mining of coal has disturbed 50,000 acres of land in Kansas. Of this, approximately 45,000 acres was mined prior to January 1, 1969 when the Mined Land Conservation and Reclamation Act went into effect which required coal companies to level and revegetate the land after mining. Many of the old spoilbanks have remained unproductive (3).

Spoilbank Characteristics

Coal strip-mining in the United States is currently done by large revolving shovels or draglines. The coal is exposed by stripping the overburden from the coal seam and depositing it to the side. This results in pits 50-90 feet wide, 40 feet deep or deeper and up to a mile long. With the first cut the overburden is placed on the soil surface next to the pit. In subsequent passes the overburden is placed in the preceding pit. The last pass leaves an open pit. The resulting spoilbanks are long parallel ridges with steep banks.

After the mining operation, the spoil is a hetergeneous mass whose physical and chemical properties are dominated by the character of geologic strata overlying the coal (11). The chemical characteristics are largely determined by the particles smaller than 2 mm because of their large surface area.

The chemical property most detrimental to plant growth in many cases is high acidity. Acidic conditions develop through the oxidation of certain sulfur compunds such as pyrite, markasite, and polysulfides. These materials may be neutral to alkaline when freshly exposed and will develop maximum acidity in about 6 months of weathering (7).

The acidity of spoilbanks varies between regions. In Iowa (7), 38 percent of the spoil material has a pH of less than 4.0, 35 percent from pH 4.0 to 7.0 and 27 percent above pH 7.0. In Illinois (11), only 5.4 percent of the spoilbanks have a pH of less than 4.0, while 21.7 percent are from pH 4.1 to 6.9, and 72.9 percent have a pH of 7.0 or greater. In Kansas[1] only 2.6 percent of the spoils are below pH 4.0, 7.7 percent are from pH 4.0 to 5.0, 60.1 percent from pH 5.0 to 7.0 and 29.6 percent have a pH of 7.0 or greater.

Not only does the pH vary between regions, but it also varies within a given area. This is primarily due to the particular formation being exposed to the surface and on the lithologic unit within the formation. In Ohio, while testing spoil material from different locations in the highwall, it was found that the layers located near the coal seam are the most acidic and are shales (27).

The toxic effect of spoils may not be due to acidity alone. Other minerals in the spoilbanks are dissolved and the spoil material becomes toxic because of high soluble salt concentrations and/or toxic levels of elements such as aluminum, iron, manganese, nickel, copper, and zinc (33).

Soluble salt problems may develop when spoil materials are exposed to the atmosphere (26). This usually is at a peak the first year and then diminishes gradually. The Ohio study showed that five very acid toxic

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[1] Unpublished data, Dr. David Whitney, Agronomy Dept., Kansas State University.

spoils produced an average of 60 tons of salts per acre the first year and that one of them yielded 130 tons. Fourteen nontoxic spoils yielded an average of 5 tons per acre with the highest being 10 tons.

Chemical weathering studies of Ohio spoils were carried out using plastic lysimeters. On nontoxic spoils, calcium was the major cation component of the leachate, exceeding magnesium and other cations, while aluminum, manganese and iron were relatively minor constituents. In contrast, the toxic spoil magnesium content exceeded calcium with potassium being relatively low. Iron, aluminum and manganese also formed a considerable portion of the cations. Upon continued weathering calcium showed evidence of steady depletion under the acid conditions while a concomitant increase in the production of iron and aluminum occurred. These were the characteristic cation differences between toxic and nontoxic spoils (24).

In Kentucky it was found that on some spoils, magnesium was much more abundant than calcium and that this imbalance could cause a reduction in plant growth (5).

Spoils vary tremendously in their plant available nutrient contents. The concentration of a given nutrient depends on the mining region and may be highly variable within a small area. Spoils have been found to range from very low to high in available phosphorus and high in extractable potassium (11). Nitrogen is usually low in spoils, however, there are some unusual cases where large amounts of nitrogen occur (7).

Reclamation Research

Revegetation is probably the most important phase of strip-mine reclamation. Most research has concentrated on some area of revegetation. Revegetation is decidedly important because it helps overcome many of the unfavorable characteristics of spoilbanks.

One of the most significant contributions of plant cover is the stabilization of the spoilbank against erosion and the reduction in runoff. Erosion adversely affects reclamation by washing away developing soil and causing sediments and toxic materials, such as sulfuric acid, to be washed into streams. Annually more than 2 million tons of sulfuric acid is washed into the Nation's streams from coal strip-mines. The reduction in runoff and increased infiltration by plant covered spoils also accelerates the leaching of soluble salts from the spoil material (33).

The most critical barrier to plant establishment and growth in most cases is pH levels lower than 4.0 and the concomitant toxic concentration of certain elements. A vast number of studies have been conducted on acidic spoilbanks where attempts have been made to overcome the acid conditions.

Studies on West Virginia spoils showed that lime was the primary material necessary for plant establishment when the pH was below 3.5 (33). Iowa studies (7) on toxic gray shales with an initial pH of 2.5 found that 21.0 tons of lime per acre raised the pH to 7.4 in 30 days but that the pH dropped to 5.2 after 8 months. The pH was raised to 4.5 in ten days by 10 tons of lime but declined to less than 3.0 after 5 months.

An extensive spoil material-lime study was carried out in Ohio (27). Samples from different highwall strata and releveled areas were tested in the greenhouse. It was found that there was a difference in acid producing potential between the samples and that pH decreased with time after an initial high point. One sample became toxic within 2 years after 42 tons of lime per acre had been applied. It was concluded that plants would grow if the pH was maintained above 4.0 and that additional liming would be necessary to neutralize the further oxidation of pyrite.

The results were then tested in the field. A releveled toxic spoil area with an initial pH of 3.2 to 3.7 was used and a split application of lime at the rate of 18.5 and 12.5 tons per acre was applied in May and October, respectively. The lime was incorporated 6 to 8 inches. The following spring the pH values were from 4.8 to 5.2 and the area was seeded. Plants grew over the entire area but there was a high rate of seedling mortality in the more acid areas. By mid-summer barren areas had developed. These areas had an average pH of 2.47 while the vegetated areas had an average pH of 5.07. The pH of the top 3 inches was 3.6 while the 3 to 6-inch depth was 2.4. It was concluded that the pH of the surface was affected by acid being transported toward the surface by capillary movement of water. It was also decided that 3.7 tons of lime per acre-inch of spoil must be applied to neutralize most of the acid in some areas and that the lime would need to be mixed 15 to 20 inches into the spoils (27).

Incubation studies (11) in Illinois on toxic shales with an initial pH of 2.3 showed that 60 tons of lime per acre was required to bring the pH to neutral. The high reactivity of this sample was due to its fine texture. Of the 2 mm fraction, 64 percent of the particles were less than .002 mm in size.

The texture of the spoil material has been found to influence plant growth. On neutral spoils the yield increased as the texture became finer. This was due to the increased availability of nutrients and the increased water holding capacity in these samples. On samples with pH values near 4.0, the yield decreased as the texture became finer. The decrease in yield was due to toxic levels of aluminum and manganese caused by the high acidity. The greater surface area of the finer textured samples caused these elements to become available in toxic quantities. In no case did the low pH samples out yield the high pH samples (34).

A long-term tree growth study on spoils in Kansas showed that the pH had increased over a 20 year period. From 1947 to 1967 average pH had increased from 5.6 to 6.1, however, some acid spots still remained. In most areas acid formation had ceased but the breakdown of basic materials was continuing so pH increased. Plant-material decay also helped ameliorate toxic pH conditions.

Other materials besides lime have been used to overcome acid conditions. One of these materials has been fly ash, the electrically precipitated by-product of burning pulverized coal.

A greenhouse experiment was carried out at Kansas State to determine the effect of fly ash on spoil pH (18). The fly ash had an initial pH of 7.7 and was used at rates up to 800 tons per acre. A lime treatment was included at the rate recommended by soil test. Three spoil samples were used with initial pH's of 3.1, 4.8, and 6.3. A preliminary investigation showed that the fly ash used in this study had a neutralizing capacity 1.5 percent as effective as pure calcium carbonate. The neutralizing effect of the fly ash and lime were found to occur quite rapidly. Emergence of oats on the pots was good on all the treatments except the control and low fly ash rates on the toxic spoil (pH 3.1). The seedlings grew on all pots except the ones where the pH remained below 4.0. Fly ash applications increased yields on all pots and the highest application rate exceeded the lime treatment indicating the fly ash contributed some beneficial physical or chemical effect on the spoil material other than neutralizing acid. The 800 ton rate of fly ash was sufficient to bring the pH to neutrality on the two nontoxic spoils but only raised the pH to about 5.0 on the toxic sample.

A field study in Kansas conducted by the State Geological Survey (15) also showed that fly ash can be used to raise the pH without any adverse effects on plant growth. Fly ash with an initial pH of greater than 9.0 was used at 132 tons per acre and lime was used at 17.4 tons per acre. The fly ash raised the pH more than the lime in most cases and under adequate rainfall conditions fescue growth was better on spoils treated with fly ash than with lime.

A field study in West Virginia (8) also showed that fly ash can be used to raise the pH of acid spoils. Three hundred and 600 tons per acre of fly ash was compared to 8 tons per acre of lime. The 600 ton per acre fly ash treatment was superior to lime which was superior to 300 tons per acre of fly ash. The advantage of the 600 ton rate of fly ash was attributed to its faster neutralization.

Other attempts at ameliorating toxic acid conditions have included the use of digested sewage sludge (19). The sludge was compared to lime and it was found that the sludge produced a more vigorous growth while improving subsurface drainage water quality. It was found that 200 to 250 dry tons of sludge per acre should be used. A laboratory study showed that sludge can raise the leachate pH while reducing total acidity, soluble salt content and soluble aluminum and iron concentrations in the spoil material.

Studies in Ohio (28,29) compared cattle manure, sewage sludge, top soil additions and mulch on toxic acid spoils. Where sewage sludge was applied or cattle manure accumulated in a feeding area, excellent plant growth was obtained. It was observed that the plant roots were confined to the zone of mixing of the material and that it would be desirable to mix the material to a depth of 12 inches or more to provide for greater root penetration. Where spoils were covered with soil from 0 to 10 inches in 2-inch increments it was found that no plants grew in the 2-inch depth and that the roots would not penetrate into the acid spoils. Mulch, along with 3.5 tons of line, was found to increase the growth of wheat on a spoil with a pH of 2.2 to 2.6. Mulch slows evaporation and maintains the spoil in a moist condition thus reducing the concentration of acid and salt in solution associated with dry spoils. The mulch also increased infiltration which is very slow on spoilbanks, especially on the highly acid areas.

Many cultural as well as soil fertility studies have been conducted on toxic as well as nontoxic spoils. Most of these studies center on methods for achieving maximum leaching of salts from the spoils and on increasing the fertility of the spoilbanks.

One of the methods that has been tried is grading for maximum water retention (20). On a flat topography a furrowed spoil surface was compared to a smooth graded surface with respect to tree survival and growth. The ravines, slopes, and ridges within the furrowed plots were also compared. It was found that plant survival, growth and reproduction were significantly better in the ravine sites than on the slope, ridge, or smooth-graded surface sites. Analyses revealed a higher pH, lower levels of soluble salts, and generally higher levels of manganese, copper, and zinc for the ravine sites than for the ridge and smooth surface sites. Calcium, magnesium, and potassium were present in greater amounts in the ridge sites than in the ravines. The furrowed plots were much improved over the smooth areas by creating a surface conducive to rainfall retention and infiltration. It has also been determined that the leaching of salts, particularly acid producing salts, is the primary asset for plant survival (26). For maximum benefit, it is necessary that the entire topography be aimed at rainfall retention and absorption.

Grading for maximum water retention enhances the two basic soil forming processes: spoil weathering and spoil modification by biological action. These processes can take place only if the surface remains intact and is not swept away by erosion, showing the importance of good ground cover (25).

The use of fly ash to supply nutrients and improve the physical characteristics of spoilbanks has been investigated. In a study to determine the soil-making potential of fly ash on spoilbanks it was determined that heavy applications could be used as a source of boron. The spoil-fly ash mixture was also lower in bulk density with a greater pore volume, greater moisture availability and higher air capacity (4).

Digested sewage sludge applications on spoilbanks increased water holding capacity and tilth. During a leaching experiment the sludge treated spoil material absorbed water much faster than the untreated material. This was attributed to the aggregation caused by the sludge additions. Sludge has also been found to overcome alkalinity as well as acid problems in spoils and has been used to upgrade large acreages of calcareous coal-mine spoils in Illinois. The superior growth on sludge treated spoils is partly due to the high nitrogen content of the sludge (19).

The use of mulch has proven beneficial for establishing grass cover (33). The spoil material loses moisture fast near the surface and forms a hard crust nearly impossible for young plants to break through. Other investigators (28) also obtained superior plant growth where a mulch was applied. Straw at 2,464 kilograms per hectare was found to give seedlings better protection from the weather and increased moisture retention.

In Wyoming where the rainfall is less than 10 inches per year some type of spoil protection was determined essential for plant establishment (14). Several methods of protection were investigated and included: mulch, for moisture conservation; jute net, for spoil stabilization; and snowfence, to hold snow for moisture. It was found that each of the treatments were superior to the control but for best results a combination of the treatments was best.

An organic mulch consisting of 5 parts decomposed hardwood sawdust, 5 parts decomposed barnyard manure and 1.5 parts F, H, and A horizon soil from a conifer forest was used to establish conifer seedling on spoils with a pH as low as 3.2. One pint of the mixture was applied to the root zone. The survival was much better where the organic matter was used. Unsterile organic matter proved to be superior to sterile organic matter, probably because of the microbes present (17).

Grading has been found to have an effect on the chemical properties of the spoils. On an Illinois spoil grading increased the phosphorus soil test an average of 40 pounds per acre by exposing fresh material. Available potassium was increased, on the average, by the same amount. Grading had no effect on pH. In some cases grading is used to revitalize spoils after nutrients are depleted by crops (11).

Many species evaluations have been carried out on spoilbanks. In many cases the species that are most productive on farm land have proven best for spoilbank use. Of particular importance though, is the use of a legume in a forage mixture. Legumes supply nitrogen which is critically short in most spoil materials (23).

Some attempts have been made to establish forages to provide ground cover while tree seedlings become established. Treatments of trees alone, trees plus grass, and trees plus a grass-legume mixture showed that after three years the herbaceous vegetation had no effect on tree survival but greatly suppressed tree growth. However, in the fourth and fifth seasons, the growth of trees in the plots dominated by the legumes exceeded the growth in plots with grass only and without herbaceous competition. Tree growth was suppressed the most by a cover of grass alone. It was assumed that the legumes were supplying nitrogen for the trees (35).

From the standpoint of vegetative cover, forage and tree mixtures were found to be superior after 15 years of research in another study (25). No competition occurred on new rocky spoils between the forages and tree seedlings. As the trees grew they provided shade to the grasses and legumes. With this protection the forage cover became heavy enough to promote the change of weathered rock into soil.

Soil fertility research shows that spoilbanks lack the A_1 horizon which is rich in organic matter and nitrogen (7). However, the first limiting nutrient varies depending on the source of spoil. In Iowa in a greenhouse study phosphorus was found to be the first limiting nutrient on a limed toxic spoil sample, while nitrogen was first limiting on a neutral gray shale.

In a study to determine fertility requirements on a nontoxic releveled spoilbank at Cokles Farm in Northumberland, it was found that if optimum fertilizer treatments were used yield levels were much the same as before mining (13). However, the level and balance of this optimum treatment was very different from that required on undisturbed land. The first year nitrogen gave no increase in yield, however it became increasingly important the second and third year. After the third year nitrogen proved to be the critical nutritional factor in almost every experiment. It was found that with adequate nitrogen soil fertility was steadily built up to a level equal to undisturbed soil. The amounts of phosphorus and potassium required differed little from those prior to mining.

The acidity of spoilbanks can be used to create soluble phosphorus on a slowly available basis from rock phosphate (33). Along with supplying phosphorus, rock phosphate supplies calcium and other elements which may be limiting in spoils.

On mountain spoils nitrogen and phosphorus were found to be insufficiently available to support vigorous growth of planted loblolly pine seedlings. With an application of nitrogen and phosphorus, direct seeded trees grew very well, but did not produce cover fast enough to retard gully erosion. Therefore, the effect of fertilizer was tested on pine-grass mixtures. Where pine was seeded alone, fertilizer treatments had no effect on seedling germination and survival through the first growing season. With the mixture, tree seedling survival was reduced more from grass competition on the unfertilized plots than on the fertilized plots. Pine seedling growth the first year increased as fertilizer rates increased. Frost-heaving affected many pine seedlings on the unfertilized plots but few were lost on the fertilized plots. By the second growing season the trees showed a very high response to the fertilizer (1).

Not all spoil materials have inadequate supplies of plant nutrients. On some of the spoil banks in Illinois, nutrients are present in amounts in excess of those found on surrounding undisturbed land (36). Thousands of acres of legume-grass pastures and hay fields have been established without the benefit of lime or fertilizer. One pasture has been in use for 33 years. In some cases, when renovation becomes necessary, regrading of the ungraded or partially graded pasture is one procedure that is used. This method, in effect, opens up a new supply of nutrients.

A study to evaluate the commercial timber-producing potential of coal-mined land in Kansas was carried out between 1947 and 1967 (10). There were considerable spoil changes over the 20 year period. The portion of soil sized particles increased 8 percent to 46.9 percent. Available phosphorus decreased from 74.5 to 53.5 ppm but was still higher than is common in most forest soils. The average potassium content increased from 86.7 to 96.4 ppm. These analyses were averaged over 61 sample locations and there was a high amount of variability between locations. It was also determined the tree performance was better on older spoils and that tree growth was best on unleveled spoils. Leveling compacted the spoils which resulted in adverse physical characteristics for tree growth.

The long term productivity of reclaimed spoilbanks can not be immediately determined. To gain insight into what reclaimed spoilbanks would be like after a century, researchers in West Virginia evaluated 70 to 130 year old spoils of surface-mined iron ore (22). An extensive survey of the physical and chemical properties was carried out and compared with adjacent undisturbed soils. The results show that the spoils are capable of supporting plants but that 70 to 130 years is not sufficient time for a soil to develop that is similar to adjacent undisturbed areas. Briefly, some of the specific findings and comparisons are as follows. The bulk density was found to be 1.47 on the spoils and 1.03 on adjacent soils. The porosity of the spoil material was found to be lower. A higher percentage of coarse particles was found in the spoils compared to the soils. Nitrogen accumulated at rates up to 100 pounds per acre per year and was almost as high in the spoils as in the local soils. In areas where legume-grass pastures were planted and cattle were grazed and fed, the nitrogen content was similar to local soils. The pH ranges were found to be similar to adjacent soils and it was found that long-time soil forming processes do not change soil horizon pH appreciably. The top inch of natural soils had a higher exchange capacity than spoils, however, at 4-5 inches the exchange capacity, bases and base saturation for natural soil horizons were lower than for the top six inches of spoil. Infiltration rate was higher on soils than on spoils. Comparisons of nutrient concentrations in plants showed that leaf phosphorus content was higher on spoil grown plants while nitrogen was lower. Root penetration was found to be much deeper on the spoils because of shallow shale beds in the soil. Forest site quality ratings showed that there were no consistent differences between soils and spoils. Pasture ratings showed the same results, however, it was determined that cattle preferred to graze on spoil pastures.

Experiments with advanced technology in the area of aerial and orbital sensing have been carried out in conjunction with strip-mine reclamation (6). This type of remote sensing could provide data useful for inventorying the location and acreage of mined land, planning reclamation of an area to be surface mined, evaluating the environmental impact of mining, and monitoring the success of mined land revegetation.

The Earth Resources Technology Satellite is proving of value in that seasonal changes enhance the identification of vegetative and moisture variations useful for categorizing the relative stages of reclamation. Because tonal character of the mined land changes with changes in vegetative cover, gross estimates can be made of the amount of revegetation. Also, contrasts in water color due to iron oxide discoloration associated with acid mine drainage have been identified and may contribute to monitoring for changes in water quality in large ponds and lakes.

High altitude aerial photography is also useful and can be used to distinguish revegetation efforts in more detail. Grass cover can be identified from tree cover and estimates of plant cover versus bare ground can be made. Heavy stream sedimentation, high turbidity, and iron oxide discoloration in water can be identified in streams and ponds over 30 feet across.

With low altitude photography more resolution can be obtained. Color infared photography makes possible the identification of vegetative types, species, percent cover and condition of vegetation.

This type of remote sensing is thought to be particularly useful for providing government and mining officials information for meeting reclamation objectives.

MATERIALS AND METHODS

Greenhouse Procedures

Four spoilbank samples and two virgin soil samples were collected from the coal mining area of southeastern Kansas (Table 1). Spoil sample number one is overburden from the Weir-Pittsburg coal. This sample was stratigraphically the lowest of the samples collected. Spoil sample number three was associated with the Mulky coal which is near the top of the Cherokee group of sedimentary rocks. Samples five and six are from the Lagondia formation which is associated to the Bevier coal. This group is in the upper one-third of the Cherokee group.[1] Soil samples two and four came from undisturbed native grass areas and are both Cherokee silt loams. Samples number one and three originated adjacent to samples number two and four, respectively.

The soil samples were dried in a forced air dryer at 60°C for one week. Grinding of the soil was accomplished with a soil shredder which was effective in breaking up soft shale and aggregates but was uneffective against unweathered rocks. The predominance of shale in the spoil samples resulted in a platy textured material. The samples were screened with a seive that had three mm by 10 mm rectangular openings to allow the thin platy particles to pass through but not the unweathered rock fragments.

Number ten cans lined with polyethene bags were used as pots. Silica sand (2.29 Kg) was placed in the bottom of each pot. The sand was used to increase the surface to volume ratio of the soil. A thin layer of soil was used to obtain maximum plant extraction of P and K. Supplemental nutrients were added to the sand layer (Table 2).

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[1] Identification of shale samples supplied by Dr. Henry Beck, Department of Geology, Kansas State University.

Table 1

CHEMICAL PROPERTIES OF SPOIL AND SOIL SAMPLES USED IN THE GREENHOUSE EXPERIMENT.

Sample No.	Description	Sample pH	Lime Requirement kg/ha ECC	Available Phosphorus ppm	Exchangeable Potassium ppm	Location
1	Spoil	5.0	8400	1.5	121.5	Sec. 5 T32, R24E
2	Virgin Soil	5.1	4480	4.0	109.0	Sec. 5 T32, R24E
3	Spoil	7.4		8.5	137.5	Sec. 26 T32, R22E
4	Virgin Soil	6.8		3.5	160.0	Sec. 26 T32, R22E
5	Spoil	7.2		14.0	113.5	Sec. 15 T29, R25E
6	Spoil	7.6		5.0	181.5	Sec. 30 T30, R23E

Table 2

PHOSPHORUS, POTASSIUM AND LIME RATES AND COMBINATIONS USED IN THE GREENHOUSE STUDY.

	Primary Nutrients	
Treatment No.	P[1/] ppm	K[2/] ppm
1	0	80
2	20	80
3	40	80
4	80	80
5	80	0
6	80	40
7	80	80
8	80	160
1-Lime[3/]	0	80
3-Lime	40	80
5-Lime	80	0
7-Lime	80	80

	Supplemental Nutrients added to each Pot	
Element	Rate ppm	Source
Mg	25.0	$MgSO_4$
Zn	8.0	$ZnSO_4$
Fe	5.0	FeEDDHA
B	1.0	$Na_2B_4O_7 \cdot 10H_2O$
S	49.3	$MgSO_4$, $ZnSO_4$
N[4/]	100.0	$(NH_2)_2CO$

1/ $NH_4H_2PO_4$

2/ KCl

3/ 8400 and 4480 kg/ha ECC on soil 1 and 2, respectively

4/ Added after each harvest

One kilogram samples of the appropriate soils were weighed out and placed in polyethene bags. The dry fertilizer, which included combinations of nitrogen, potassium, and lime was added to the soil and the sample thoroughly mixed to incorporate the fertilizer material. Then the soil was formed into a thin layer on the bottom of the mixing bag and the phosphorus fertilizer solution added. Each phosphorus addition included 12.5 microcurries of ^{32}P to aid in determining fertilizer phosphorus uptake. The bags were mixed again to mix the phosphorus fertilizer. During the mixing operation the bags were sealed to eliminate any leakage of the radioactive material. The soils were then added to the pots. Phosphorus, potassium, and lime treatment combinations are listed in Table 2.

Perennial ryegrass (Lolium perenne) was seeded on the surface of each pot and covered with 457 grams of silica sand. The pots were arranged in a completely random design with three replications. Supplemental light was supplied with six-200 watt incandescent light bulbs on a light period from 6 a.m. to 8 p.m. Minimum temperature was set at 20°C. Maximum temperature was set at 30°C, however, temperatures exceeded this during hot, sunny days. The study was initiated on October 6, 1972 and terminated on April 30, 1973.

The moisture holding capacity was determined for the soils and sand. The moisture content of the pots was maintained near field capacity by weighing the pots. Clippings were taken from the pots on November 13, December 18, January 25, March 12, and April 30. After the first and second harvests, small core soil samples were collected for phosphorus and potassium analyses. At the termination of the study, the soils were analyzed for phosphorus, potassium, and pH.

Analytical Procedures

The plant clippings were dried in a forced air dryer for four days at

60° C. The dried samples were weighed for yield then ground through a 2 mm screen. Five hundred milligram samples of the plant tissue were dry ashed in a muffle furnace at 200° C for one hour and then at 475° C for 2.5 hours. The ashed samples were taken up in 10 ml 0.1 N HCl. The beakers were warmed and allowed to stand for six hours and then filtered through #42 Whatman filter paper into 25 ml volumetric flasks and brought to volume with 0.1 N HCl. Aliquots of the extractant were then used in subsequent phosphorus and potassium analyses.

The first two harvests were analyzed for ^{32}P activity. A counting solution of 800 ml toluene, 200 ml Triton X counting solution and five g of PPO (2, 5-diphenyloxazole) was used.[2] On the first harvest 10 ml of the counting solution and 0.5 ml of the sample solution was used. On the second harvest 20 ml of the counting solution and 0.9 ml of the counting solution was used. The short half-life of the ^{32}P resulted in a low activity by the second harvest making the larger volume desirable by increasing counting accuracy. A Beckman LS-200B liquid scintillation system was used for counting. A two minute and five minute counting time was used for the first and second harvests, respectively.

The results were used to calculate the percent phosphorus in the plant that came from the fertilizer and to determine an available phosphorus index for the soil (16). The equations used were:

$$\% \text{ P in the plant from the fertilizer} = (C/C_o)100$$
$$\text{Available soil P index} = (C_o/C - 1)X$$

where

C_o = counts per minute per mg P in the fertilizer
C^o = counts per minute per mg P in the plant
X = mg P added to the soil.

[2] Procedure supplied by Dr. Herbert Moser, Department of Chemistry, Kansas State University.

Phosphorus concentrations were determined by the vanadate-molybdate precedure. A ml aliquot of the sample solution was mixed with 10 ml of the ammonium molybdate-vanadate solution in a 50 ml volumetric flask. The mixture was diluted to volume with deionized water and mixed again. After 30 minutes the samples were read on a Beckman DB spectrophotometer at 440 mμ. Potassium concentrations were determined by diluting 1 ml aliquots of the sample to 11 ml with deionized water and read on a Perkin-Elmer 146 flame photometer.

Phosphorus was extracted from the soil samples with Bray's No. 1 extracting solution (.025 N HCl and .03 N NH_4F). Color was developed by the sulfonic acid reduction method and read on a model 6C Coleman spectrophotometer at 660 mμ. Potassium was extracted from the soil with 1.0 N $NH_4C_2H_3O_2$ adjusted to pH 7.0. The extracts were read on a model 146 Perkin-Elmer flame photometer. pH's were determined using a 1:1 soil-water paste with a standard glass electrode pH meter.

Kansas State University's IBM 360 computer system was used for statistical analyses on all data and for plotting of all figures. All data was subjected to analysis of variance procedures.

RESULTS AND DISCUSSION

The experiment was designed to evaluate phosphorus, potassium, and lime application effects on six soil materials. The lime treatments were included only on soils 1 and 2 because of their low pH's. Radioactive phosphorus was used to aid in phosphorus uptake analysis. Measurements of radioactivity in the plant were taken on harvests 1 and 2 only because of the short half-life of ^{32}P. Yields were not taken on 4th harvest samples.

Dry matter yields as affected by phosphorus and potassium treatments and soil source are shown in Figures 1 and 6. The affect of phosphorus on plant phosphorus concentration, percent plant phosphorus that originated from the fertilizer and the available soil phosphorus index are represented in Figures 2 through 4. Plant potassium concentration as affected by potassium treatment is given in Figure 8. Analyses of available soil phosphorus and potassium as affected by phosphorus and potassium treatment, respectively, are presented in Figures 5 and 9. Appendix Tables I through XVI contain all detailed data and include the results of lime treatments. Tables 3 through 18 report all analyses of variance.

Results of Phosphorus Fertilization

Analyses of variance for dry matter yield as affected by phosphorus treatment and soil source are listed in Table 3. The dry matter yields are shown in Figure 1 and Appendix Tables I through IV.

Harvest 1 yields on the virgin soils (2 and 4) responded dramatically to phosphorus additions and exceeded all other soils in yield with the 20, 40, and 80 ppm phosphorus treatments (Figure 1). Only one spoilbank soil (1) responded to phosphorus fertilization. Smaller differences due to soil occurred at harvest 2 and 3, but by harvest 5 there were large yield differences between the soils, however, response to phosphorus fertilization was

Table 3

ANALYSES OF VARIANCE OF YIELD, PLANT PHOSPHORUS CONCENTRATION (%P), PLANT PHOSPHORUS UPTAKE, PLANT POTASSIUM CONCENTRATION (%K) AND PLANT POTASSIUM UPTAKE AS AFFECTED BY PHOSPHORUS TREATMENTS AND SOIL SOURCE.

Source	df	Yield Mean Squares	%P Mean Squares	P uptake Mean Squares	%K Mean Squares	K uptake Mean Squares
Harvest 1						
Soil (S)	5	4279567 **	0.00399 *	37.777 **	3.05727 **	3992.90 **
P level (P)	3	2620395 **	0.06740 **	108.373 **	0.91660 **	2488.50 **
S X P	15	373914 **	0.00662 **	11.137 **	0.29576 *	482.78 **
Error	48	37456	0.00119	0.915	0.12492	141.11
Harvest 2						
Soil (S)	5	1478381 **	0.01063 **	17.4700 **	6.40849 **	2594.19 **
P level (P)	3	893167 **	0.06492 **	36.9279 **	5.81179 **	128.80 **
S X P	15	195020 **	0.01211 **	6.9742 **	0.35239 **	116.21 **
Error	48	26763	0.00245	0.0673	0.05591	33.19
Harvest 3						
Soil (S)	5	878912 **	0.01063 **	9.7465 **	4.28830 **	3165.93 **
P level (P)	3	1428677 **	0.03092 **	24.3446 **	1.08440 **	131.46 ns
S X P	15	202510 **	0.00157 **	1.3557 **	0.39892 **	44.46 ns
Error	48	29780	0.00019	0.0465	0.06749	47.94
Harvest 4						
Soil (S)	5	Yields were not	0.00398 **		3.54762 **	
P level (P)	3	taken on harvest	0.01075 **		1.09214 **	
S X P	15	4 samples.	0.00128 **		0.23214 **	
Error	48		0.00008		0.05987	
Harvest 5						
Soil (S)	5	5497754 **	0.00369 **	11.3518 **	7.58677 **	10520.34 **
P level (P)	3	2221332 **	0.01075 **	14.9772 **	0.88782 **	133.34 ns
S X P	15	329347	0.00084 **	0.6885 **	0.45741 **	147.35 **
Error	48	132173	0.00005	0.1518	0.02393	56.57

* Sig. at .05 level. ** Sig. at .01 level.

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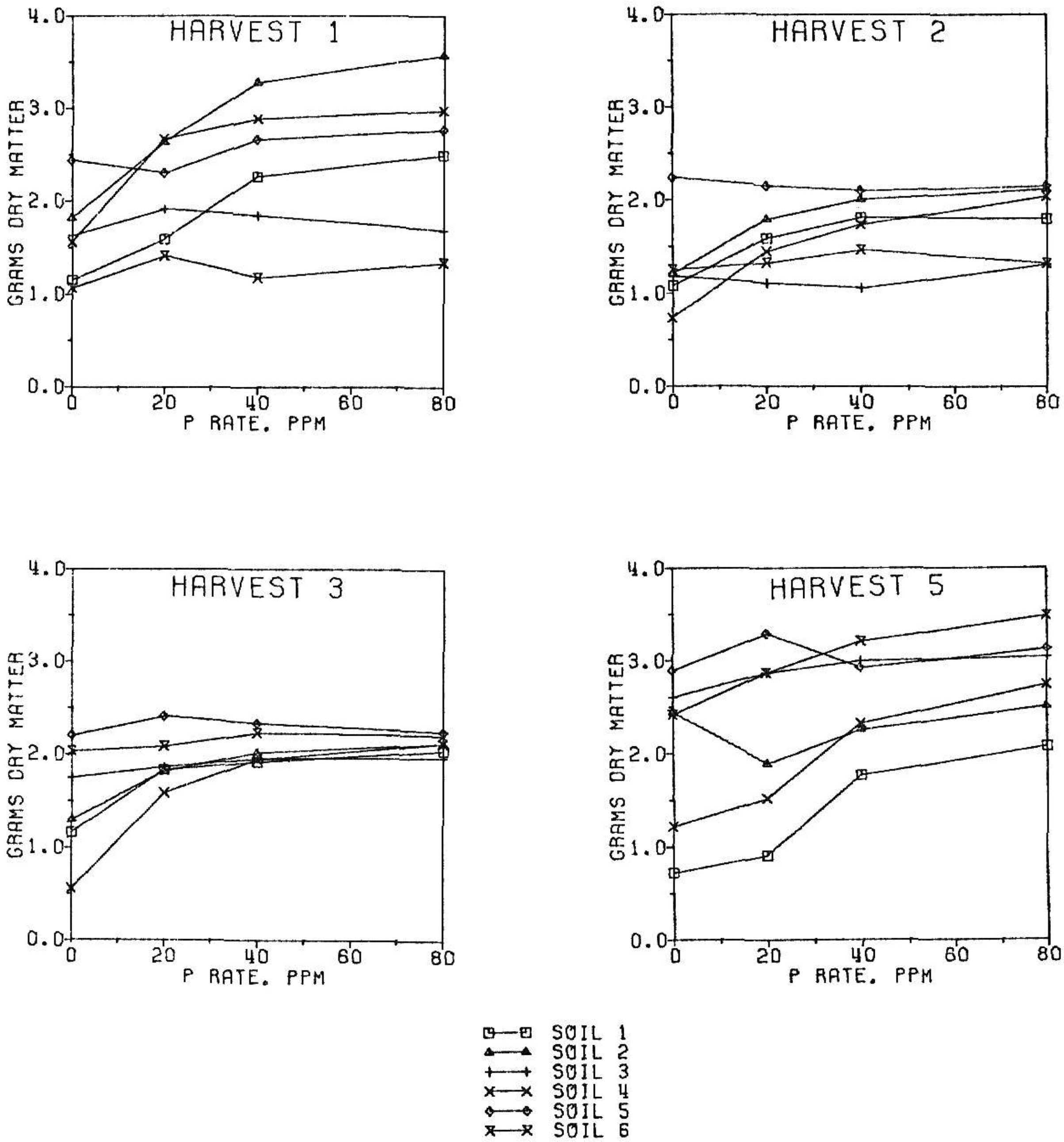


Figure 1 - Effects of phosphorus rate and soil source on dry matter production of perennial ryegrass.

less dramatic. The three soils (3, 5 and 6) which did not respond to phosphorus applications on harvest 1 were producing the highest dry matter yields by the fifth harvest at all phosphorus rates. This suggests that these three soils maintained an adequate level of available phosphorus under the intensive cropping conditions. The different responses to phosphorus between the soils resulted in a highly significant soil by phosphorus rate interaction (Table 3).

Soils 1, 2 and 4 were expected to respond to phosphorus fertilization because of their low available soil phosphorus (Table 1). The low yields obtained on the other three soils (3, 5 and 6) at the first harvest was unexpected. The low initial yields on these soils has some important implications. The phosphorus concentration (Figure 2) of plants grown on these soils were not low relative to the other soils indicating that some other factor besides low available phosphorus was limiting growth. This is also supported by the fact that by harvest 5 these three soils exceeded the other soils in dry matter production. One possible explanation is that some element was available in toxic quantities at first and became less available as the study progressed. Another possible explanation is that some minor element was deficient when the study was initiated and as the spoil material weathered the element became more available.

One of the most important results is that after more than six months of intensive cropping three out of the four spoilbank soils produced far greater dry matter yields, especially on the no phosphorus treatments, than did the virgin soils.

Plant phosphorus concentrations (Figure 2) were significantly increased by phosphorus additions at all harvests (Table 3). At harvest 1 plant phosphorus concentration was increased on all soils by phosphorus treatments

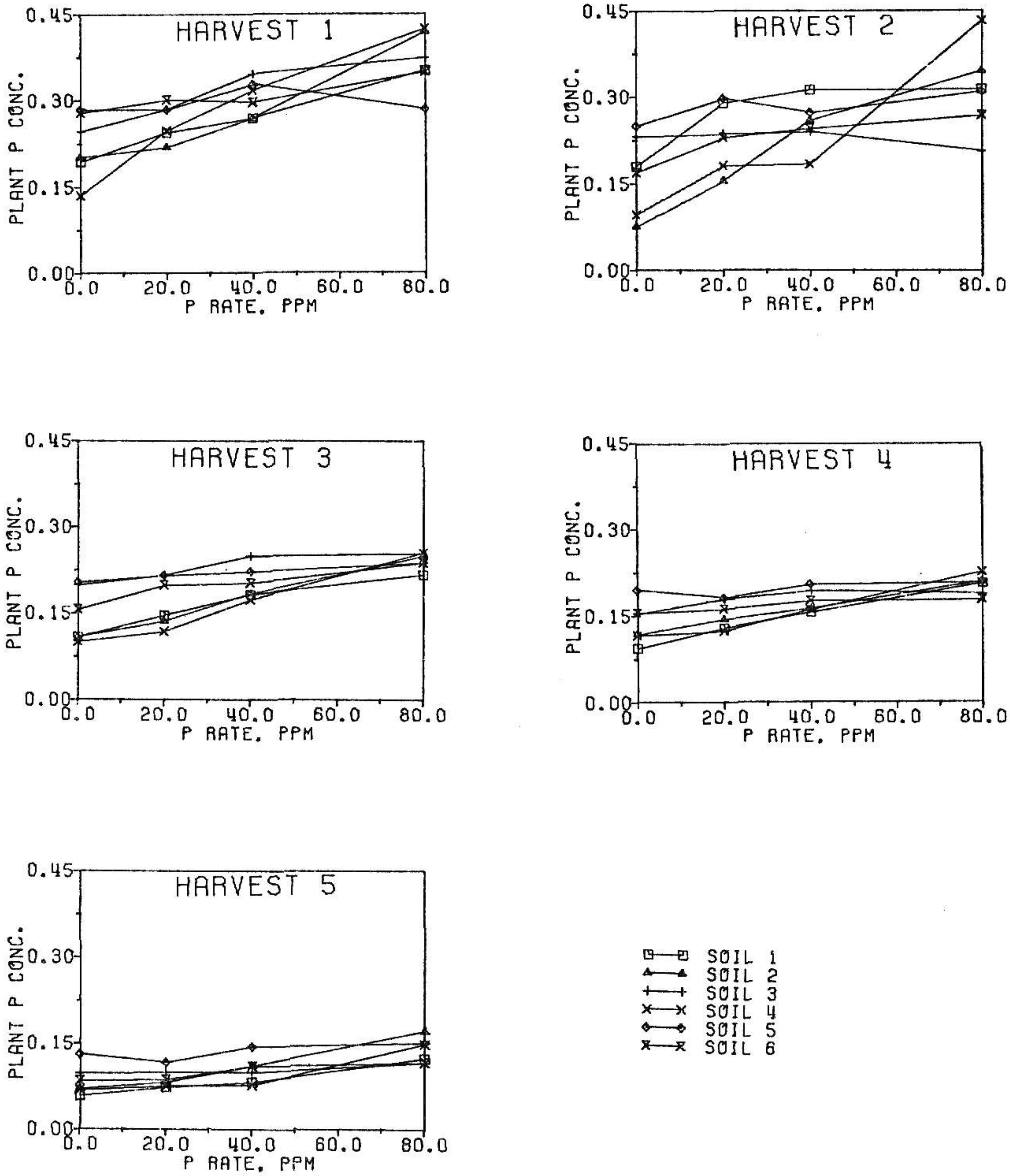


Figure 2 - Effects of phosphorus rate and soil source on phosphorus concentration of perennial ryegrass.

(Figure 2), however the soil by phosphorus rate interaction was significant (Table 3), indicating that some increased more than others. The plants grown on the virgin soils (2 and 4) showed the greatest increases in P content with P application at all five harvests.

Plant phosphorus concentration diminished with time, however harvest 5 yields were still comparable to harvest 1 yields indicating that phosphorus was not significantly limiting growth (Figure 1).

The use of ^{32}P made it possible to determine whether the plant phosphorus originated from the fertilizer or from the soil (Figure 3). The soil by phosphorus rate interaction on this determination was not significant indicating that all soils responded in the same manner to the phosphorus additions (Table 4). Even though all soils responded in the same manner, there were considerable differences between the soils reflecting their varying abilities to supply native soil phosphorus.

An available soil phosphorus index derived from further calculations on the same data are presented in Figure 4. When these results are compared with the original soil analyses data in Table 1, it can be seen that there is a close correlation between the two. These data show that the soil test results give an accurate prediction of the plant-extractable phosphorus. Analyses of variance for plant phosphorus from the fertilizer and soil phosphorus index are given in Table 4.

Analyses of variance for the affect of phosphorus rate on plant potassium concentration and uptake are given in Table 3. The significant difference due to increased phosphorus rate is a decrease in plant potassium concentration (Appendix Tables VII-XI). This is a dilution factor that occurred from phosphorus stimulating plant growth. The soil by phosphorus rate interaction was significant at all harvests indicating the differing abilities

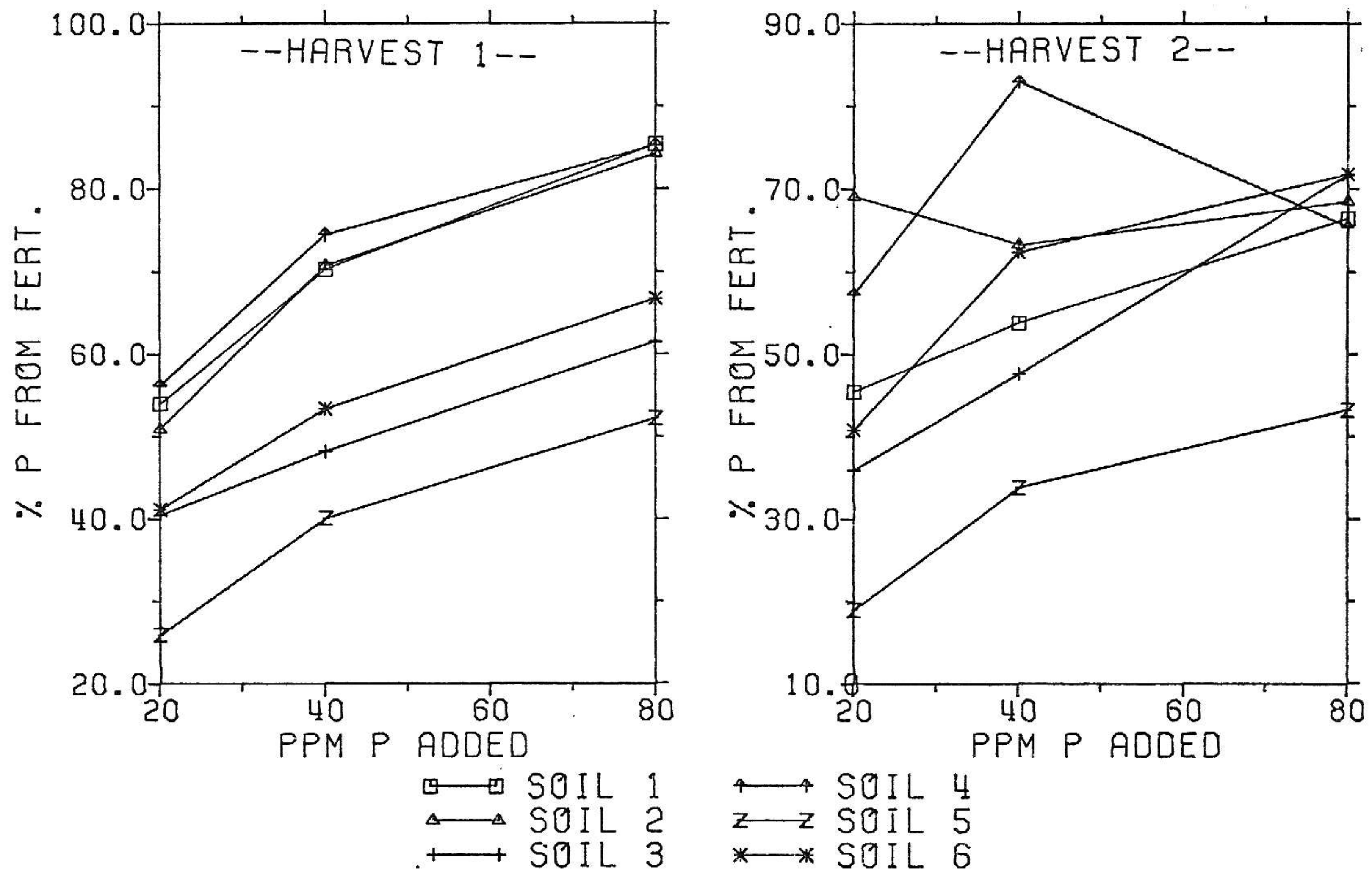


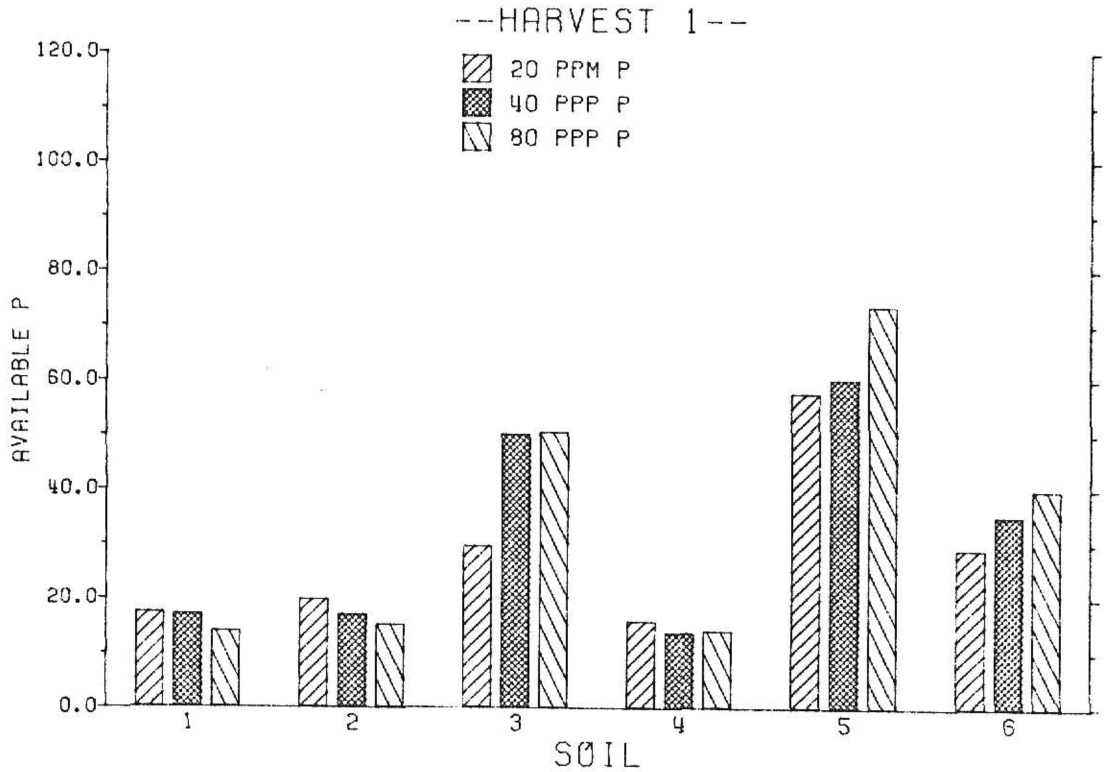
Figure 3 - Effects of phosphorus rate and soil source on percent phosphorus in perennial ryegrass obtained from applied fertilizer phosphorus.

Table 4

ANALYSES OF VARIANCE OF THE PERCENT PLANT PHOSPHORUS FROM THE FERTILIZER (FERT. P) AND THE AVAILABLE PHOSPHORUS INDEX OF THE SOIL (INDEX P) AS AFFECTED BY PHOSPHORUS TREATMENTS AND SOIL SOURCE

Source	df	Fert. P Mean Squares	Index P Mean Squares
Harvest 1			
Soil (S)	5	1564.18 **	3451.99 **
P level (P)	2	3500.79 **	184.79 ns
S X P	10	22.15 ns	116.96 ns
Error	36	23.35	78.89
Harvest 2			
Soil (S)	5	1580.22 **	5836.20 **
P level (P)	2	1835.71 **	1066.20 *
S X P	10	252.10 ns	237.78 ns
Error	36	131.89	219.93

* Sig. at .05 level. ** Sig. at .01 level.



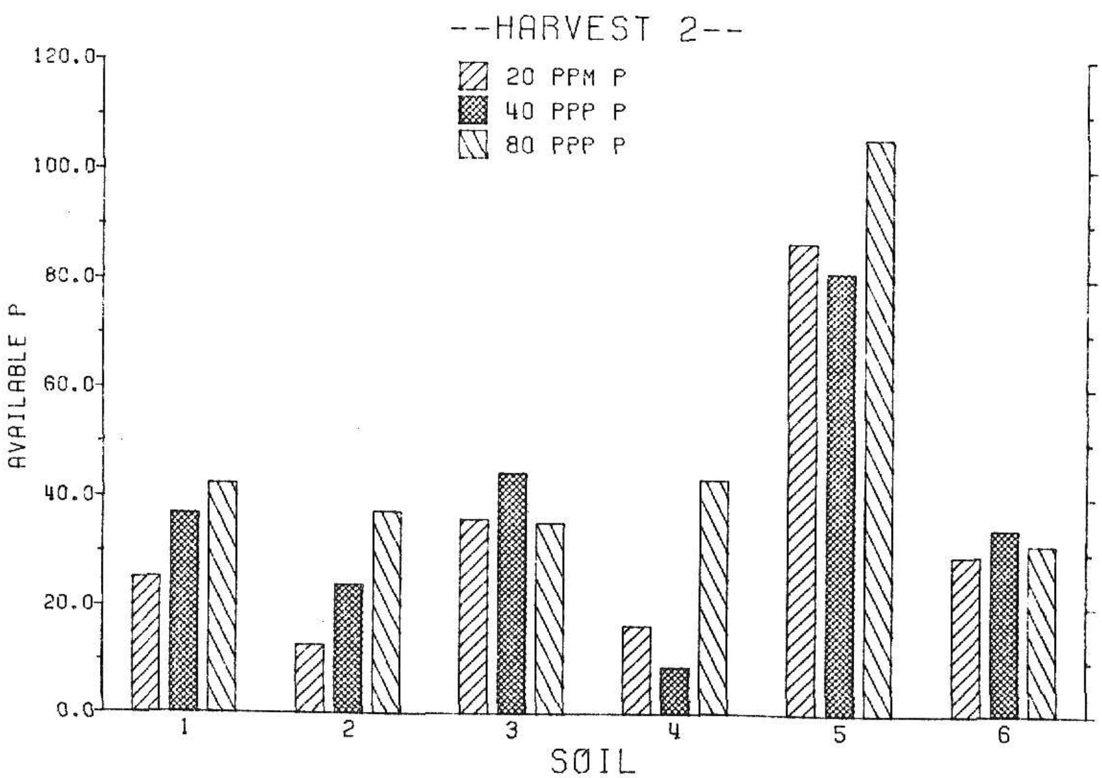


Figure 4 - Effects of phosphorus rate and soil source on available soil phosphorus index.

of the soils to supply potassium. The differences became greater with time. Total potassium uptake was significantly increased as phosphorus rate increased (Table 3).

Soil phosphorus data are given in Figure 5 and Appendix Tables XII-XIV. Analyses of variance are given in Table 5. Phosphorus additions greatly increased the available soil phosphorus content on all soils except soil 1. After the second harvest the spoilbank soils remained static with respect to available phosphorus, whereas the virgin soils (2 and 4) continued to decline. This reflects the inferior ability of the virgin soils to maintain an available phosphorus supply. All of the soils, even on the no phosphorus treatments, increased over the initial level in available phosphorus at the first and/or second harvest. This reflects some rapid weathering under greenhouse conditions that released phosphorus faster than the plants were utilizing it.

These data reflect the superior phosphorus supplying power for three of the four spoilbank soils when compared to the virgin soils.

Results of Potassium Fertilization

Analyses of variance of dry matter production as affected by potassium treatments and soil source are given in Table 6. There were significant differences between soils at all harvests. Potassium application caused significant yield differences on the first four harvests. The potassium X soil interaction was not significant at any harvest.

There are large differences between soils with respect to yield at the first harvest (Figure 6) with the virgin soil (2 and 4) out producing the spoilbank soils. In later harvests the virgin soils declined in yield relative to the spoilbank soils. At the final harvest the spoilbank soils were out producing the virgin soils. The decline in plant growth on the virgin

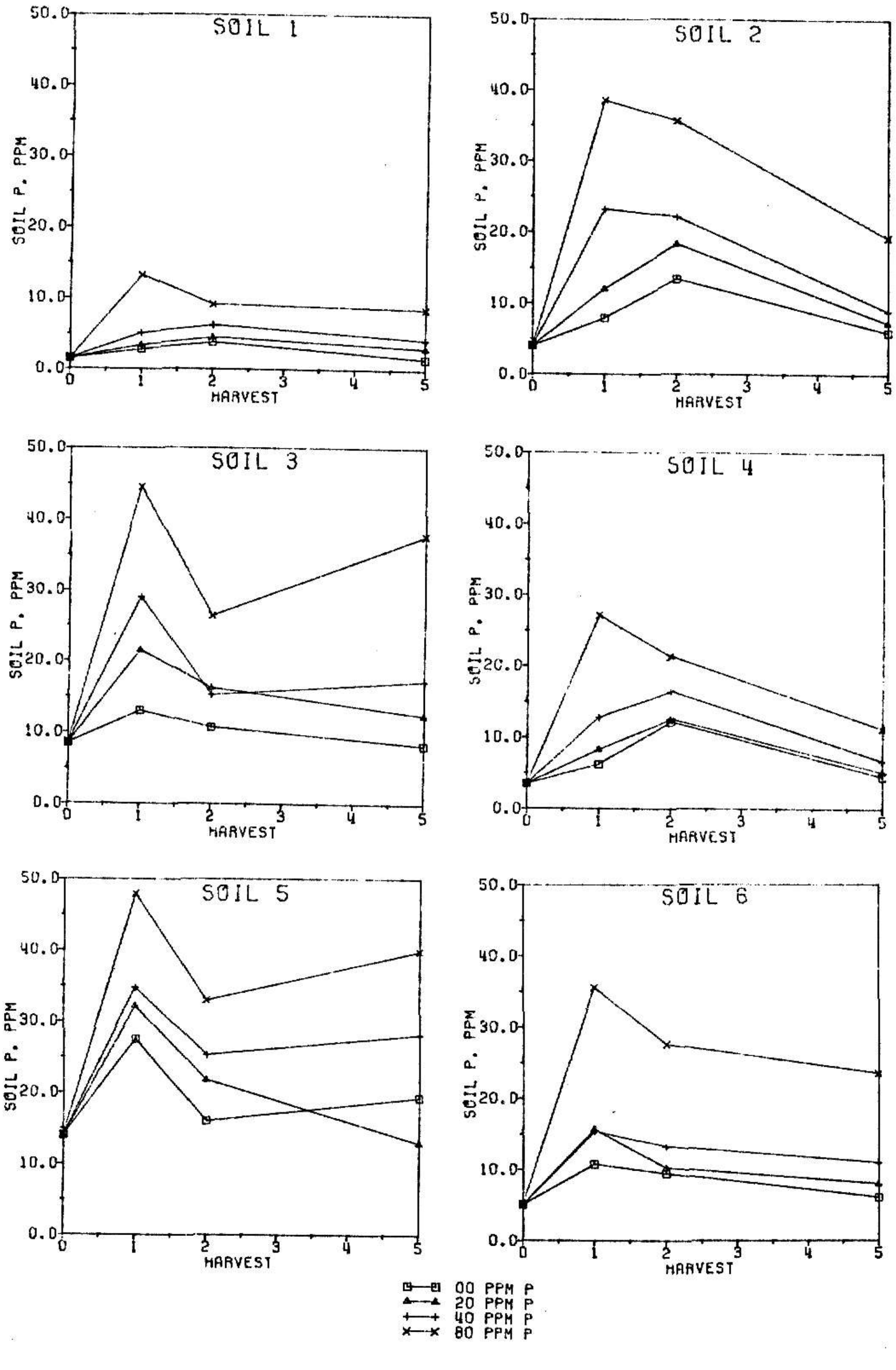


Figure 5 - Effects of phosphorus rate and time on available soil phosphorus.

Table 5

ANALYSES OF VARIANCE OF AVAILABLE SOIL PHOSPHORUS AND POTASSIUM AS AFFECTED BY PHOSPHORUS TREATMENTS AND SOIL SOURCE

Source	df	P Mean Squares	K Mean Squares
Harvest 1			
Soil (S)	5	1256.02 **	7837.86 **
P level (P)	3	1817.30 **	223.03 ns
S X P	15	41.60 **	144.19 ns
Error	48	12.92	153.68
Harvest 2			
Soil (S)	5	494.013 **	9926.18 **
P level (P)	3	712.630 **	428.71 ns
S X P	15	25.970 ns	374.08 ns
Error	48	25.970	271.58
Harvest 5			
Soil (S)	5	895.178 **	6360.52 **
P level (P)	3	866.667 **	8.33 ns
S X P	15	44.877 **	52.27 ns
Error	48	2.368	31.66

* Sig. at .05 level. ** Sig. at .01 level.

Table 6

ANALYSES OF VARIANCE OF YIELD, PLANT POTASSIUM CONCENTRATION (%K), PLANT POTASSIUM UPTAKE, PLANT PHOSPHORUS CONCENTRATION (%P) AND PLANT PHOSPHORUS UPTAKE AS AFFECTED BY POTASSIUM TREATMENTS AND SOIL SOURCE.

Source	df	Yield Mean Squares	%K Mean Squares	K uptake Mean Squares	%P Mean Squares	P uptake Mean Squares
Harvest 1						
Soil (S)	5	535100 **	5.49366 **	4261.27 **	0.03668 **	154.320 **
K level (K)	3	429443 *	2.26757 **	4599.65 **	0.00243 ns	3.845 ns
S X K	15	135532 ns	0.67972 **	924.51 **	0.00066 ns	2.110 ns
Error	48	117618	0.17874	197.96	0.00133	3.445
Harvest 2						
Soil (S)	5	1688748 **	6.80087 **	1785.92 **	0.04201 **	44.7525 **
K level (K)	3	63118 **	0.41847 **	164.97 **	0.01106 **	7.7809 **
S X K	15	50492 ns	0.12719 *	79.55 *	0.00171 ns	1.3785 ns
Error	48	42100	0.05435	38.28	0.00181	1.3141
Harvest 3						
Soil (S)	5	355639 **	8.05805 **	435525 **	0.00329 **	3.33137 **
K level (K)	3	237103 **	0.09172 ns	5132 ns	0.00082 ns	0.29589 ns
S X K	15	51150 ns	0.09177 ns	8899 *	0.00074 *	0.33307 ns
Error	48	34802	0.05622	4495	0.00380	0.22119
Harvest 4						
Soil (S)	5	Yields were not	6.73749 **		0.00304 **	
K level (K)	3	taken on harvest	0.23212 **		0.00019 ns	
S X K	15	4 samples.	0.04339 ns		0.00022 ns	
Error	48		0.03175		0.00013	
Harvest 5						
Soil (S)	5	2642511 **	11.1509 **	1269584 **	0.00236 **	4.44048 **
K level (K)	3	23775 ns	0.0088 ns	1801 ns	0.00031 ns	0.11373 ns
S X K	15	119952 ns	0.6433 **	5559 ns	0.00015 ns	0.14466 ns
Error	48	87368	0.0243	3799	0.00012	0.16892

* Sig. at .05 level. ** Sig. at .01 level.

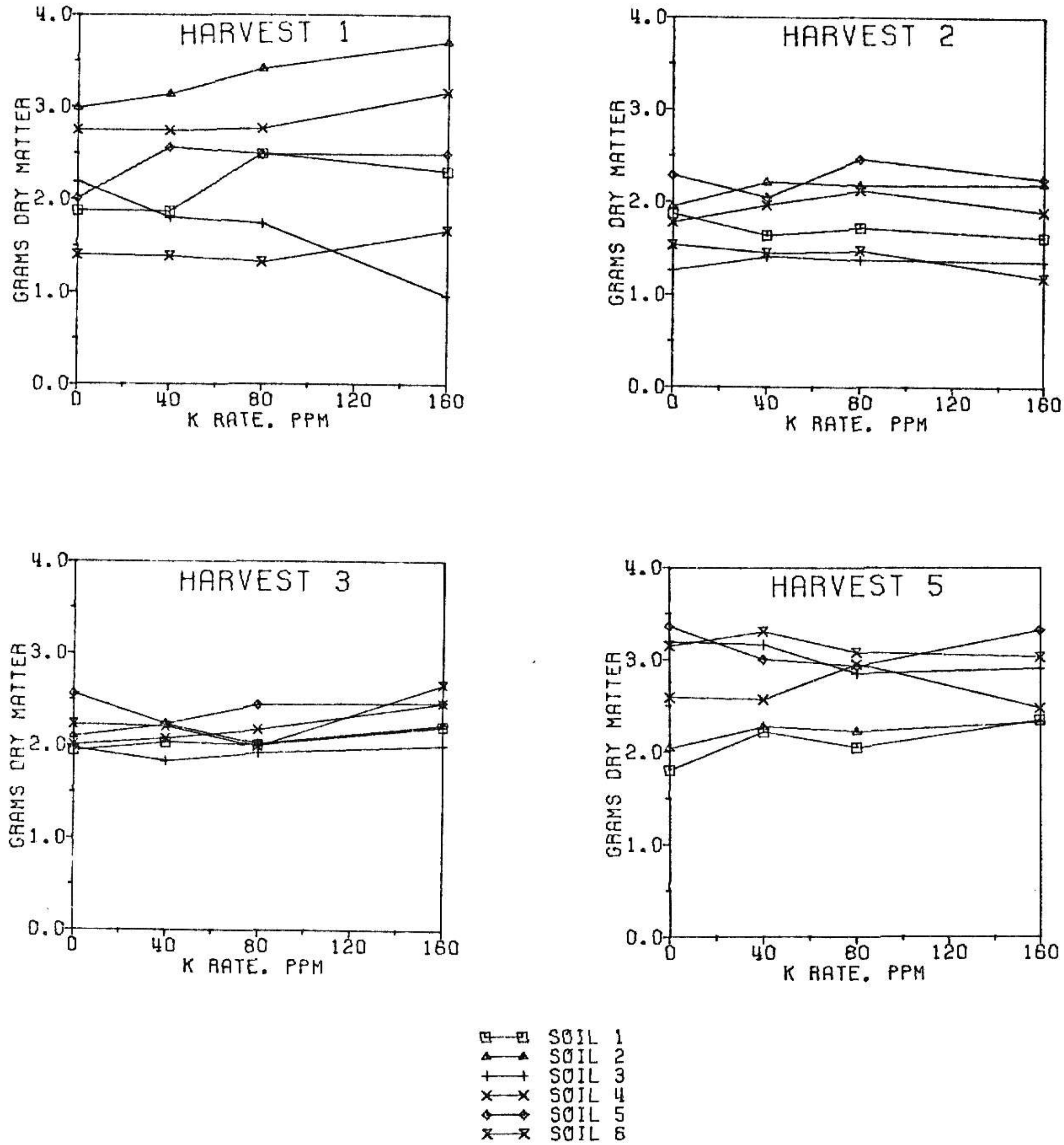


Figure 6 - Effects of potassium rate and soil source on dry matter production of perennial ryegrass.

soils is a direct result of low available soil potassium after six months of intensive cropping (Figure 9) and is reflected in the very low plant potassium concentrations (Figure 8, Table 6 and Appendix Tables VII-XI).

Potassium treatments caused only small increases in yield at the first three harvests and had no significant affect by the fifth harvest (Figure 6, Table 6 and Appendix Tables VII-XIII). At each successive harvest, there was a steady decline in plant potassium concentration.

Potassium treatments had no effect on plant phosphorus concentration except at the second harvest were phosphorus concentration and uptake was increased (Table 9 and Appendix Tables VII-XI).

Data on extractable soil potassium (Figure 9 and Appendix Tables XIV-XVII) show that the potassium treatments used were not sufficient to increase the available potassium content of the soil to a degree that effectively increased yields throughout the study. The initial luxury consumption of potassium by the plants at the higher potassium rates also contributed to a deficiency of potassium at later harvests. Harvest 1 total potassium uptake on some of the treatments were in excess of the amount of potassium added to the soil. Even though the spoilbank soils maintain relatively high exchangeable potassium contents, potassium uptake was severely reduced in the later harvests because of the small volume of soil. Potassium applications proved to be insufficient because of the small volume of soil and high potassium uptake of the plants at the first harvest.

Soil potassium data are presented in Figure 8 and Appendix Tables XII-XIV. Analyses of variance are in Table 8. Soil potassium declined rapidly from its initial level to the first harvest. This reflects the initial rapid rate of potassium uptake with much of it being luxury consumption. There is no explanation at this time for the increase in extractable

Table 7

ANALYSES OF VARIANCE OF THE PERCENT PLANT PHOSPHORUS FROM THE FERTILIZER (FERT. P) AND THE AVAILABLE PHOSPHORUS INDEX OF THE SOIL (INDEX P) AS AFFECTED BY POTASSIUM TREATMENTS AND SOIL SOURCE.

Source	df	Fert. P Mean Squares	Index P Mean Squares
Harvest 1			
Soil (S)	5	2696.68 **	20526.6 **
K level (K)	3	164.10 ns	1722.6 ns
S X K	15	63.08 ns	1848.6 ns
Error	48	72.15	2152.2
Harvest 2			
Soil (S)	5	877.515 **	9544.62 **
K level (K)	3	250.426 *	1417.41 *
S X K	15	26.595 ns	1417.41 ns
Error	48	66.084	366.19

* Sig. at .05 level.   ** Sig. at .01 level.

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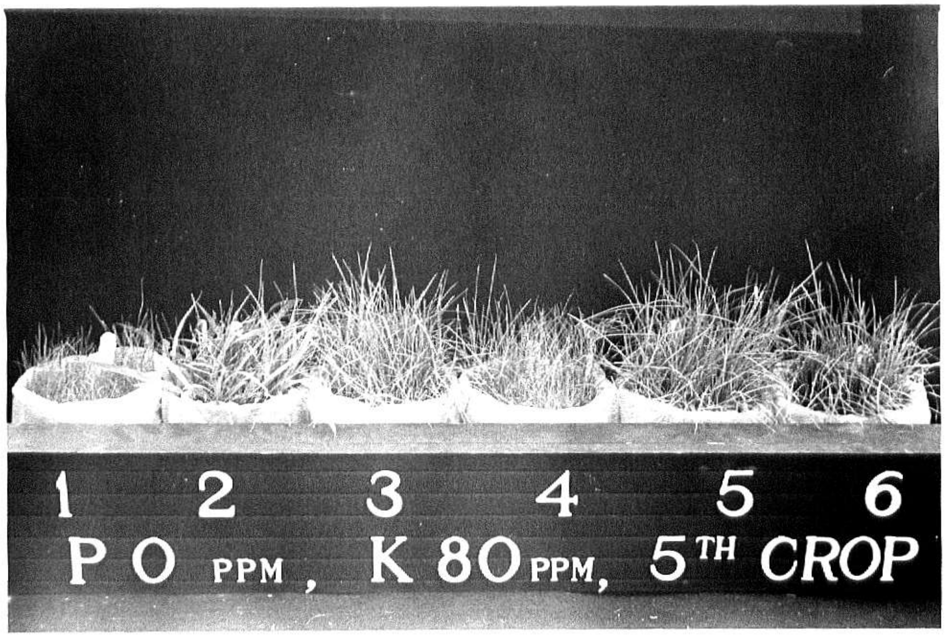

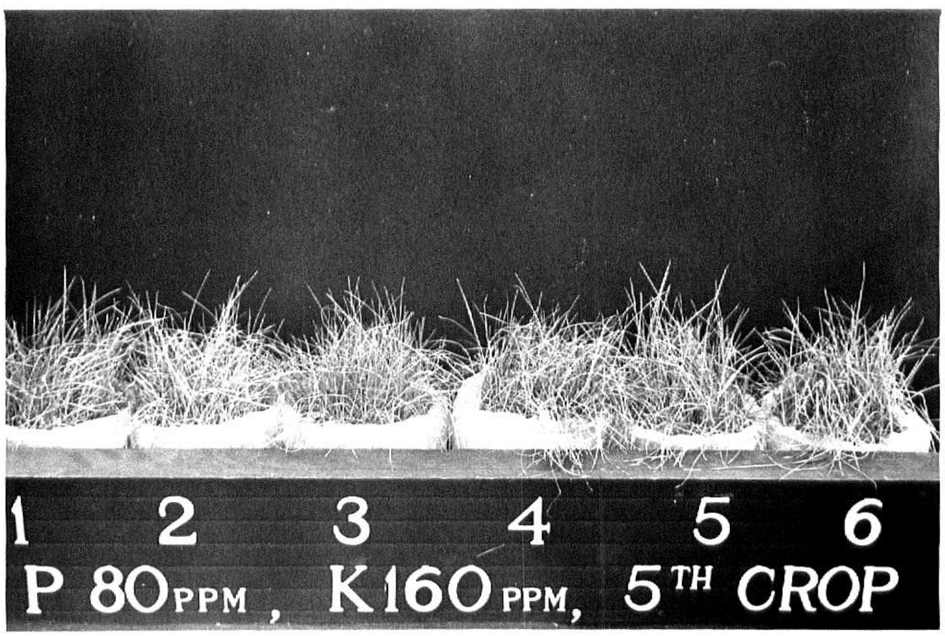

Figure 7 - Effects of phosphorus application on strip-mine soils.

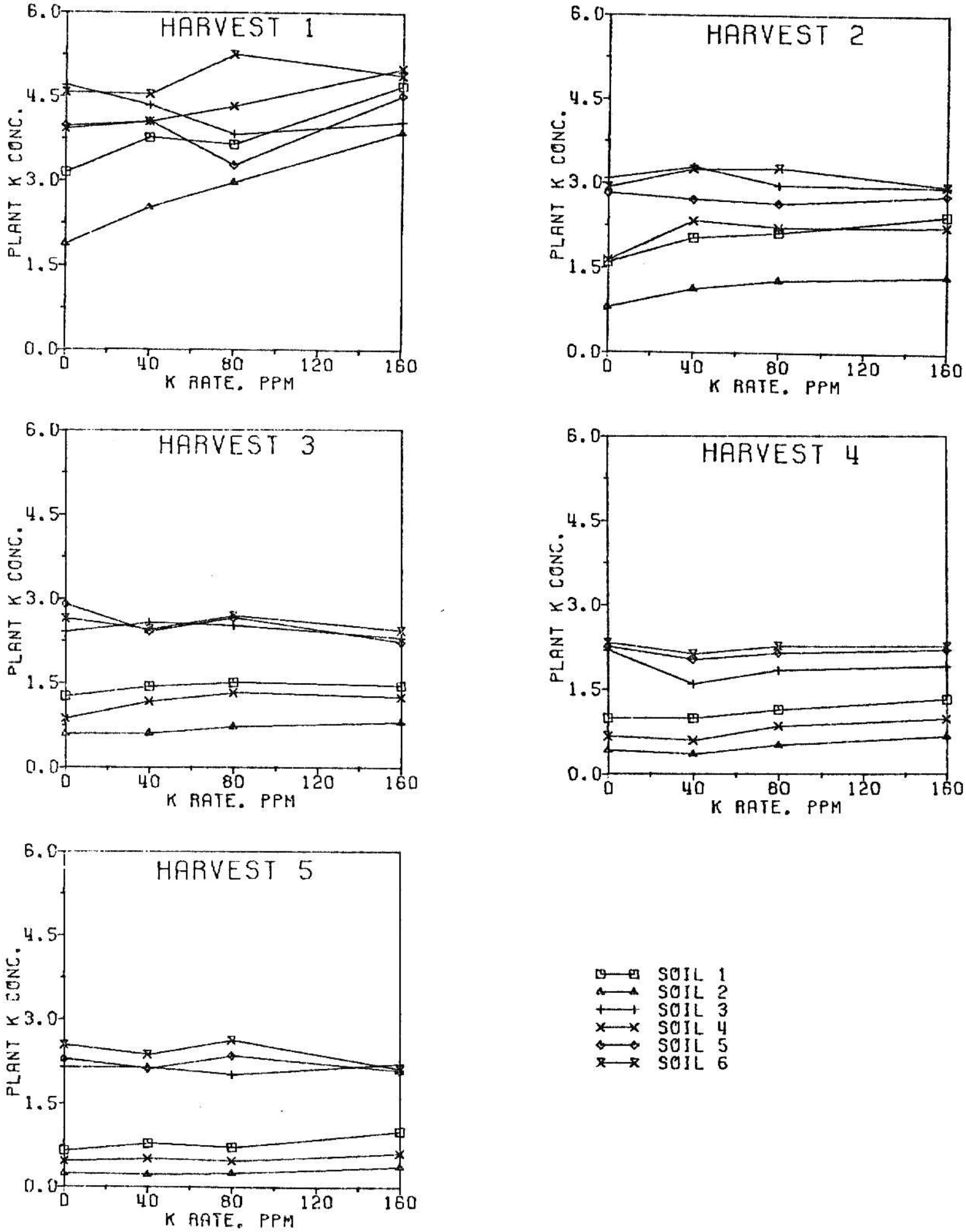

Figure 8 - Effects of potassium rate and soil source on potassium concentration of perennial ryegrass.

Table 8

ANALYSES OF VARIANCE OF AVAILABLE SOIL PHOSPHORUS AND POTASSIUM AS AFFECTED BY POTASSIUM TREATMENTS AND SOIL SOURCE.

Source	df	P Mean Squares	K Mean Squares
Harvest 1			
Soil (S)	5	2142.71 **	7068.35 **
K level (K)	3	59.56 ns	545.56 *
S X K	15	63.81 ns	183.44 ns
Error	48	50.33	162.84
Harvest 2			
Soil (S)	5	726.559 **	7466.64 **
K level (K)	3	16.971 ns	2490.34 **
S X K	15	18.144 ns	263.44 *
Error	48	23.312	139.01
Harvest 5			
Soil (S)	5	1677.95 **	5527.32 **
K level (K)	3	.71 ns	58.45 ns
S X K	15	16.44 ns	37.03 ns
Error	48	8.82	42.36

* Sig. at .05 level. ** Sig. at .01 level.

Table 9

ANALYSES OF VARIANCE OF SOIL pH AT HARVEST 5 AS AFFECTED BY PHOSPHORUS AND LIME TREATMENTS AND SOIL SOURCE AND BY P AND K TREATMENTS AND SOIL SOURCES.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
Soil (S)	1	0.6016	*	Soil (S)	1	2.04167	**
P level (P)	1	0.0016	ns	K level (K)	1	0.02667	ns
Lime (L)	1	10.6666	**	Lime (L)	1	7.48197	**
S X P	1	1.2150	**	S X K	1	0.01500	ns
S X L	1	0.0000	ns	S X L	1	1.12667	**
P X L	1	0.0066	ns	K X L	1	0.00167	ns
S X P X L	1	0.9600	**	S X K X L	1	0.00667	ns
Error	16	0.0833		Error	16	0.04083	

* Sig. at .05 level. ** Sig. at .01 level.

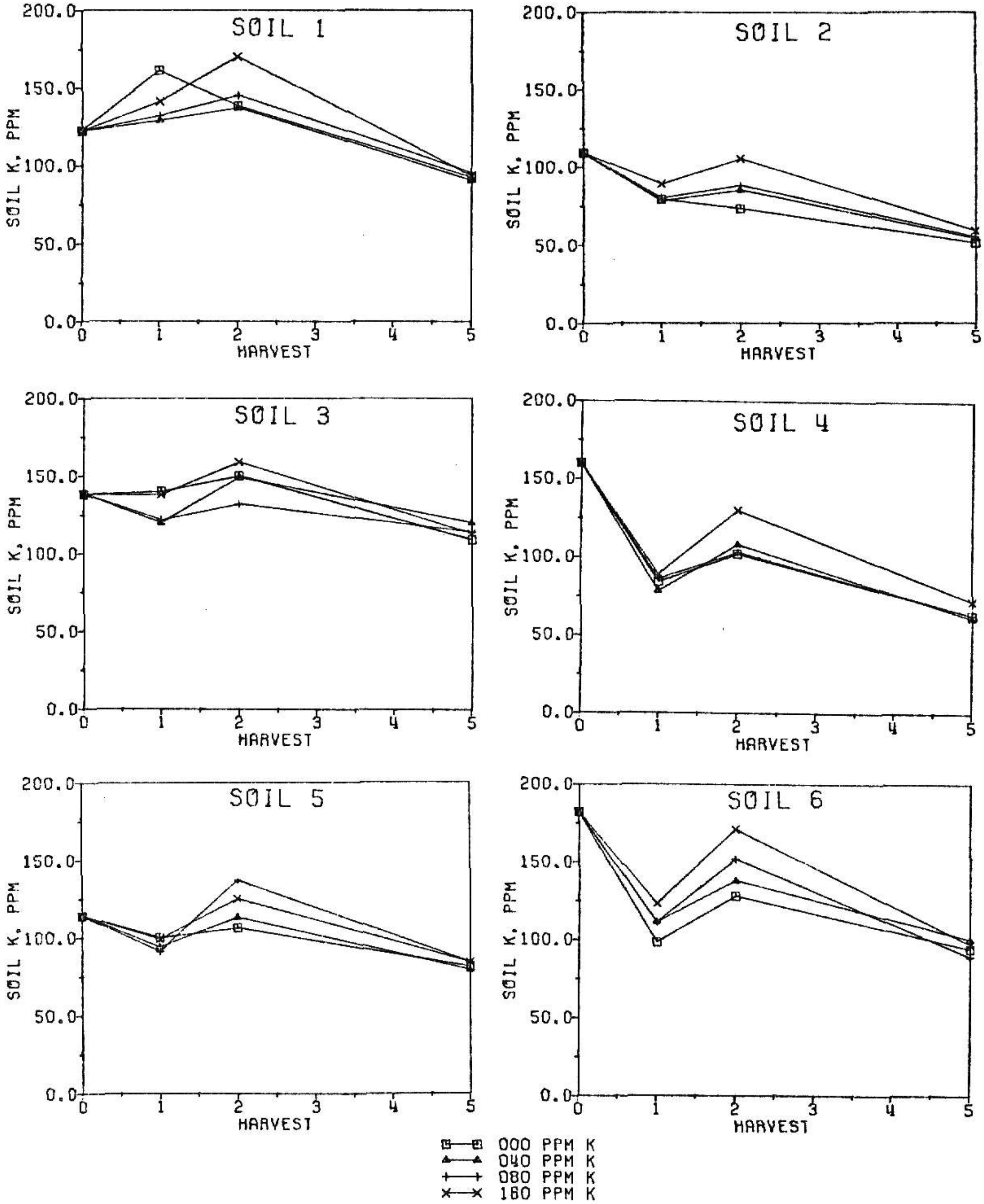

Figure 9 - Effects of potassium rate and time on extractable soil potassium.

potassium from harvest 1 to harvest 2. Perhaps a rapid weathering process took place to establish equilibrium after the initial rapid rate of potassium removal. The soils which were able to maintain the highest level of soil potassium produced the highest yields in the final harvest. The virgin soils (2 and 4) were inferior to the spoilbank soils in this respect.

Potassium treatments had no affect on available soil phosphorus (Tables 7 and 8).

<u>Results of Lime Additions to Acid Soils</u>

Lime treatments were included on soils 1 and 2 because of their low pH's (5.0 and 5.1, respectively). Lime rates were 8400 kg/ha effective calcium carbonate (ECC) on soil 1 and 4480 kg/ha ECC on soil 2. Phosphorus rates were 0 and 40 ppm and potassium rates were 0 and 80 ppm. Soil pH's were taken at the final harvest only.

The pH's of the two acid soils were significantly increased by liming (Table 9). The final pH of the spoilbank soil (1) was significantly higher than the virgin soil (2) (Appendix Table XIV).

Analyses of variance for yield as affected by lime and phosphorus treatments are given in Table 10. Yields were decreased at harvest one on the two acid soils (1 and 2) when lime was included. The yield on soil 1 at harvest two (Appendix Table I) was decreased by liming while soil 2 yields were increased with lime (Appendix Table II), thus giving a significant soil by lime interaction at harvest 2 (Table 10). The yield reductions caused by liming are not consistently associated with changes in plant phosphorus or potassium concentrations (Appendix Tables VII and VIII). This indicates that the yield decrease caused by liming is not entirely due to a decreased availability of these two nutrients.

Table 10

ANALYSES OF VARIANCE OF DRY MATTER YIELD AS AFFECTED BY PHOSPHORUS AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
		Harvest 1				Harvest 3	
Soil (S)	1	3199590	**	Soil (S)	1	221952	**
P level (P)	1	8824575	**	P level (P)	1	4161668	**
Lime (L)	1	461205	**	Lime (L)	1	281233	**
S X P	1	179747	ns	S X P	1	2562	ns
S X L	1	75152	ns	S X L	1	35882	ns
P X L	1	33227	ns	P X L	1	49504	ns
S X P X L	1	22	ns	S X P X L	1	10416	ns
Error	16	42025		Error	16	13878	
		Harvest 2				Harvest 5	
Soil (S)	1	939708	**	Soil (S)	1	2914157	**
P level (P)	1	5229467	**	P level (P)	1	4851903	**
Lime (L)	1	18872	ns	Lime (L)	1	554800	ns
S X P	1	273	ns	S X P	1	293267	ns
S X L	1	333468	**	S X L	1	991860	**
P X L	1	164507	*	P X L	1	1297815	*
S X P X L	1	9640	ns	S X P X L	1	942877	*
Error	16	25629		Error	16	182943	

* Sig. at .05 level.   ** Sig. at .01 level.

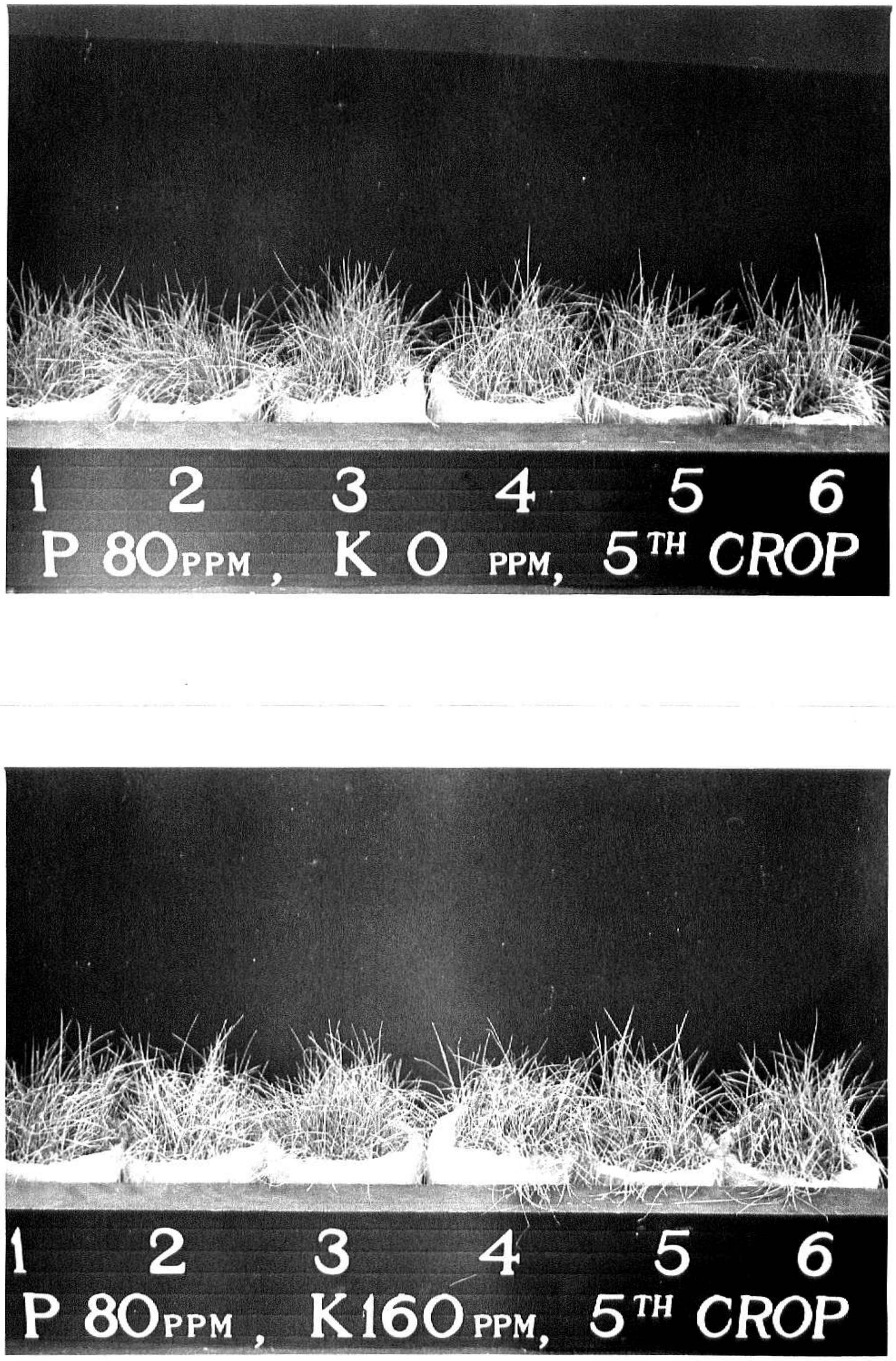

Figure 10 - Effects of potassium applications on strip-mine soils.

Plant phosphorus concentrations (Appendix Tables VII-XI) are less consistent with treatment than yields. Analyses of variances are listed in Table 11. The only consistent trend that developed was that liming tended to increase plant phosphorus concentration at the later harvests.

The percent phosphorus in the plant that came from the fertilizer is decreased on both acid soils with the addition of lime at harvest 1 (Appendix Table VI). The available soil phosphorus index was increased with liming (Appendix Table VI). Both are significant at the five percent level (Table 12) and indicate that lime either caused the release of soil phosphorus and/or caused the fixation of some of the fertilizer phosphorus. Total phosphorus uptake (Table 13) was reduced by liming, indicating that the lime caused a fixation of the fertilizer phosphorus or, through some mechanism unrelated to phosphorus, caused a decrease in dry matter yields. The same trends were observed on the plant phosphorus concentrations of the potassium treatments, however, they were not significant.

Harvest 2 results show a dramatic increase in the percent phosphorus in the plant that came from the fertilizer when lime was added (Appendix Table V and Table 14). The available soil phosphorus index was very low on the limed treatments. Again, liming caused a large decrease in total phosphorus uptake. These results show that there was fixation of the soil phosphorus since the first harvest. The results of the soil analyses do not show this but it is possible that the acid extracting solution for the soil analyses released some phosphorus that was unavailable to the plants (Appendix Tables XII and XIII, and Table 15). By harvest 5 total uptake of phosphorus was increased by liming. Because essentially all radioactivity had decayed by this time, it was impossible to determine the source of the phosphorus, however, it seems apparent that the adverse affects of liming were no longer present.

Table 11

ANALYSES OF VARIANCE OF PLANT PHOSPHORUS CONCENTRATION AS AFFECTED BY PHOSPHORUS AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
		Harvest 1				Harvest 4	
Soil (S)	1	0.00023	ns	Soil (S)	1	0.00595	*
P level (P)	1	0.04905	**	P level (P)	1	0.01042	**
Lime (L)	1	0.00095	ns	Lime (L)	1	0.00177	ns
S X P	1	0.00067	ns	S X P	1	0.00035	ns
S X L	1	0.00003	ns	S X L	1	0.00170	ns
P X L	1	0.00238	ns	P X L	1	0.00101	ns
S X P X L	1	0.00025	ns	S X P X L	1	0.00000	ns
Error	16	0.00093		Error	16	0.00096	
		Harvest 2				Harvest 5	
Soil (S)	1	0.01297	*	Soil (S)	1	0.00413	**
P level (P)	1	0.09350	**	P level (P)	1	0.00531	**
Lime (L)	1	0.03792	**	Lime (L)	1	0.00116	**
S X P	1	0.00043	ns	S X P	1	0.00088	**
S X L	1	0.00608	ns	S X L	1	0.00021	ns
P X L	1	0.00687	ns	P X L	1	0.00005	ns
S X P X L	1	0.00177	ns	S X P X L	1	0.00008	ns
Error	16	0.00258		Error	16	0.00010	
		Harvest 3					
Soil (S)	1	0.00091	**				
P level (P)	1	0.03110	**				
Lime (L)	1	0.00000	ns				
S X P	1	0.00160	**				
S X L	1	0.00073	*				
P X L	1	0.00004	ns				
S X P X L	1	0.00141	**				
Error	16	0.00010					

* Sig. at .05 level. ** Sig. at .01 level.

Table 12

ANALYSES OF VARIANCE OF THE PERCENT PLANT PHOSPHORUS FROM THE FERTILIZER AND THE AVAILABLE SOIL PHOSPHORUS INDEX AS AFFECTED BY LIME AND SOIL SOURCE.

Plant Phosphorus from Fertilizer				Available Phosphorus Index of the Soil			
Source	df	Mean Squares	F	Source	df	Mean Squares	F
		Harvest 1				Harvest 1	
Soil (S)	1	65.800	ns	Soil (S)	1	100.456	ns
Lime (L)	1	272.462	*	Lime (L)	1	281.300	*
S X L	1	78.432	ns	S X L	1	104.194	ns
Error	8	830.432		Error	8	41.566	
		Harvest 2				Harvest 2	
Soil (S)	1	26.46	ns	Soil (S)	1	160.08	ns
Lime (L)	1	4944.26	*	Lime (L)	1	1948.45	*
S X L	1	466.75	ns	S X L	1	95.25	ns
Error	8	898.70		Error	8	231.44	

* Sig. at .05 level. ** Sig. at .01 level.

Table 13

ANALYSES OF VARIANCE OF PLANT PHOSPHORUS UPTAKE AS AFFECTED BY PHOSPHORUS AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
		Harvest 1				Harvest 3	
Soil (S)	1	16.583	**	Soil (S)	1	207.09	**
P level (P)	1	114.328	**	P level (P)	1	3634.40	**
Lime (L)	1	4.567	*	Lime (L)	1	76.46	**
S X P	1	2.498	ns	S X P	1	123.30	**
S X L	1	0.185	ns	S X L	1	96.87	**
P X L	1	0.084	ns	P X L	1	20.72	*
S X P X L	1	0.163	ns	S X P X L	1	100.04	**
Error	16	0.905		Error	16	3.86	
		Harvest 2				Harvest 5	
Soil (S)	1	0.05520	ns	Soil (S)	1	728.31	**
P level (P)	1	70.19549	**	P level (P)	1	1211.96	**
Lime (L)	1	8.73747	**	Lime (L)	1	201.20	**
S X P	1	0.12084	ns	S X P	1	65.30	*
S X L	1	2.18226	ns	S X L	1	1.51	ns
P X L	1	2.29340	ns	P X L	1	136.46	**
S X P X L	1	0.07855	ns	S X P X L	1	111.06	**
Error	16	0.87912		Error	16	11.00	

* Sig. at .05 level. ** Sig. at .01 level.

Table 14

ANALYSES OF VARIANCE OF THE PERCENT PHOSPHORUS FROM THE FERTILIZER AND THE AVAILABLE SOIL PHOSPHORUS INDEX AS AFFECTED BY POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE.

Plant Phosphorus from Fertilizer				Available Phosphorus Index of the Soil			
Source	df	Mean Squares	F	Source	df	Mean Squares	F
		Harvest 1				Harvest 1	
Soil (S)	1	284.524	*	Soil (S)	1	283.524	*
K level (K)	1	143.130	ns	K level (K)	1	489.877	ns
Lime (L)	1	169.654	ns	Lime (L)	1	557.481	ns
S X K	1	54.692	ns	S X K	1	270.077	ns
S X L	1	16.186	ns	S X L	1	144.992	ns
K X L	1	4.191	ns	K X L	1	106.470	ns
S X K X L	1	52.362	ns	S X K X L	1	244.928	ns
Error	16	57.343		Error	16	258.975	
		Harvest 2				Harvest 2	
Soil (S)	1	238.896	ns	Soil (S)	1	561.246	ns
K level (K)	1	251.036	ns	K level (K)	1	839.693	ns
Lime (L)	1	330.635	ns	Lime (L)	1	833.788	ns
S X K	1	125.949	ns	S X K	1	296.384	ns
S X L	1	230.391	ns	S X L	1	307.307	ns
K X L	1	30.510	ns	K X L	1	73.710	ns
S X K X L	1	34.224	ns	S X K X L	1	116.865	ns
Error	16	122.835		Error	16	281.904	

* Sig. at .05 level. ** Sig. at .01 level.

Table 15

ANALYSES OF VARIANCE OF AVAILABLE SOIL PHOSPHORUS AND POTASSIUM AS AFFECTED BY PHOSPHORUS AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
	Soil Phosphorus				Soil Potassium		
		Harvest 1				Harvest 1	
Soil (S)	1	1034.90	**	Soil (S)	1	25026.0	**
P level (P)	1	618.13	**	P level (P)	1	330.0	ns
Lime (L)	1	42.66	*	Lime (L)	1	651.0	*
S X P	1	337.49	**	S X P	1	35.0	ns
S X L	1	14.41	ns	S X L	1	12.0	ns
P X L	1	11.20	ns	P X L	1	782.0	*
S X P X L	1	6.20	ns	S X P X L	1	360.3	ns
Error	16	7.88		Error	16	136.4	
		Harvest 2				Harvest 2	
Soil (S)	1	1258.60	**	Soil (S)	1	14701.5	**
P level (P)	1	241.93	**	P level (P)	1	66.6	ns
Lime (L)	1	29.48	**	Lime (L)	1	2521.5	*
S X P	1	72.10	**	S X P	1	640.6	ns
S X L	1	18.72	*	S X L	1	888.1	ns
P X L	1	3.52	ns	P X L	1	450.6	ns
S X P X L	1	0.73	ns	S X P X L	1	130.6	ns
Error	16	2.28		Error	16	376.5	
		Harvest 5				Harvest 5	
Soil (S)	1	128.343	**	Soil (S)	1	7280.16	**
P level (P)	1	56.733	**	P level (P)	1	468.16	**
Lime (L)	1	9.753	**	Lime (L)	1	522.66	**
S X P	1	2.870	*	S X P	1	6.00	ns
S X L	1	0.003	ns	S X L	1	228.16	*
P X L	1	0.350	ns	P X L	1	48.16	ns
S X P X L	1	1.653	ns	S X P X L	1	10.66	ns
Error	16	0.568		Error	16	28.33	

* Sig. at .05 level. ** Sig. at .01 level.

The fixation of the soil phosphorus is most likely a reversion of phosphorus to a less available form through a reaction associated with $CaCO_3$ because the decreased availability was not observed on the unlimed treatments. By the end of the study an equilibrium was established which made phosphorus more available on the limed treatments. The final pH (Appendix Table XIV) was within the range of maximum phosphorus availability on the limed treatments (2).

Plant potassium concentration as affected by lime and phosphorus rates are given in Appendix Tables VII-XI. Potassium concentrations were increased by liming at harvest 1, 4, and 5 and decreased by liming at harvest 2 and 3. The increased potassium concentration at harvest 1 is possibly a result of the decreased yield which resulted in luxury consumption of potassium on the limed treatments. The equilibration of the lime and the concomitant increase in pH probably made potassium more available by harvest 4 and 5, resulting in greater plant potassium concentrations. Analyses of variance for plant potassium concentration as affected by lime are given in Table 16.

Liming the acid soils had no significant effect on yield, on the potassium study, until the fifth harvest (Table 17 and Appendix Tables I-IV). This is probably due to an increase in pH which makes potassium more available, or due to the release of potassium to the soil solution when calcium reacts with the clay. Plant potassium concentration is unaffected by liming at the first harvest (Appendix Table VII) but is decreased at the second and third harvests (Appendix Tables VIII and IX). At the fourth and fifth harvests liming increased the plant potassium concentration (Appendix Tables X and XI). These trends were also observed in the soil analyses (Appendix Tables XII-XIV and Table 18) and reflects the increased availability of potassium that can occur when acid soils are limed (31).

Table 16

ANALYSES OF VARIANCE OF PLANT POTASSIUM CONCENTRATION AS AFFECTED BY POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
	Harvest 1				Harvest 4		
Soil (S)	1	6.40666	**	Soil (S)	1	2.60700	**
K level (K)	1	5.78202	**	K level (K)	1	0.24604	ns
Lime (L)	1	0.00027	ns	Lime (L)	1	0.57970	*
S X K	1	0.34082	ns	S X K	1	0.00400	ns
S X L	1	0.01927	ns	S X L	1	0.02734	ns
K X L	1	0.21282	ns	K X L	1	0.03604	ns
S X K X L	1	0.02042	ns	S X K X L	1	0.00004	ns
Error	16	0.12140		Error	16	0.09124	
	Harvest 2				Harvest 5		
Soil (S)	1	3.72093	**	Soil (S)	1	1.73344	**
K level (K)	1	0.95600	**	K level (K)	1	0.00844	ns
Lime (L)	1	0.26256	*	Lime (L)	1	0.10010	**
S X K	1	0.00070	ns	S X K	1	0.00004	ns
S X L	1	0.00510	ns	S X L	1	0.05320	*
K X L	1	0.06510	ns	K X L	1	0.00050	ns
S X K X L	1	0.00700	ns	S X K X L	1	0.00570	ns
Error	16	0.03866		Error	16	0.00750	
	Harvest 3						
Soil (S)	1	2.71353	**				
K level (K)	1	0.14260	*				
Lime (L)	1	0.39784	**				
S X K	1	0.02870	ns				
S X L	1	0.01354	ns				
K X L	1	0.00510	ns				
S X K X L	1	0.09000	*				
Error	16	0.01705					

* Sig. at .05 level. ** Sig. at .01 level.

Table 17

ANALYSES OF VARIANCE OF YIELD AS AFFECTED BY POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
		Harvest 1				Harvest 3	
Soil (S)	1	5568666	**	Soil (S)	1	176816	*
K level (K)	1	749066	**	K level (K)	1	3313	ns
Lime (L)	1	30104	ns	Lime (L)	1	70416	ns
S X K	1	80504	ns	S X K	1	2440	ns
S X L	1	18504	ns	S X L	1	47882	ns
K X L	1	18150	ns	K X L	1	5581	ns
S X K X L	1	170016	ns	S X K X L	1	15301	ns
Error	16	50020		Error	16	22159	
		Harvest 2				Harvest 5	
Soil (S)	1	1128400	**	Soil (S)	1	74705	ns
K level (K)	1	21600	ns	K level (K)	1	726276	*
Lime (L)	1	42336	ns	Lime (L)	1	4530097	**
S X K	1	83544	ns	S X K	1	17334	ns
S X L	1	160720	ns	S X L	1	612801	*
K X L	1	3552	ns	K X L	1	109215	ns
S X K X L	1	28842	ns	S X K X L	1	43435	ns
Error	16	24207		Error	16	108889	

* Sig. at .05 level. ** Sig. at .01 level.

Table 18

ANALYSES OF VARIANCE OF AVAILABLE SOIL PHOSPHORUS AND POTASSIUM AS AFFECTED BY POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE.

Source	df	Mean Squares	F	Source	df	Mean Squares	F
	Soil Phosphorus				Soil Potassium		
		Harvest 1				Harvest 1	
Soil (S)	1	3252.68	**	Soil (S)	1	23002.0	**
K level (K)	1	65.33	ns	K level (K)	1	210.0	ns
Lime (L)	1	471.70	**	Lime (L)	1	12.0	ns
S X K	1	21.65	ns	S X K	1	210.0	ns
S X L	1	0.06	ns	S X L	1	135.3	ns
K X L	1	4.33	ns	K X L	1	392.0	ns
S X K X L	1	7.93	ns	S X K X L	1	459.3	ns
Error	16	21.19		Error	16	199.8	
		Harvest 2				Harvest 2	
Soil (S)	1	2784.25	**	Soil (S)	1	21901.0	**
K level (K)	1	2.34	ns	K level (K)	1	442.0	**
Lime (L)	1	329.30	**	Lime (L)	1	737.0	**
S X K	1	4.77	ns	S X K	1	108.3	*
S X L	1	84.00	*	S X L	1	7.0	ns
K X L	1	21.85	ns	K X L	1	40.0	ns
S X K X L	1	29.26	ns	S X K X L	1	1.0	ns
Error	16	15.58		Error	16	23.9	
		Harvest 5				Harvest 5	
Soil (S)	1	742.593	**	Soil (S)	1	9600.00	**
K level (K)	1	79.570	*	K level (K)	1	2.66	ns
Lime (L)	1	8.760	ns	Lime (L)	1	560.66	**
S X K	1	32.900	ns	S X K	1	16.66	ns
S X L	1	17.170	ns	S X L	1	0.0	ns
K X L	1	0.070	ns	K X L	1	54.00	ns
S X K X L	1	0.120	ns	S X K X L	1	10.66	ns
Error	16	15.774		Error	16	14.04	

* Sig. at .05 level. ** Sig. at .01 level.

CONCLUSIONS

The results of this investigation showed that three out of the four spoilbank soils were superior to virgin soils of the same locale with respect to plant extractable phosphorus and potassium. After an initial period of slow growth, three of four spoilbank soils produced higher dry matter yields, supported higher phosphorus and potassium concentrations in the plants, and maintained higher levels of available phosphorus and exchangeable potassium in the soil. Soil test results were found to accurately predict the initial plant available phosphorus and potassium content of the soil. After a period of intensive cropping, it was found that several of the spoilbank soils were able to maintain a higher level of plant available potassium than a virgin soil with a comparable initial soil test level.

The results show that releveled spoilbank soils may, after several years of weathering, be equal or superior to adjacent virgin soils with respect to plant production. Several considerations should be made, however, when spoilbanks are to be used for crop production. Taking proper soil samples and following the results of the soil test is of primary importance. If lime is required it should be applied well ahead of planting to allow for equilibrium reactions to take place. The results on the one acid spoilbank soil indicate that liming will depress phosphorus availability for several months. After this initial period phosphorus becomes more available as the lime comes to equilibrium with the soil.

There are some other important considerations besides phosphorus and potassium nutrition and liming when spoilbanks are to be used for crop production. Nitrogen is particularily important because of the low organic matter content and the low microbiol activity in the spoil material. Manure additions would be beneficial in both respects as well as supplying many other essential nutrients and improving the physical condition of the soil.

Another detrimental property of spoilbanks is their coarse texture as a result of unweathered fragments of shale and rock. This type of soil has a low water holding capacity which results in poor plant survival during dry periods. Some type of ground cover during seedling establishment would be helpful in retarding evaporation.

The future productive potential of spoilbanks appears to be excellent. The accumulation of organic matter and the weathering of rocks and shale should improve the physical condition of the material as well as release additional nutrients. The establishment of a plant cover will retard erosion, improve infiltration and promote the leaching of undesirable salts, and enhance the weathering and the soil forming processes.

LITERATURE CITED

1. Bengtson, S. W., D. A. Maysand, and J. C. Allen. 1973. Revegetation of coal spoil in northeastern Alabama: Effect of timing of seeding and fertilization on establishment of pine-grass mixtures. In Research and applied Technology symposium on mined-land reclamation. Pittsburgh, Penn. p. 208-214.

2. Buckman, H. O. and N. C. Brady. 1969. The nature and properties of soils. 7th edition. The Macmillan Co., Toronto, Ontario. p. 379-411.

3. Camin, Kay. 1971. An action plan for redeveloping southeast Kansas lands disturbed by surface mining. In Mined-land redevelopment workshop. Special distribution publication 58, State Geological Survey of Kansas, Lawrence, Kan. p. 9-14.

4. Capp, John P. and D. W. Gillmore. 1973. Soil-making potential of powerplant fly ash in mined-land reclamation. In Research and applied technology symposium on mined-land reclamation. Pittsburgh, Penn. p. 178-186.

5. Cummins, D. G., W. T. Plass, and C. E. Gentry. 1965. Chemical and physical properties of spoilbanks in the eastern Kentucky coal fields. U. S. Forest Service Research Paper CS-17. Central States Experiment Station, Columbus, Ohio.

6. Deely, D. J., O. R. Russell, and F. J. Wobber. 1973. Applications of aerial and orbital remote sensing to the study of mined lands. In Research and applied technology symposium on mined-land reclamation. Pittsburgh, Penn. p. 15-25.

7. Einspahr, Dean W., A. L. McComb, F. F. Riecken, and W. D. Shrader. 1955. Coal spoil-bank materials as a medium for plant growth. Proceedings of the Iowa academy of science 62:329-344.

8. Engle, Carl F. and John P. Capp. 1967. Flyash: New hope for strip spoil. In Science. W. Va. Agr. Exp. Sta. Bull. No. 544.

9. Geyer, Wayne Allan. 1971. Survival and growth of trees on coal spoils in southeastern Kansas. Ph.D. Thesis, Univ. of Minnesota.

10. Geyer, Wayne A. and Nelson F. Rogers. 1972. Spoils change and tree growth on coal-mined spoils in Kansas. J. of Soil and Water Conservation 27:114-116.

11. Grandt, A. F. and A. L. Lang. 1958. Reclaiming Illinois strip coal land with legumes and grasses. Univ. of Ill. Agr. Exp. Sta. Bull. 628. Urbana, Ill.

12. Howe, Wallace B. 1956. Stratigraphy of pre-marmaton desmoinesian (cherokee) rocks in southeastern Kansas. State Geological Survey of Kansas Bull. 123. Lawrence, Kan.

13. Hunter, F. and J. Pringle. 1966. Soil fertility studies on restored opencast coal sites. Chemistry and Industry. p. 790.

14. Jacoby, Pete W., Jr. 1969. Revegetation treatments for stand establishment on coal spoil banks. J. of Range Management 22(2):94-97.

15. Kovacic, W. and R. G. Hardy. 1972. Progress report: Utilization of fly ash in the reclamation of coal mine spoil banks in southeastern Kansas. State Geological Survey Bull. 204. Lawrence, Kan.

16. Larsen, S. 1952. The use of ^{32}P in studies on the uptake of phosphorus by plants. Pl. Soil 4:1-10.

17. Lowry, Gerald L. 1960. Conifer establishment on coal spoils as influenced by certain site factors and organic additions at planting time. Soil Sci. Soc. Am. Proc. 24:316-318.

18. Murphy, Larry. 1971. Effects of fly ash as a soil amendment on strip-mined soils. Special Dist. Publ. 58. State Geological Survey of Kansas. Lawrence, Kan. p. 15-20.

19. Peterson, J. R. and J. Gschwind. 1973. Amelioration of coal mine spoils with digested sewage sludge. In Research and applied technology symposium on mined-land reclamation. Pittsburgh, Penn. p. 187-196.

20. Riley, Charles V. 1973. Furrow grading - key to successful reclamation. In Research and applied technology symposium on mined-land reclamation. Pittsburgh, Penn. p. 159-177.

21. Siehl, G. H. 1971. The issues related to surface mining. Compiled for H. M. Jackson, Chairman, Committee on Interior and Insular Affairs, United States Senate, A National Fuels and Energy Policy Study Serial No. 92-10. U. S. Government Printing Office, Washington.

22. Smith, R. M., E. H. Tryon, and E. H. Tyner. 1971. Soil development on mine spoil. West Va. Univ. Agr. Exp. Sta. Bull. 604T. Morgantown, W. Va.

23. Struthers, P. H. 1960. Forage seedings help reclaim acres of spoil banks. Ohio farm and home research. Vol. 45.

24. Struthers, P. H. 1964. Chemical weathering of strip-mine spoils. The Ohio J. of science 64:125-131.

25. Struthers, P. H. and J. P. Vimmerstedt. 1965a. Advances in stripmine reclamation. Ohio report 50:3-5.

26. Struthers, P. H. and J. P. Vimmerstedt. 1965b. Rapid stripmine reclamation. Ohio report 50:84-85.

27. Sutton, Paul. 1970a. Reclamation of toxic coal mine spoilbanks. Ohio report 55:99-101.

28. Sutton, Paul. 1970b. Restoring productivity of coal mine spoilbanks. Ohio report 55:62-63.

29. Sutton, Paul. 1973. Establishment of vegetation on toxic coal mine spoils. In Research and applied technology symposium on mined-land reclamation. Pittsburgh, Penn. p. 153-158.

30. Tien, Pei-lin. 1973. Petrology and mineralogy of underclays in cherokee group (middle pennsylvanian), Kansas. Ph.D. Thesis, Univ. of Kan.

31. Tisdale, Samuel L. and Werner L. Nelson. 1966. Soil fertility and fertilizers. 2nd edition. The Macmillan Co., Toronto, Ontario.

32. Trumbull, James. 1960. Coal fields of the United States (map-sheet 1). Department of Interior, United States Geological Survey. p. 1.

33. U.S.D.A., Agricultural Research Service. 1971. Project recovery. Agricultural research 19:8-9.

34. VanLear, D. H. 1971. Effects of spoil texture on growth of K-31 tall fescue. USDA Forest Ser. Res. Note NE-141, Northeastern Forest Exp. Sta. Upper Darby, Pa.

35. Vogel, W. G. 1973. The effect of herbaceous vegetation on survival and growth of trees planted on coal-mine spoils. In Research and applied technology symposium on mined-land reclamation. Pittsburgh, Penn.

36. Weber, L. S. 1970. The development and use of coal surface-mined lands in Illinois. In Land-use problems in Illinois. Environmental Geology Notes No. 46, Illinois State Geological Survey. Urbana, Ill.

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APPENDIX

Table I

YIELD OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 1

Nutrient Rate		Soil Number					
		Milligrams Dry Matter/Pot					
P ppm	K ppm	1	2	3	4	5	6
0	80	1145	1816	1626	1558	2433	1061
20	80	1590	2631	1911	2663	2295	1408
40	80	2261	3275	1841	2883	2658	1171
80	80	2488	3568	1680	2971	2760	1331
80	0	1871	2985	2186	2746	2003	1395
80	40	1866	3135	1801	2741	2556	1381
80	80	2488	3411	1735	2760	2483	1318
80	160	2298	3704	1958	3156	2488	1665
Plus Lime							
0	80	1056	1500				
40	80	2020	2813				
80	0	2003	3048				
80	80	2325	3096				

Table II

YIELD OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 2

Nutrient Rate		Soil Number					
		Milligrams Dry Matter/Pot					
P ppm	K ppm	1	2	3	4	5	6
0	80	1074	1201	1174	728	2234	1248
20	80	1585	1791	1103	1446	2146	1320
40	80	1809	2002	1055	1737	2097	1462
80	80	1799	2117	1310	2038	2152	1319
80	0	1863	1948	1258	1775	2279	1530
80	40	1636	2209	1408	1966	2042	1448
80	80	1713	2171	1370	2119	2456	1469
80	160	1617	2192	1354	1893	2246	1180
Plus Lime							
0	80	689	1367				
40	80	1835	2420				
80	0	1692	2240				
80	80	1727	2373				

Table III

YIELD OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 3

Nutrient Rate		Soil Number					
		Milligrams Dry Matter/Pot					
P ppm	K ppm	1	2	3	4	5	6
0	80	1156	1292	1746	554	2199	2027
20	80	1831	1817	1865	1585	2406	2082
40	80	1919	2019	1953	1944	2331	2230
80	80	2942	2118	1964	2124	2239	2201
80	0	1941	2094	1962	2002	2554	2222
80	40	2029	2220	1829	2074	2233	2201
80	80	2004	2016	1920	2170	2440	1985
80	160	2200	2224	1999	2456	2462	2652
Plus Lime							
0	80	1246	1453				
40	80	2107	2439				
80	0	1980	2210				
80	80	2003	2295				

Table IV

YIELD OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 5

Nutrient Rate		Soil Number					
		Milligrams Dry Matter/Pot					
P ppm	K ppm	1	2	3	4	5	6
0	80	717	2438	2604	1219	2888	2416
20	80	906	1886	2866	1518	3286	2864
40	80	1769	2255	2995	2326	2922	3208
80	80	2075	2508	3038	2738	3125	3483
80	0	1798	2038	3190	2585	3356	3146
80	40	2213	2272	3160	2564	3002	3303
80	80	2043	2219	2847	2948	2946	3076
80	160	2345	2323	2906	2471	3319	3026
Plus Lime							
0	80	1359	1474				
40	80	2548	3014				
80	0	2937	2700				
80	80	3281	2989				

Table V

PERCENT PLANT PHOSPHORUS FROM FERTILIZER AND AVAILABLE SOIL PHOSPHORUS INDEX AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 1

Nutrient Rate		Soil Number											
		1		2		3		4		5		6	
P ppm	K ppm	Fert. P	Index P	Fert. P	Index P	Fert. P	Index P	Fert. P	Index P	Fert. P	Index P	Fert. P	Index P
20	80	53.9	17.3	50.4	19.7	40.6	29.5	56.1	15.8	25.9	57.7	41.1	29.0
40	80	70.3	17.0	70.7	16.9	48.1	49.9	74.5	13.7	40.0	60.1	53.4	35.1
80	80	85.4	13.9	84.3	15.1	61.4	50.4	85.3	14.0	52.2	73.5	66.7	39.9
80	0	82.0	17.6	76.7	24.3	72.9	33.2	85.9	13.3	37.5	106.8	65.3	43.2
80	40	80.1	19.9	78.9	21.5	58.5	57.0	84.4	14.8	44.9	98.8	69.6	35.4
80	80	86.0	13.1	80.8	19.2	62.9	47.7	79.5	21.4	50.7	78.3	64.3	45.2
80	160	77.4	25.9	67.3	43.2	59.6	57.1	83.4	16.0	39.7	125.0	57.3	67.2
Plus Lime													
40	80	65.8	20.8	56.0	32.5								
80	0	80.4	20.1	66.0	49.5								
80	80	80.2	20.0	77.6	23.1								

Table VI

PERCENT PLANT PHOSPHORUS FROM FERTILIZER AND AVAILABLE SOIL PHOSPHORUS INDEX AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 2

Nutrient Rate		Soil Number											
		1		2		3		4		5		6	
P	K	Fert.	Index	Fert.	Index	Fert.	Index	Fert.	Index	Fert.	Index	Fert.	Index
ppm	ppm	P	P	P	P	P	P	P	P	P	P	P	P
20	80	45.3	25.2	69.0	12.7	35.9	35.8	57.3	16.3	18.9	86.5	26.4	40.8
40	80	53.7	36.9	63.2	23.9	47.6	44.3	82.9	8.7	33.7	81.1	62.4	34.2
80	80	66.4	42.4	68.5	37.2	71.8	35.2	65.3	43.2	43.1	105.6	31.5	71.8
80	0	69.8	35.0	71.9	35.0	67.9	39.0	62.3	49.5	48.6	87.0	69.3	39.4
80	40	71.1	33.1	63.7	45.7	61.0	55.9	66.0	41.2	45.3	97.6	67.2	41.1
80	80	63.3	47.8	61.0	52.9	53.9	70.6	63.8	45.8	38.0	134.3	58.8	56.2
80	160	63.1	46.8	62.6	47.9	57.1	61.0	67.1	39.4	43.7	108.4	60.8	53.3
Plus Lime													
40	80	106.8	5.7	91.4	4.1								
80	0	78.8	24.0	73.3	29.4								
80	80	81.6	20.6	62.1	49.2								

Table VII

PHOSPHORUS AND POTASSIUM CONCENTRATIONS OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 1

Nutrient Rate		Soil Number											
P	K	1		2		3		4		5		6	
ppm	ppm	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K
0	80	0.193	4.21	0.202	4.03	0.246	4.37	0.135	4.29	0.283	4.20	0.278	5.04
20	80	0.244	4.44	0.218	3.22	0.284	4.11	0.247	3.98	0.283	4.03	0.300	4.42
40	80	0.268	3.95	0.268	2.36	0.345	3.61	0.316	3.70	0.326	4.46	0.295	4.73
80	80	0.351	4.24	0.418	3.07	0.374	4.37	0.424	4.06	0.283	4.24	0.348	4.65
80	0	0.382	3.14	0.423	1.87	0.387	4.70	0.494	3.92	0.346	3.98	0.336	4.57
80	40	0.360	3.77	0.414	2.52	0.384	4.34	0.490	4.05	0.338	4.06	0.328	4.55
80	80	0.325	3.64	0.403	2.96	0.367	3.82	0.458	4.34	0.307	3.27	0.353	5.25
80	160	0.348	4.71	0.390	3.87	0.344	4.05	0.477	5.01	0.329	4.52	0.357	4.89
Plus Lime													
0	80	0.152	4.34	0.178	4.21								
40	80	0.280	4.44	0.271	3.17								
80	0	0.341	2.96	0.345	1.69								
80	80	0.369	3.95	0.356	3.04								

Table VIII

PHOSPHORUS AND POTASSIUM CONCENTRATIONS OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 2

Nutrient Rate		Soil Number											
P	K	1		2		3		4		5		6	
ppm	ppm	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K
0	80	0.179	4.18	0.075	3.30	0.231	4.18	0.096	4.47	0.249	3.94	0.169	4.60
20	80	0.288	3.15	0.154	2.16	0.235	3.88	0.180	3.10	0.296	3.86	0.229	4.17
40	80	0.312	2.56	0.259	1.51	0.239	3.78	0.183	2.66	0.272	3.36	0.245	3.99
80	80	0.313	2.52	0.345	1.45	0.205	3.40	0.432	2.27	0.309	3.48	0.268	3.99
80	0	0.318	1.59	0.315	0.80	0.214	3.09	0.441	1.64	0.268	2.81	0.262	2.92
80	40	0.318	2.03	0.375	1.13	0.241	3.29	0.414	2.33	0.276	2.71	0.304	3.25
80	80	0.394	2.12	0.396	1.28	0.290	2.96	0.429	2.23	0.356	2.65	0.302	3.27
80	160	0.339	2.43	0.323	1.36	0.255	2.94	0.393	2.23	0.329	2.79	0.272	2.96
Plus Lime													
0	80	0.084	2.67	0.078	2.38								
40	80	0.184	1.91	0.161	1.13								
80	0	0.263	1.49	0.334	0.69								
80	80	0.263	1.74	0.377	1.03								

Table IX

PHOSPHORUS AND POTASSIUM CONCENTRATIONS OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 3

Nutrient Rate		Soil Number											
P	K	1		2		3		4		5		6	
ppm	ppm	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K
0	80	0.108	2.38	0.109	1.72	0.198	2.80	0.100	2.91	0.203	2.16	0.157	2.42
20	80	0.146	1.70	0.136	0.97	0.216	2.31	0.118	1.43	0.215	2.32	0.198	2.48
40	80	0.182	1.95	0.184	0.78	0.249	2.62	0.173	1.34	0.223	2.37	0.203	2.74
80	80	0.217	1.77	0.250	0.66	0.254	2.64	0.256	1.25	0.239	2.50	0.238	2.64
80	0	0.229	1.26	0.263	0.60	0.221	2.41	0.272	0.86	0.216	2.90	0.225	2.64
80	40	0.219	1.43	0.241	0.60	0.242	2.57	0.248	1.17	0.233	2.41	0.253	2.45
80	80	0.220	1.50	0.250	0.73	0.242	2.51	0.284	1.32	0.239	2.65	0.246	2.70
80	160	0.208	1.44	0.241	0.81	0.250	2.29	0.258	1.25	0.236	2.21	0.189	2.43
Plus Lime													
0	80	0.115	2.28	0.107	1.38								
40	80	0.153	1.39	0.208	0.60								
80	0	0.199	1.11	0.278	0.29								
80	80	0.184	1.04	0.270	0.61								

Table X

PHOSPHORUS AND POTASSIUM CONCENTRATIONS OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 4

Nutrient Rate		Soil Number											
P	K	1		2		3		4		5		6	
ppm	ppm	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K
0	80	0.094	1.66	0.118	0.91	0.154	2.16	0.177	2.12	0.195	1.92	0.157	1.95
20	80	0.129	1.26	0.145	0.46	0.179	1.43	0.125	0.99	0.182	1.57	0.163	1.82
40	80	0.156	0.98	0.163	0.54	0.193	2.12	0.162	0.96	0.205	2.06	0.177	2.18
80	80	0.206	0.83	0.210	0.50	0.188	1.82	0.227	0.73	0.209	1.82	0.179	1.98
80	0	0.208	0.98	0.197	0.42	0.203	2.19	0.237	0.66	0.197	2.25	0.178	2.32
80	40	0.204	0.98	0.193	0.36	0.188	1.59	0.229	0.60	0.203	2.03	0.193	2.12
80	80	0.193	1.13	0.212	0.51	0.186	1.83	0.232	0.84	0.208	2.14	0.199	2.26
80	160	0.180	1.32	0.192	0.66	0.194	1.90	0.235	0.97	0.197	2.19	0.188	2.25
Plus Lime													
0	80	0.107	1.89	0.116	1.18								
40	80	0.143	1.46	0.184	0.65								
80	0	0.181	1.28	0.256	0.58								
80	80	0.169	1.59	0.236	0.84								

Table XI

PHOSPHORUS AND POTASSIUM CONCENTRATIONS OF PERENNIAL RYEGRASS AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 5

Nutrient Rate		Soil Number											
P	K	1		2		3		4		5		6	
ppm	ppm	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K	%P	%K
0	80	0.058	2.10	0.070	0.59	0.098	2.39	0.068	2.32	0.130	1.91	0.084	2.38
20	80	0.073	1.22	0.082	0.42	0.099	2.19	0.075	1.22	0.116	2.02	0.086	2.44
40	80	0.082	0.99	0.111	0.29	0.099	2.29	0.077	0.64	0.144	2.24	0.111	2.61
80	80	0.125	0.86	0.173	0.36	0.116	2.36	0.150	0.51	0.151	2.28	0.116	2.36
80	0	0.137	0.65	0.156	0.24	0.120	2.15	0.152	0.46	0.134	2.29	0.118	2.54
80	40	0.119	0.79	0.149	0.22	0.118	2.14	0.140	0.51	0.153	2.13	0.119	2.37
80	80	0.130	0.73	0.159	0.25	0.118	2.02	0.138	0.48	0.153	2.36	0.128	2.63
80	160	0.117	1.01	0.151	0.38	0.116	2.21	0.128	0.62	0.134	2.08	0.123	2.11
Plus Lime													
0	80	0.073	1.79	0.089	0.61								
40	80	0.084	1.13	0.132	0.31								
80	0	0.121	0.91	0.206	0.25								
80	80	0.113	0.91	0.188	0.31								

Table XII

AVAILABLE SOIL PHOSPHORUS AND POTASSIUM AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 1

Nutrient Rate		Soil Number											
		1		2		3		4		5		6	
P ppm	K ppm	P ppm	K ppm	P ppm	K ppm	P ppm	K ppm	P ppm	K ppm	P ppm	K ppm	P ppm	K ppm
0	80	2.8	121.7	7.9	68.7	13.0	128.3	6.2	99.3	27.5	95.3	10.7	113.7
20	80	3.4	136.0	12.0	75.7	21.5	130.7	8.3	82.0	32.1	96.0	15.6	116.0
40	80	5.1	150.7	23.2	77.3	29.0	142.3	12.8	88.7	34.7	93.7	15.3	122.3
80	80	13.2	138.7	38.5	80.0	44.5	143.7	27.1	85.3	47.9	96.7	35.5	109.3
80	0	12.8	160.7	39.2	79.3	49.2	140.0	28.6	83.7	49.8	100.3	39.0	98.3
80	40	11.3	128.7	37.3	78.7	41.9	120.0	24.5	77.7	45.3	94.3	40.5	111.0
80	80	11.7	132.0	32.0	80.0	57.7	122.0	25.3	86.0	50.7	91.0	40.2	111.0
80	160	15.5	141.0	41.1	89.3	42.2	138.3	27.4	89.3	44.1	99.3	27.7	123.0
Plus Lime													
0	80	3.6	152.7	9.8	81.3								
40	80	6.6	143.3	29.8	82.7								
80	0	22.1	137.7	46.0	83.3								
80	80	20.4	142.7	42.8	82.7								

Table XIII

AVAILABLE SOIL PHOSPHORUS AND POTASSIUM AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 2

		1		2		3		4		5		6	
P	K	P	K	P	K	P	K	P	K	P	K	P	K
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
0	80	3.8	162.8	13.4	95.0	10.7	156.7	12.1	138.7	16.0	116.0	9.4	148.3
20	80	4.5	150.3	18.3	87.0	16.2	161.3	12.5	125.0	21.7	109.3	10.2	198.7
40	80	6.2	144.7	22.1	88.7	15.3	157.7	16.4	121.7	25.3	116.7	13.2	154.0
80	80	9.1	146.3	35.6	86.0	26.4	155.3	21.3	118.7	33.0	113.3	27.5	148.7
80	0	10.6	138.0	25.3	72.7	21.7	150.7	25.5	102.7	29.8	106.0	22.4	128.0
80	40	10.2	136.7	32.4	85.3	23.4	149.7	22.1	108.0	32.8	112.7	19.1	137.7
80	80	10.0	145.3	30.9	87.7	24.5	132.0	23.5	103.0	31.5	137.3	25.1	152.0
80	160	10.4	170.3	37.4	105.3	23.4	159.0	23.0	130.3	31.7	124.7	22.5	171.0
Plus Lime													
0	80	3.8	166.7	16.2	114.3								
40	80	7.1	157.0	27.2	134.7								
80	0	13.9	151.0	40.5	87.0								
80	80	14.0	152.3	37.9	97.7								

Table XIV

SOIL pH AND AVAILABLE PHOSPHORUS AND POTASSIUM AS AFFECTED BY PHOSPHORUS, POTASSIUM AND LIME TREATMENTS AND SOIL SOURCE - HARVEST 5

Nutrient Rate		Soil Number																	
		1			2			3			4			5			6		
P ppm	K ppm	P ppm	K ppm	pH	P ppm	K ppm	pH	P ppm	K ppm	pH	P ppm	K ppm	pH	P ppm	K ppm	pH	P ppm	K ppm	pH
0	80	1.5	78.7	5.1	5.9	49.7	4.7	8.2	119.7	7.5	4.6	72.3	5.6	19.3	78.7	7.4	6.0	97.7	7.7
20	80	3.0	85.3	4.9	7.1	55.3	4.7	12.4	121.7	7.6	5.1	63.3	5.9	24.0	87.3	7.5	7.9	91.7	7.6
40	80	4.1	84.3	5.1	19.1	54.0	4.7	17.3	114.3	7.6	6.7	62.7	5.8	28.1	82.7	7.5	10.9	97.7	7.7
80	80	8.6	83.7	5.0	19.1	54.0	4.7	37.7	119.7	7.6	11.2	65.0	5.7	39.8	77.7	7.5	23.4	103.7	7.7
80	0	9.8	91.7	5.0	25.1	51.3	4.8	29.1	109.3	7.6	14.0	63.7	5.7	39.1	81.3	7.6	23.4	94.3	7.6
80	40	8.7	90.3	4.9	21.3	54.3	4.8	38.8	120.0	7.6	13.2	61.0	5.8	38.9	79.3	7.5	22.3	100.0	7.7
80	80	8.5	95.0	5.0	18.9	55.3	4.9	36.1	114.0	7.6	11.3	63.7	5.8	38.9	83.7	7.5	24.3	89.0	7.7
80	160	8.7	92.7	5.0	18.6	59.0	4.9	33.5	113.3	7.6	12.5	71.7	5.7	40.1	84.3	7.5	22.9	96.7	7.7
Plus Lime																			
0	80	3.1	90.0	6.8	6.5	51.3	5.7												
40	80	5.1	104.0	6.0	11.0	60.7	6.5												
80	0	12.7	105.7	6.5	24.4	62.7	5.5												
80	80	11.4	100.3	6.6	18.6	63.3	5.6												

PLANT EXTRACTION OF PHOSPHORUS AND POTASSIUM FROM RECLAIMED STRIP-MINED SOILS IN KANSAS

by

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Four strip-mine and two virgin soils from the coal-mining region of southeastern Kansas were used to study the plant extractable phosphorus and potassium in strip-mine soils and to determine if the available phosphorus and potassium are accurately measured by soil testing.

The plant extractable phosphorus and potassium content of three of the four strip-mine soils were found to be higher than virgin soils after 28 weeks of intensive cropping (5 harvests) in the greenhouse. The fourth strip-mine soil was found to be about equal to the virgin soils. The three superior strip-mine soils maintained higher levels of available soil phosphorus and potassium throughout the study.

After an initial period of slow growth, three of the four spoilbank soils produced higher dry matter yields, produced higher phosphorus and potassium concentrations in the plants, and maintained higher levels of available phosphorus and exchangeable potassium in the soil. Soil test results were found to accurately predict the initial plant available phosphorus and potassium content of the soil. After 28 weeks of intensive cropping, it was found that several of the spoilbank soils were able to maintain a higher level of plant available potassium than a virgin soil with a comparable initial soil test level.

When lime was added to the two acid soils (one spoilbank, pH 5.0 and one virgin soil, pH 5.1) yields and plant phosphorus uptakes were depressed at the first harvest, but were significantly increased by the fifth harvest. Liming lowered phosphorus availability at the first two harvests but had significantly increased it's availability by the fifth harvest. Potassium availability was increased by liming at harvests 4 and 5. Liming significantly increased the pH of both soils.