USDA United States Department of Agriculture | Cooperative States Research Service Washington, D.C. 20250 | CSRS-1

EPA United States Environmental Protection Agency | Office of Research and Development | Industrial Environmental Research Laboratory Cincinnati, Ohio 45268 | EPA-600/7-77-093 August 1977

# RECLAMATION OF SURFACE MINED COAL SPOILS

Interagency
Energy-Environment
Research and Development
Program Report

## RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/7-77-093
August 1977

# RECLAMATION OF SURFACE MINED COAL SPOILS

by

Richard I. Barnhisel
Kentucky Agricultural Experiment Station
Agronomy Department
University of Kentucky
Lexington, Kentucky 40506

CSRS IAG No. D6-E762

Project Officer

Ronald D. Hill

Resource Extraction and Handling Division
Industrial Environmental Research Laboratory - Cincinnati
Cincinnati, Ohio 45268

This study was conducted in cooperation with the Cooperative State Research Service, U.S.D.A., Washington, D. C. 20250

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

## DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory - Cincinnati, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

## FOREWORD

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

Reported here is the results of a study supported cooperatively by U. S. Department of Agriculture and U. S. Environmental Protection Agency at the Kentucky Agricultural Experiment Station. A study was conducted to evaluate several soil treatments of reclaimed coal mines to improve plant establishment and growth. The results of this work should provide to the reclamation specialist of a mining company or control agency additional methods to establish good ground cover to minimize the environmental problem from surface mining. For further information contact the Extraction Technology Branch of the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

## ABSTRACT

Field experiments were established in western Kentucky on four types of surface-mined coal spoils. These areas were selected to represent the extremes in spoil materials commonly encountered in reclamation. This report presents evidence that mine spoils may be successfully reclaimed when proper levels of fertility have been restored.

With the provision for retaining rainfall on the spoils, yields of mixed legume-fescue forage exceed 4 metric tons per hectare (2 T/acre). These yields are equal to or greater than those of adjacent non-mined land. The advantage of a rough surface created by ripping or subsoiling was obtained at all levels of applied phosphorus. The use of a chisel plow or heavy-duty disk produced a rough micro-relief that also produced significantly greater forage yields than obtained from smooth graded plots.

It was found that phosphorus and water are more commonly the limiting factors in obtaining an adequate degree of vegetative cover and associated forage yield than the acidic nature of spoils. However, in acidic spoils lime must be incorporated in order to effectively improve the growing conditions. Downward movement of lime should not be expected to occur at a rate sufficiently high to improve the growing conditions of spoils for plants. Acidic spoils also tend to be much more droughty than adjacent non-acid spoils as the result of a restricted rooting depth.

TABLE OF CONTENTS

Table of Contents (cont'd) Page

LIST OF TABLES

List of Tables (cont'd)

ACKNOWLEDGEMENTS

This study was conducted cooperatively by the Agronomy Department with Southwind Coal Mining Co., Peabody Coal Co., and Kentucky Reclamation Association Inc. The cooperating companies assisted by providing land on which the experiments described were conducted, technical assistance in planning as well as providing labor in the establishment of the experimental treatments and their subsequent evaluation.

The diligent work of Mr.James L. Powell, Reclamation Supervisor, Peabody Coal Co., Mr. Richard Buddeke, Southwind Coal Co. and and Mr. Ben Walcott, KRA is greatfully acknowledged. Without the assistance of these persons, the field work could not have been conducted. The completion of this project would not have been possible without the assistance of Mr. Gary W. Akin and Mr. Wayne Ebelhar, both of whom are graduate assistants, as well as several undergraduate assistants.

C. Oran Little served as Project Officer for the Kentucky Agricultural Experiment Station, and Eilif V. Miller coordinated the effort for the Cooperative State Research Service, USDA.

# I. CONCLUSIONS

A significant forage response to applied phosphorus was obtained for Ky 31 tall fescue and red clover planted on neutral surface-mined coal spoils. This response was enhanced on plots that were ripped or subsoiled. The effect of ripping significantly increased forage production at all phosphorus levels tested. The ripping improved the microrelief which resulted in keeping more rainfall on the spoil areas, hence reduction in runoff should have occurred although this was not measured. The rough spoil surface temporarily stores water so that the effect of the poor infiltration property of spoils could be counteracted. An improved microrelief was obtained by both the chisel plow and the heavy-duty disk, therefore, these implements may be used in place of the rippers thus large acreages could be economically treated. Yields from fescue red clover forage, when ample phosphorus was applied, equaled those of adjacent non-mined lands.

The acid nature of spoils appears to reduce vegetative cover indirectly both by the fixation of phosphorus as iron-phosphate and the restriction of root growth and in effect acid spoils are unusually droughty. Yields obtained from a slightly acid shale location were significantly larger than those from an acid shale site. As demonstrated in earlier research, the acid spoils are more harmful to legumes than Ky 31 tall fescue.

Both disking or chisel plowing were effective in lime incorporation. The incorporation of added lime appears to be extremely important and downward movement below zone of incorporation should be expected to occur only at a very slow rate.

It is apparent that on acid spoils competition for water between grasses and legumes may be more critical than on slightly acid or neutral spoils. The selection of more drought tolerant plant species may be beneficial on such surface-mined spoils.

## II. RECOMMENDATIONS

An evaluation should be made at each mine site of the potential spoil materials that could occupy the graded surface. These potential spoils should be considered with respect to their suitability as a growing media for the various plant species that could be planted during revegetation. This information will allow the surface-mine operator to consider alternative mining practices such as, spoil placement or segregation versus chemical amendments necessary to obtain the desired properties of spoils so that a suitable vegetative cover may be obtained.

Recognition and subsequent correction of several possible limiting factors will allow reclaimed surface-mined areas to realize their maximum agricultural potential. Such limitations include: (1) a general low fertility of spoils with respect to phosphorus, nitrogen, and possibly potassium; (2) acidic properties both active and the potential acidity which may be released by the oxidation of sulfide minerals; and (3) droughty nature of spoil materials including physical properties as water storage capacity, infiltration and particle size or textural components. An evaluation of the suitability of any given spoil material with respect to its chemical properties may be obtained by submitting samples to testing laboratories (such as the Kentucky Agricultural Experiment Station) which are equipped to handle such spoil materials.

The phosphorus fertility status should be determined on all spoil materials prior to seeding. Spoils may be tested with procedures commonly used to test soils, however, only limited research is presently available to determine if the fertilizer rates as recommended from thest tests are applicable to the reclamation of spoils. Yields from plots fertilized according to the recommended levels should be measured over several years inorder to determine if a single application at seeding will sustain both a vegetative cover and forage production. Supplemental applications of phosphorus may be needed with time since spoil tests taken from established plots were much lower the second growing season.

The nitrogen status of mined spoils should be expected to be nil as the organic matter levels are essentially zero. Applications of nitrogen will be necessary to establish a vegetative cover. At least one legume species should be included in all reclamation plantings. Care should be taken in applying nitrogen as not to reduce the effectiveness of the legume to supply nitrogen, in addition, split applications of nitrogen appears to reduce the competition between grass and legume species.

The amount of available potassium should be determined for all spoils. In general, shaly spoils appear to supply adequate amounts for maximum growth. Based on a limited amount of information, it appears that sandy spoils may not have adequate potassium levels. This research project was not conducted over a sufficient amount of time to evaluate changes in potassium levels for plots in which the forage produced was removed.

Lime additions should be made based on test results from both the active acidity (measured by a test such as the SMP buffer method) and the total potential acidity (oxidation of sulfide minerals). All lime should be incorporated into the spoils to facilitate as deep a rooting zone as possible. Field evaluations of these laboratory tests are needed as both a function of lime rates and time. Recommendations made from both the SMP buffer and total potential acidity tests were done with the assumptions commonly used for soils. Therefore, the assumptions as to reaction rate, lime quality and fineness of grind should be tested at various lime rates.

An effort to create a rough surface, on a micro-scale, should be made in the preparation of a site for seeding. This practice not only reduces runoff and its accompanying erosion, but also providing more available moisture for utilization by the vegetative species. Although it was assumed that yield response of the roughest plots was the result of greater available moisture, this theory should be tested on small water sheds or with a rainfall simulator.

It is apparent that a mulch will be beneficial in both the establishment of a vegetative cover and the maintenance of forage production on surface-mined spoils. The effect of the mulch appeared to increase the amount of available moisture as well as allow a significant phosphorus response. These benefits were found on a neutral shale site which was somewhat unexpected. The experimental design did not allow us to separate the effects of mulch versus subsoiling since mulch was not applied to the control areas. Subsequent testing will be necessary not only on shaly but also the more droughty sandy spoils.

Since moisture holding capacity and water infiltration of spoils should be largely a function of spoil type, geologic maps should serve as a basis of preplanning so that the operator can place the most desirable materials on the surface. Considerations as to the chemical properties of the respective geologic formations should have a precedence over water holding or infiltration considerations. Since geologic maps are not prepared on a scale to show detail and since assumptions are made in the mapping process by extending information from a few rock outcrops to large areas, verification should be made as to the thickness and other changes in the various geologic formations as mining takes place.

The plant species used in the reclamation effort should be made according to the projected agricultural use as well as to their tolerances to drought or high temperatures, to their ability to grow at low phosphorus fertility levels and to their possible tolerance to toxic levels of iron, manganese and aluminum. These three types of adverse conditions may or may not occur simultaneously on any given site. For Kentucky climatic conditions, Ky 31 tall fescue provided both an adequate vegetative cover as well as producing forage yields equal to those of non-mined land. These results were obtained on shaly spoils which had lime requirements of less than 30 metric tons per hectare (13 T/acre). On more acid and/or droughty sandy spoils, tall fescue did not prove to be successful. On a trial area, a small plot of common bermudagrass was seeded and although additional testing is required, it appears that bermudagrass may serve to revegetate this spoil type.

The suitability of reclaimed surface-mined land for sustained agricultural production is not known. The effect of removing forage by animal grazing and the subsequent recycling of nutrients may be beneficial in the formation of a "soil". Other pasture or range management practices such as reseeding or renovation, applications of nitrogen and other fertilizers as well as clipping or mowing should be evaluated on reclaimed areas. Changes in plant species, vegetative cover, stand density as a result of the above management practices should be evaluated in field trials.

Areas requiring additional research

Associated with the above recommendations, comments were made as to areas in which additional research is needed for verification of these recommendations over longer periods of time. Many of these gaps in the research findings will be filled with the monitoring of the established areas associated with this research project but for others additional field experiments will be required. Based on the research finding presented in this report the specific areas requiring additional research are as follows: (1) Burial of acid shale vs heavy liming, (2) benefits of mulching on various spoil types, (3) evaluation of tillage and other techniques to provide more efficient use of available moisture including the evaluation of micro-climate and the promotion of water infiltration rather than runoff, (4) evaluation of fertility requirements such as nitrogen, phosphorus and potassium in order to obtain sustained forage production especially as on mined land having a high agricultural potential, and (5) evaluation mixtures of plant species and management systems that stimulate natural succession.

In addition, much has been speculated as to the benefits of top-soiling in reclamation. Most likely there are many areas in the United States in which top-soiling would be beneficial, but in other areas, especially in Kentucky, the available topsoil materials may have physical and chemical properties less desirable than certain geologic materials, therefore, the assumption that topsoiling is always better is not valid. The contribution of sediment of this topsoil material should be evaluated especially when it overlies spoils of contrasting physical properties. The cost-benefit relationships of topsoiling should be investigated as well as determining how one should reconstruct a soil to maximize the agricultural potential of the reclaimed land.

This report covers the findings from one and one half years of laboratory and field work on a series of selected minespoil sites. Follow-up research now under way on existing experimental areas and on new sites will permit further precision of reclamation recommendations in subsequent reports by the author.

## III. INTRODUCTION

Considerable acreages of land have been and are being disturbed by surface mining of coal in the two coal fields of Kentucky. Although mining techniques are different, similar problems exist in the reclamation of these spoils from a chemical and physical viewpoint. The project, as proposed, deals with surface mining in the western Kentucky coal field.

In Kentucky, progress from demonstrations, field trials, and research projects have been reported (eg. Berg and Vogel, 1968; Berg and Vogel, 1973; Curtis, 1971; Vimmerstedt, 1970; and Vogel, 1973). These have been largely restricted, however, to investigations in eastern Kentucky and although success has been achieved, only limited application can be made for western Kentucky. This lack of application largely resulted from the difference in surface mining techniques as well as the terrain. In western Kentucky, area mining is used whereas in eastern Kentucky, surface mining follows the contour. These two mining techniques result in significant differences in topography and associated reclamation problems. Area mining used in western Kentucky results in poorer moisture conditions as the disturbed area is not buffered by undisturbed regions. The order or priorities or steps needed with respect to achievement of successful reclamation are not the same.

Chemical, physical and mineralogical properties of spoils are highly variable. This variability occurs simultaneously on a macro and micro scale. Variations with respect to major rock strata are important in the overall consideration of a reclamation plan but not any more so than are variations in chemical environment on a small scale can result in bare or reduced vegetative cover. The presence of sulfide minerals in particular pyrite and marcasite, associated with coal deposits potentially may release ions toxic to plant growth (eq. Barnhisel and Massey, 1969; Berg and May, 1969; Cummins _et al._, 1965; Massey, 1972; Massey and Barnhisel, 1972; and Plass and Vogel, 1973). These toxic conditions could explain the lack of consistent establishment of vegetation on acid spoils.

Although it seems that simple addition of lime to spoils when acid conditions exist would solve this problem of reclamation, prediction of lime rates that allow economic solution are not known. A literature search will reveal that very few replicated experiments have been conducted for determination of proper lime rates and none in Kentucky (Funk, 1962; Plass, 1969; Sutton, 1973; Czapowskyj, 1976).

Although not all spoils are acidic at time of seeding, in the past, poor vegetation was usually attributed to acidity. Some of these spoils may have become acid after failure in reestablishment of vegetation. Such an occurrence was believed to have been the result of other factors such as lack of phosphorus or other plant nutrients and the generally droughty nature of spoils. Observations of spoils in which a vegetative cover was absent reveal an appearance of a "desert" pavement. Chances for survival and growth of scattered existing plants under such conditions is extremely poor. These areas became "moonscapes" and the cause often placed on the wrong thing, acidity, whereas the lack of available moisture more frequently is the culprit. This deficiency was further ignored as the result of the paradoxical conditions associated with a "desert" pavement that being, an unusually high runoff rate as the result of both poor infiltration and temporary water storage.

The objectives of this study were: (1) to determine the chemical and physical properties of surface mined coal spoils and to determine how these properties affect establishment and survival of vegetative cover; (2) to develop a method of tillage compatible with the physical properties of spoils as to produce a stable microrelief which allows increased infiltration of rainfall and its subsequent utilization by vegetation, and (3) to evaluate, in field experiments, the lime rates predicted from both the standard SMP buffer pH method and a hydrogen peroxide oxidation potential total acidity test.

Objectives presented above were evaluated either separately or in combinations at four locations. These sites were selected to give a range of chemical and physical conditions typical of spoils found in the western Kentucky coal field. Data from a preliminary study which had been established in anticipation of obtaining the present grant are also included in this report.

## IV. METHODS AND MATERIALS

### GEOLOGICAL DESCRIPTIONS OF RECLAMATION SITES

#### NEUTRAL SHALE SITE

Spoils consisted of overburden from the Elm Lick coal bed (sometimes referred to as No. 6 or the Dunbar coal bed) of lower Pennsylvanian Age. The coal bed ranges in thickness up to 1 meter with occasionally two rider seams of 0.5 meter thickness each. Spoils were comprised of gray, weakly cemented shale and siltstone rock fragments. These materials were relatively hard when first exposed but within six months decomposed to a material having a texture of loam with varying amounts of thin (0.5 to 1 cm) rock fragments of weakly cemented sandstone. The weathered spoils generally have a neutral pH with little or no sulfide minerals, i.e. zero potential acidity. Where the rider coal seams are thin, or the ash content high, this coal is incorporated into the spoils during mining and when this occurs the resulting spoils may have a slightly acid pH. Specific chemical and physical data are presented later.

The field study was located in Ohio Co., Geologic Map of the Rosine Quadrangle, GQ-928 with approximate coordinates of 37° 24' north latitude and 86° 41' 30" west longitude. The site has an approximate elevation of 200 meters MSL with a slope of 6 percent and a southwest aspect.

#### SLIGHTLY ACID SHALE SITE

Spoils at this location were derived from overburden from the same coal bed described above. The proportion of carbonaceous shale immediately above the Elm Lick coal was thicker at this location and accounts for its slightly more acid pH. The greater frequency and thickness of the weakly cemented sandstone strata also resulted in a more rocky spoil. In addition, the shale member contained nodules of hard clay-ironstone that when weathered have a red, purplish-red or dark brown color.

The field study was located at approximate coordinates of 37° 25' north latitude, 86° 47' west longitude. The elevation is approximately 170 meter MSL with a slope of 2 percent and a eastern aspect.

ACID SHALE SITE

Spoils at this location were derived from the overburden associated with the No's 9, 11 and 13 coal beds of middle and upper Pennsylvanian Age. As the result of inversion during mining, the major proportion of the spoil materials is probably derived from strata above the No. 9 coal bed. These strata contain siltstone, shale and sandstone beds. The shale immediately above the coal is highly carbonaceous and flaggy with a pyritic or sulfide bearing mineral that contributes to the acidic nature of these spoils. Most of this shaly material is buried during mining but when incorporated into the spoils, zones of extremely acidic spoils occur in erratic shapes when graded. The sandstone materials contain some pyrite that upon weathering contributes to the acidic nature of the spoil. Overburden above the No. 11 and 13 coal beds consist of shale, sandstone and limestone beds. The contribution of these materials to the spoils if uniformly mixed would be less than one-fourth of the total thickness. Limestone rock fragments when present in the spoil tend to be large, hard and ineffective in neutralizing the acid associated with No. 9 overburden.

The study site is located at approximate coordinates of 37° 17' north latitude, 86° 57' 30" west longitude. The site has an elevation of approximately 120 meters MSL with a slope of 3 percent and a north aspect.

VERY ACID SANDSTONE SITE

Spoils at this location were derived from overburden associated with the No.'s 11 and 12 coal. The rock strata are composed of medium grain sandstone above the No. 12 that weathers to a bright-orange, brown color. This sandstone contains sulfide minerals which, when oxidized, results in an extremely acid spoil. Separation between the No. 11 and 12 coal beds is usually less than 10 meters and consists of limestone, shale and underclay. This material has been randomly mixed with the sandstone overburden. The sandstone portion makes up more than 80 percent of the spoil materials. The limestone fragments remaining are hard massive rock of boulder size whereas the shale and underclay materials are blended in with the sandstone upon grading.

This study site is located at approximate coordinates of 37° 17' 30" north latitude and 87° 14' 30" west longitude. The elevation is about 135 meters MSL and with a slope of 5 percent and a southerly aspect.

# FIELD EXPERIMENTS

Neutral Shale Site. All experimental treatments described below were established in the spring planting season (March). The experiment described below was established to answer questions raised by objectives 1 and 2 of section III. This site was located on land mined by the Southwind Coal Mining Co. Inc.

A randomized split-plot experimental design with six replications was employed to test the effect of site preparation and phosphorus fertilizer on the establishment of red clover *(Trifolium pratense L.)* and Kentucky 31 tall fescue *(Festuca arundinacea)* as a vegetative cover. The four tillage-site preparation treatments were performed on the contour, with a plot size of 6.1 x 20.1 meters (20 x 66 feet). The preparation treatments were the whole plots and included: (1) smooth graded and disked one time with a tractor-mounted disk; (2) smooth graded and disked three times with the same disk: (3) smooth graded, disked three times, and ripped (or subsoiled) with two ripper spikes mounted on the tool bar of a D-9 Caterpillar tractor; and (4) smooth graded, disked three times, ripped (or subsoiled) and a mulch equivalent to 1680 kg fescue hay per hectare (1500 lbs/acre) was applied. The rippers used in treatments (3) and (4) were operated at a depth of 60 cm (24 in) and the tractor made two passes per plot so that the ripped channels were spaced approximately 1.5 meters (5 feet) apart.

Each of the whole plots was divided into three subplots 6.1 x 6.7 meters (20 x 22 feet) for the various phosphorus treatments. The phosphorus fertilizer (concentrated superphosphate, i.e. 0-46-0) was applied at the following rates: (a) 0 kg P/ha; (b) 84 kg P/ha (75 lb P/acre); and (c) 168 kg P/ha (150 lb P/acre).

Nitrogen was uniformly applied as ammonium nitrate at a rate of 28 kg N/ha (25 lb N/acre) at seeding. An additional 28 kg N/ha was applied both in the fall and the following spring.

The seeding rates for fescue and red clover was 44.8 and 13.4 kg/ha (40 and 12 lb/acre), respectively. All seed and fertilizers were applied to the surface after the tillage treatments were established.

Spoil samples were collected prior to establishment of the various phosphorus-tillage treatments, two months following establishment from each sub-plot. The following year, spoil samples were collected from each subplot in the spring and following the second forage harvest in August. Each sample was a composite of two subsamples taken from the upper 15 cm of each plot.

Forage samples were not collected the first or establishment year. The following May, forage harvests were made from randomly chosen areas from each of the subplots with a rotary lawn mower. All harvests were made perpendicular to the travel of the tillage implements. The fresh plant weight was determined in the field and subsamples were taken from each subplot to determine both moisture and plant chemical composition. These plant samples were placed in plastic bags, sealed, and frozen using dry ice. The plant samples were maintained frozen until they were placed in an oven for moisture analysis.

Slightly Acid Shale Site. The use of rippers, as described in the above experiment, produced an apparent stable microrelief, however, two factors may prevent its acceptance: (a) the use of a large Caterpillar tractor would be costly and (b) large rock are brought to the surface by this tillage practice and the surface no longer satisfied the smooth grading requirement. Therefore the experiment described below was established as an alternative. All treatments were established in the fall seeding season (September) as it is at this time the majority of reclamation plantings are made in western Kentucky. Objectives numbers one and two of Section III, page 5, are associated with this experiment.

The site on which the following experiment was located was mined by the Southwind Coal Mining Co. Inc. A randomized split-plot experimental design with four replications was used in which the whole plots were three tillage treatments (1) smooth graded; (2) disked with large heavy-duty pull-type wheel disk; and (3) chisel plowed. These three treatments are given above in order of increased roughness. Superimposed on each of the tillage treatments as subplots were various legume species seeded with Kentucky 31 tall fescue (*Festuca arundinacea*). These species included: red clover (*Trifolium pratense L.*); white clover (*Trifolium repens L.*); crownvetch (*Coronilla varia L.*); yellow sweetclover (*Melilotus officianalus*); alfalfa (*Medicago sativa L.*); sericea lespedeza (*Lespedeza cuneata*); and birdsfoot trefoil (*Lotus corniculatus L.*). All subplots were 5 x 10 meters (16.5 x 33 ft) and the various plant species were seeded with hand spreaders on the spoil surface after the tillage was performed. The fescue was seeded uniformly over the entire area at a rate of 40 kg/ha (35 lb/A). The legumes were seeded at rates recommended for agricultural soils (See Kentucky Agr. Exp. Sta. publication AGR-18 for recommended seeding rates). Uniform rates of phosphorus, 84 kg P/ha (75 lb P/acre), and nitrogen, 28 kg N/ha (25 lb N/acre), were applied at seeding to entire area. An additional application of nitrogen, at the above rate, was applied in the following spring.

Sampling techniques with respect to forage and spoil samples were the same as those described for the previous study.

Acid Shale Site. The identical experiment as described above (b) Slightly Acid Shale Location, was also established on land mined by Peabody Coal Co. Experimental objectives numbers one and two are also applied to the study of this location. At the time of establishment of this experiment, the pH of the spoils was not below the minimum pH level required by the Division of Reclamation, hence, Ag lime was not applied. The following summer, and after the second forage harvest, the pH had dropped below these standards and Ag lime was applied at a rate of 15 metric tons/ha (7 t/acre) without incorporation.

Very Acid Sandstone Site. All experimental treatments described below were established in the fall planting season (September) on land mined by Peabody Coal Co. This experiment was designed to answer questions raised by objectives 1, 2, and 3 of section III. Previous experience by coal companies in the area indicated that very large lime rates would be required. Two lime rates were chosen, 67.2 metric tons/ha (30 t/acre) and 134.4 metric tons/ha (60 t/acre) based on the SMP buffer pH method. Unfortunately, after the site was chosen, it was determined that essentially all the sulfide minerals had been already oxidized and hence the SMP buffer lime requirement and potential acidity lime requirement were the same. In addition to the two lime rates, two methods of lime incorporation were used, disking with a heavy-duty wheel disk and with a chisel plow. These incorporation methods were compared with surface applied lime. A randomized block experimental design was used with four replications and all plots were 10 by 10 meters (33 x 33 feet). Immediately after the lime treatments were established, the entire area was seeded to Ky 31 tall fescue at 40 kg/ha and a mixture legume species (alfalfa, red clover, crownvetch, birdsfoot trefoil and sericea lespedeza). The rate of each legume used was one-fifth that of the recommended rates for agricultural soils. On one of the incorporation treatments, the seeding of the legumes was delayed until March. This resulted in the following ten combinations of lime incorporation - seeding treatments: (1) 67.2 mt/ha (30 T/acre) of Ag lime incorporated by disking; (2) 134.4 mt/ha (60 T/acre) disked; (3) 67.2 mt/ha incorporated by chisel plowing: (4) 134.4 mt/ha chisel plowed; (5) 67.2 mt/ha incorporated by disking but legume seeded in following spring; (6) 134.4 mt/ha disked and delayed legume seeding; (7) 33.6 mt/ha incorporated by chisel plowing, then 33.6 mt/ha applied to the surface; (8) 67.2 mt/ha incorporated by chisel plowing, then 67.2 mt/ha applied on the surface; (9) 67.2 mt/ha applied to freshly smooth graded plots without incorporation; and (10) 134.4 mt/ha of Ag lime applied to the surface. All lime was applied by a spreader truck and a border zone around each plots was rates.

Forage samples were collected by the technique described in section a of the above. However, because of the poor vegetative growth and subsequent yields, only one forage harvest was made. Spoil samples were taken as described above except the last sampling, one year after establishment, were increment samples. These were collected from 0-5, 5-10 and 10-15 cm depths with sufficient numbers of probings to yield at least 250 gram. This usually required 10 such subsamples and these were taken randomly over the 10 x 10 meter area.

Evaluation of Microrelief. Changes in the microrelief created by the rippers were evaluated with a device constructed similar to that described by Curtis and Cole, 1972. A 1 x 1.5 meter piece of peg-board was framed with aluminum angle and holes drilled at 2.5 cm intervals in this angle frame so that 1 meter copper coated steel welding rods would freely slide up and down. On each end of the peg-board was secured a small section of capped, 7.6 cm pipe.

Steel fence posts were driven into the spoils so that the peg-board frame could be slopped over the permanent reference stakes. Once the peg-board was in place, the steel rods were lowered as to touch the spoil surface. The micro-relief of the spoil surface was recorded one week after establishment as well as at two and four months.

## LABORATORY METHODS

Spoil Sample Preparation. All spoil samples collected in the field were air dried. They were ground to pass a 2 mm screen with a mechanical grinder and stored in plastic bags until analyzed.

pH Measurement in Water, KCl and SMP Buffer Solutions. Appropriate amounts of each spoil sample was weighed into 100 ml plastic beakers so that a one-to-one solid:liquid ratio was obtained in the case of $H_2O$ and 1N KCl and a 1:2 ratio for the SMP buffer. The SMP buffer was made up according to the directions of Shoemaker et al., 1961. The pH's of the samples were determined after 30 minutes, with occasional stirring, using a Corning model 7 pH meter equipped with glass and calomel electrodes.

Phosphorus Analysis. All spoil samples were tested for "available" phosphorus using a method adapted from Bray and Kurtz, 1945 often referred to as the "Bray-1 method" Spoil samples collected from the neutral shale experimental site in which various phosphorus rates had been applied were subjected to the phosphorus fractionation procedure proposed by Chang and Jackson, 1957. This method partitions the total phosphorus into four components: (1) "available" or ammonium chloride extractable phosphorus; (2) aluminum phosphate; (3) iron phosphate; and (4) calcium phosphate.

Potential Acidity. The potential acidity of selected samples from each experimental location were analyzed by a hydrogen perioxide oxidation technique. Briefly this involves finely grinding the sample to a "flour", oven drying, and weighing a 2.0000 g sample into a tall form, 500 ml beaker. Successive 10 ml additions of 30% $H_2O_2$ was added until rapid oxidation reaction does not take place. Supplemental heating may be needed to insure that the sulfide oxidation reaction takes place. After the reaction is completed, the acid released is titrated to neutrality with standardized NaOH.

Exchangeable Cations: Calcium, Potassium, Magnesium and Sodium. Exchangeable cations of selected spoil samples were determined by the neutral normal, ammonium acetate method. Briefly this method includes extraction of 10 g samples with successive small portions of neutral N $NH_4OAc$ using a Buchner funnel until 100 ml volume is obtained. The displaced Ca, K and Na was determined with a Technicon flame photometer and Mg with a Varian atomic absorption instrument.

Plant Sample Preparation. Forage samples collected in the field were maintained below freezing temperatures until moisture analyses could be determined. The fresh moist weights were determined and the samples were placed in an oven maintained at 70°C. After drying, the oven-dry weight was determined, samples were ground to pass a 40 mesh screen with a Wiley mill. All ground samples were stored in sealed plastic bags until further analyses at which time they were redried at 70°C and remixed before subsamples were withdrawn.

Chemical Composition of Plants. Calcium, magnesium, potassium, phosphorus, manganese and iron was determined in all plant samples from solutions prepared by the wet-ashing technique. In this method, the organic matter is removed by oxidation in a nitric-perchloric acid solution. This acid is evaporated to dryness and the remaining salts are dissolved in N HCl. Calcium and K were determined by flame photometry, phosphorus by a molybdate blue method. The Mg, Mn and Fe concentrations of the HCl solution were determined with an atomic absorption instrument.

Total nitrogen was determined on forage samples taken from the neutral shale location by the Kjeldhal method. Nitrogen determinations were not made on the plant samples from the other experimental locations.

## V. RESULTS AND DISCUSSION

### NEUTRAL SHALE SITE

Establishment of Vegetative Cover: A uniform plant stand for both red clover and fescue was established on all plots. These observations were made after three weeks by counting the numbers of fescue and red clover seedlings in three randomly chosen 0.6 $m^2$ area from each subplot.

Visual observations made in the field at three months indicated that the size of both red clover and fescue plants on plots that were ripped were larger than the disked plots. However, when plant stand counts were analyzed, there were no statistically significant differences among any of the four site preparation tillage treatments nor were there significant interactions among the tillage and phosphorus treatments.

When the phosphorus fertilizer treatments were averaged over all tillage treatments, a significant difference was found and these data are summarized in Table 1. The 84 and 168 kg P/ha treatments had a significantly greater number of both fescue and red clover plants than those found on plots receiving no phosphorus. The differences in plant stands between the 84 and 168 kg/ha phospohrus treatments were not significant.

In general, seedlings surviving on the zero phosphorus treatment were experiencing serious phosphorus deficiency symptoms. Subsequent stand counts were not made due to the difficulty in obtaining accurate numbers as the result of larger plant size and the tillering of fescue. It is believed that had data been collected that it would have paralleled that reported in Table 1 with one exception. On zero

Table 1. Effect of phosphorus treatments on the survival of fescue and red clover plants at three months, averaged across all tillage treatments at the neutral shale site.

| Phosphorus Applied | Ky 31 Fescue | Red Clover | Total Plants |
|---|---|---|---|
| kg/ha | | plants/$m^2$ | |
| 0 | 255 | 70 | 225 |
| 84 | 378 | 113 | 491 |
| 168 | 372 | 123 | 495 |
| $LSD_{.05}$ | 28 | 17 | 42 |
| $LSD_{.01}$ | 38 | 23 | 55 |

phosphorus plots, essentially all the red clover plants died and the stand of fescue thinned. There were scattered sweet clover seedlings observed on some of the zero fescue plots. This plant species was later determined to have come from a contamination in the red clover seed used.

Changes in Chemical Properties of the Spoils: The stand counts indicated that there was a vegetative response to the applied phosphorus. The availability of phosphorus is measured by Bray-1 phosphorus tests dramatically illustrates the effect of these phosphorus treatments and these data are presented in Table 2. These phosphorus values in Table 2 have been averaged across all tillage treatments since there were no significant interactions between these two experimental variables nor differences in phosphorus level as the result of tillage treatment. It is apparent that although the addition of phosphorus raised the available phosphorus well above required levels for establishment, the Bray-1 phosphorus was much lower the second growing season. The reduction in the levels of available phosphorus is most likely the result of its fixation into chemically bound non-available forms. Any phosphorus removed as the result of plant harvests would not significantly contribute to this reduction in Bray-1 phosphorus levels. If phosphorus levels continue to decline, the levels may not be sufficient to maintain adequate vegetative cover and/or yields would be expected to decline.

Data for the pH measured in both water and KCl and exchangeable cations are presented in Table 3. These average values have been presented since there were no significant differences as the result greater than the ripped treatment. At only the highest phosphorus treatment was the ripped and mulched treatment greater than the disked 1x treatment. In addition, the ripped treatment was not significantly greater than the disked 1x treatment at any of the three phosphorus treatments.

When the phosphorus treatment means were subjected to statistical analyses (data not shown as such), a significant response (LSD 1% level) was obtained between each phosphorus treatments. A similar comparison made for tillage treatment means revealed that there was no significant difference between the (disked 1x) versus (3x) treatments nor between the (ripped) and (ripped with mulch) treatments. the (ripped and mulched) treatment was greater than both disking treatments at 1% level and at the same level of significance, the (ripped) treatment was greater than (disked 3x) treatment. However, ripped alone was not larger than disking one time.

The chemical composition data of harvested forage are presented in Table 6. These values have been averaged across all tillage treatments. Only one of these components was significantly related to the applied phosphorus, that being percent iron, which decreased with the first level of applied phosphorus. Levels of Mg also tended to be less as phosphorus was increased whereas, percentages of P, K and Mn, N and Ca tended to remain constant or rise slightly.

SLIGHTLY ACID SHALE SITE

Establishment of vegetative cover. After the site was prepared and seeded in September, little rainfall occurred for about three weeks. This may have had an eventual effect on the legume stand. By mid-October, the effect of the tillage treatments were quite evident.

Table 2. Bray-1 phosphorus levels averaged over all tillage treatments as affected by phosphorus applications at the neutral shale site.

| Time following establishment | Applied Phosphorus 0 | 84 kg/ha | 168 kg/ha |
|---|---|---|---|
| | - - - - - - - - - kg P/ha | - - - - - - - - - | |
| 0 (Check) | 2 | 2 | 2 |
| 2 months | 4 | 64 | 184 |
| 13 months | 2 | 37 | 74 |
| 20 months | 2 | 31 | 68 |

Table 3. Exchangeable cations and pH measurements averaged over all tillage and phosphorus treatments at the neutral shale site.

| Time following establishment | pH $H_2O$ | pH KCl | Exchangeable Cations Ca | Mg | K | Na |
|---|---|---|---|---|---|---|
| | | | - - - - - - meq/100 g - - - - - | | | |
| 0 (Check) | 7.16 | 7.01 | 3.40 | 4.59 | 0.17 | 0.15 |
| 2 months | 7.03 | 6.76 | 3.10 | 4.35 | 0.19 | 0.39 |
| 13 months | 7.40 | 6.74 | 3.21 | 3.38 | 0.23 | 0.05 |
| 20 months | 7.55 | 6.78 | 3.61 | 3.85 | 0.25 | 0.04 |

of the imposed phosphorus and tillage treatments on these chemical properties. From the data, it appeared that there was a small increase in pH following establishment of the experimental treatments. The drop in pH at 2 months is most likely the result of sampling as the initial pH values, eq. 7.16, is the mean of six observations made from a composite sample from each of the six replications, whereas, all other values represent means from 72 observations. The trends in the levels for exchangeable cations are somewhat erratic with the exception of potassium which tends to increase with time. This small increase may be the result of physical and/or chemical weathering of the micaeous shale that is a major component of these spoils, however, it does represent an equivalent increase in available potassium of about 70 kg/ha. According to test levels, the available potassium has increased from the low to medium test range. In soils, it is uncommon to find exchangeable Mg levels that exceed Ca, but from a plant nutrition point of view, the test levels of both of these cations are in the acceptable range.

Data illustrating the effect of phosphorus applications on the phosphorus forms as extracted by the method proposed by Chang and Jackson, 1957, are given in Table 4. It is apparent that the initial levels of $H_2O$-soluble and aluminum phosphorus forms are rather low. All of the $H_2O$-P forms would be available to plants and a small unknown proportion of the Al-P form. These levels are compatible with those given in Table 1 for Bray-1 extractable phosphorus. The influence of the 84 and 168 kg/ha addition of phosphorus had on the levels of each phosphorus form is quite evident. Large increases at 2 months for both Al-P and Fe-P reflect these applications. Only a small change

Table 4. Changes in phosphorus forms with time as a result of phosphorus application averaged across all tillage treatments.

| Time Following Establishment | Phosphorus Applied | $H_2O$-P | Phosphorus Form Al-P | Fe-P | Ca-P | Total P |
|---|---|---|---|---|---|---|
| months | - - - - - - - - - - - | | kg/ha - - - - - - - - - - - - - - | | | |
| 0 | 0 | 9.6 | 44.9 | 46.8 | 495.9 | 597.2 |
| 2 | 0 | 4.2 | 27.4 | 63.2 | 525.6 | 620.4 |
| | 84 | 9.2 | 164.5 | 170.2 | 557.4 | 902.3 |
| | 168 | 35.0 | 321.2 | 229.0 | 563.7 | 1148.9 |
| 13 | 0 | 4.1 | 22.8 | 123.3 | 588.1 | 738.3 |
| | 84 | 6.3 | 131.4 | 231.5 | 653.7 | 1022.9 |
| | 168 | 11.8 | 217.6 | 265.6 | 605.6 | 1100.6 |

in the most insoluble form was found at 2 months. At 13 months following establishment of the treatments, the levels of Al-P decreased whereas Fe-P and Ca-P experienced increases. The reductions in both $H_2O$-P and Al-P are most likely the result of at least two factors: (1) conversion of these forms to the more insoluble Fe-P and Ca-P and (2) the removal of phosphorus by the plants growing on these areas. It should be noted that the total of all of these forms for each level of phosphorus applied does not remain constant with time as theory would predict. In addition, the difference between the totals as the result of added phosphorus does not equal that applied. Both of these discrepancies may be the result of at least two factors. The first being, the original method proposed that total phosphorus was to be determined by total dissolution of the sample and this was not done due to the laborous procedure required. There are phosphorus forms other than those four forms presented in Table 4. These additional forms are often grouped into a form called "occluded" phosphorus that are not extracted because they are covered by insoluble compounds or otherwise do not physically come in contact with the extracting solution. These occluded phosphorus forms may become uncovered as the result of weathering and hence the apparent total phosphorus may increase with time. Similarly, under other conditions, the extracted phosphorus may be reduced by covering otherwise extractable phosphorus by iron oxides, etc. The second factor that could explain the apparent abnormalities in the phosphorus sum, with time and between rates of addition, is sampling errors in the field. Movement of spoils and phosphorus into depressions created by the tillage treatments could result in a phosphorus concentrating effect. However, since variations in total phosphorus were independent of tillage treatment, this second explanation is less likely than the first.

Forage yield response to phosphorus - tillage treatments. There were significant differences in forage yields as the result of the imposed treatments. The yield data are summarized in Table 5. The LSD's for both the 5 and 1% levels of significance are given at the bottom of Table 5. The following statements can be made concerning the comparisons of yields from various treatment combinations. For all four tillage treatments, the addition of 84 kg/ha of phosphorus resulted in a highly significant increase in forage yield. The further addition of phosphorus did not result in a significantly greater yield for the disked plots but significantly greater yields were obtained fromripped plots. The apparent explanation for this yield response was related to the available moisture in that, for the disked treatments (either 1x or 3x), water was limiting the expression of phosphorus on yield. The ripping increased available water and thus allowed a phosphorus response. Even for these ripped plots, water may have been limiting to a degree on some plots and thus the yield response was only significant at the 5 percent level.

Comparison of tillage treatments reveal that even though disking 3x produced lower yields, they were not significantly lower at any of the three phosphorus rates. Apparently, disking three times produced a smoother surface following establishment than only one disking. Comparisons between yield data from the (disked 3x, ripped and mulched) treatment with the (disked 3x) treatment the former was significantly higher at all three phosphorus levels. However, at none of the phosphorus levels was the ripped and mulched treatment significantly

Table 5. Effect of phosphorus and tillage treatments on forage yields of fescue - red clover hay at the neutral shale site.

| Tillage Treatment | 0 kg/ha | Applied Phosphorus 84 kg/ha | 168 kg/ha |
|---|---|---|---|
| | - - - - - - - - - - | kg/ha* | - - - - - - - - - - |
| Disked 1x | 347 | 2298 | 3040 |
| Disked 3x | 124 | 1616 | 2239 |
| Disked 3x, ripped | 465 | 2902 | 3859 |
| Disked 3x, ripped, mulched | 1355 | 3263 | 4268 |

*Total yield of two harvests, weights adjusted to 10 percent moisture.

$LSD_{.05}$ between phosphorus trts. for any specific tillage trt. = 816

$LSD_{.01}$ between phosphorus trts. for any specific tillage trt. = 1092

$LSD_{.05}$ between tillage trts. for any specific P trt. = 1104

$LSD_{.01}$ between tillage trts. for any specific P trt. = 1499

Table 6. Effect of applied phosphorus on chemical composition of red clover-fescue forage harvested 17 months after establishment at the neutral shale site.

| Phosphorus Applied | Chemical Compaonent | | | | | | |
|---|---|---|---|---|---|---|---|
| | P | N | Ca | Mg | K | Fe | Mn |
| kg/ha | - - - - - - - - - - - | | | % | - - - - - - - - - - - - - - - - | | |
| 0 | 0.08 | 1.37 | 0.75 | 0.34 | 1.20 | 0.223 | 0.023 |
| 84 | 0.08 | 1.28 | 0.75 | 0.32 | 1.29 | 0.041 | 0.038 |
| 168 | 0.11 | 1.37 | 0.69 | 0.31 | 1.36 | 0.039 | 0.040 |

Fexcue growth was prominent in the depressions left by the chisel plowing treatment giving an effect that appeared as if the area had been drilled with a grain drill. The plant height of fescue in the chiseled treatment was at least three times greater than the other two treatments. The disked treatment had a more uniform looking vegetative cover than the smooth graded treatment but the plant size on these two treatments were similar. Although density of the stand on the disked treatment was at least two fold better than the smooth graded plots, in both cases plants occurred only in micro-depressions. For smooth graded plots, the depressions were the result of indentations caused by rocks being pressed into the spoils when the area was "back bladed." The disk used at this site was a conventional form type wheel disk and a greater difference between the disked treatment and the chiseled treatment was apparent here than was observed for the acid site prepared with a heavy-duty wheel disk.

By the following April, the apparent effect of the tillage treatments was less pronounced and only with close insepction could one tell the location of any particular treatment. At this time, the plant height was the same on all three tillage treatments. However, it appeared that stand density was greatest on the chiseled treatment, followed by the disked and then the smooth graded treatments. Plant stand measurements were independent of the size and tillering nature of fescue, which dominated the stand.

Observations were made with respect to the survival of each legume species. A reasonably good stand of alfalfa and birdsfoot trefoil was obtained on all plots to which it was seeded regardless of tillage treatments. In general, it appeared that a greater size of plants occurred on chiseled plots although measurements were not actually taken. An average to poor stand was obtained for red clover, white clover and sweet clover. The stands on chiseled plots were perhaps somewhat better than the disked and smooth graded plots on two of the four replications. Although scattered crownvetch plants were observed in the fall on all plots, virtually none of them survived the winter. Those plots on which crownvetch did survive included the chiseled and disked treatments of one replication and the chiseled plot of two of the remaining three replications. By fall or one year after establishment, and particularly after harvesting, all of these crownvetch plants had died. There was no evidence of any sericea lespedeza plants in any of the tillage treatments.

Changes in chemical properties of the spoils. The data for the pH values measured in water, KCl and the SMP buffer solutions are given in Table 7. These data were averaged across all tillage and legume treatments since there was no significant difference as the result of these variables. It was observed that the $H_2O$ pH values were only slightly greater than the pH value necessary for meeting 5.5 pH value the requirment set by Division of Reclamation. Loss of the legume species from the stand at this location may have been the result of these marginal pH's. However, the lime requirement based on SMP buffer values would not indicate large lime needs. Only one value approaches the pH of 6.7 below which, lime is usually recommended. The mean pH values represented in Table 7 were derived from individual measurements from each of the 96 subplots some of which were sufficiently acid to require as much as 10 metric tons/ha whereas others had an alkaline pH.

Table 7. Changes in pH following establishment of tillage-legume treatments in September at the Slightly Acid Site.

| Time after establishment in months | pH measured in | | |
|---|---|---|---|
| | $H_2O$ | KCl | SMP buffer |
| 0 | 5.6 | 5.0 | 7.3 |
| 1 | 5.6 | 5.1 | 7.2 |
| 8 | 5.8 | 5.0 | 6.8 |
| 13 | 5.6 | 4.8 | 7.1 |

Table 8. Changes in Bray-1 phosphorus levels following the establishment of tillage-legume treatments in September at the Slightly Acid Site.

| Time after establishment in months | Chiseled | Tillage Treatment<br>Disked | Smooth Graded |
|---|---|---|---|
| | - - - - - - - - - - | kg/ha | - - - - - - - - - - - - |
| 0* | 4 | 4 | 4 |
| 1 | 53 | 63 | 49 |
| 8 | 21 | 48 | 37 |
| 13 | 20 | 29 | 30 |

*Sampled prior to applying 84 kg/ha of phosphorus.

Changes in available phosphorus as measured by the Bray-1 method are given in Table 8. Initially, the phosphorus level was very low. The addition of 84 kg/ha of phosphorus resulted in a significant increase in available phosphorus. The reductions of Bray-1 phosphorus levels at 8 and 13 months were observed. This reduction was the result of at least two factors (a) formation of iron and aluminum phosphate compounds which are not extracted by the Bray-1 method or (b) the result of the fescue-legume vegetation reducing phosphorus levels as the result of plant uptake. There was a trend for the chiseled plots to be lower than either the disked or smooth graded plots.

Spoil samples were subjected to neutral normal ammonium acetate extraction to evaluate levels of exchangeable Ca, Mg, K and Na. These data are not presented as there were no significant differences between any of the tillage and/or legume species treatments. All levels of these cations were at an acceptable level for plant growth. The level of potassium was in the medium range and perhaps the yields from the legume treatments could have been higher had potassium supply been increased.

Forage response to tillage treatments. Two harvests were made from the various legume-tillage treatments, the first in May and the other in August. Data from these harvests are presented in Tables 9 and 10, respectively. All of the yield values were adjusted to 10 percent moisture for cured hay.

Comparisons made for yields between legumes of any tillage treatment are probably not valid due to the variability in legume stands. Comparisons of yields between tillage treatments for any legume are valid in the case of alfalfa, birdsfoot trefoil and red clover and of these three, only the red clover yield from the chiseled treatment was significantly greater than the red clover yield from the smooth graded treatment. Some of the other species also approached being significant of the 5% level but since the legume stands were poor or non-existent, these differences really represent response of fescue to the tillage treatment. In addition, when all legume treatments were averaged for each tillage treatment, the yield from the chiseled treatment was greater than the smooth graded plot at the 5 percent level of significance.

Comparisons of yield data from the second harvest indicate that the overall effect of tillage no longer produced a significant difference between chiseled and the smooth graded treatments. The yield of the red clover-fescue chiseled treatment was greater than both disked and smooth graded treatments. All other tillage treatments within a legume were not significantly different.

Table 9. Effect of the tillage treatments on fescue-legume forage yields* for the first harvest (May) at the slightly acid site.

| Legume-Ky 31 Fescue Mixture | Tillage Treatment Chiseled | Disked | Smooth Graded |
|---|---|---|---|
| | kg/ha | | |
| Alfalfa | 2258 | 1802 | 1975 |
| Birdsfoot Trefoil | 3010 | 2576 | 1995 |
| Red Clover | 3265 | 2585 | 1640 |
| White Clover | 2688 | 2134 | 2495 |
| Sweet Clover | 3048 | 2562 | 2173 |
| Crownvetch | 3464 | 2207 | 2171 |
| Sericia Lespedeza | 2833 | 2049 | 1630 |
| Interstate S. Lespedeza | 2013 | 1976 | 1560 |
| Mean - all legumes | 2822 | 2236 | 1955 |

*Yields adjusted to 10 percent moisture.

$LSD_{.05}$ for tillage treatment means is 702 kg/ha.

Table 10. Effect of the tillage treatments on fescue-legume forage yields* for the second harvest (August) at the slightly acid site.

| Legume-Ky 31 Fescue Mixture | Tillage Treatment Chiseled | Disked | Smooth Graded |
|---|---|---|---|
| | | kg/ha | |
| Alfalfa | 1113 | 944 | 652 |
| Birdsfoot Trefoil | 1063 | 558 | 450 |
| Red Clover | 1857 | 712 | 410 |
| White Clover | 662 | 274 | 1068 |
| Sweet Clover | 943 | 498 | 666 |
| Crownvetch | 1055 | 493 | 443 |
| Sericea Lespedeza | 353 | 592 | 321 |
| Interstate S. Lespedeza | 616 | 273 | 248 |
| Mean - all legumes | 992 | 542 | 531 |

*Yields adjusted to 10 percent moisture.

$LSD_{.05}$ for tillage treatment means is 710 kg/ha.

## ACID SHALE SITE

Establishment of vegetative cover. A good stand of Ky 31 tall fescue was obtained on all tillage treatments. The density and plant height at any given time during the fall months was superior at this location as compared to the slightly acid shale site. Although both locations were seeded the same day, a rain storm passed over this acid site that by-passed the other location. This not only had the effect of causing a earlier emergence but the differences in plant height as a result of tillage treatment was less pronounced. Essentially there was no difference in plant size between the disked and chiseled treatments but both were somewhat better than the smooth graded treatment. The rainfall factor may explain part of the similarity between the disked and chiseled treatments and the remaining contributing factor is the influence of the heavier disk used at the acid shale site which "cut in" more and thus left a surface similar to chisel plowing. The influence that the earlier emergence may have had with respect to giving a better appearance at the acid shale site did not persist in the spring as plant densities and heights were the same at both locations. This appearance of uniform density was from a distance and upon closer insepction, the chiseled and disked treatments had a higher plant population than the smooth graded plots.

The degree to which legumes were established at the acid shale site was much less than obtained on the other location. This most likely was the result of a lower phosphorus status. Only two species were established on all three tillage treatments and even then, stands were poor.

Alfalfa and sweet clover stands were ranked poor with birdsfoot trefoil and red clover very poor. The latter two species were found only on the disked and chiseled treatments. On an occasional plot could one find white clover plants while sericea lespedeza and crownvetch plants were not observed on any tillage treatment with one exception. In one area, fescue was not seeded and the various legumes were seeded in pure stands. The reduced competition for moisture on this adjacent area resulted in the establishment of all seven legume species, however, stands were still poor for most, especially alfalfa, and red clover. On the other hand, sericea lespedeza and birdsfoot trefoil were established as well as a few scattered crownvetch plants.

Changes in chemical properties of the spoils. The data for the pH values measured in water, KCl and SMP buffer solutions are given in Table 11. These data were averaged across all tillage and legume treatments since there were no significant differences as the result of these variables. The pH values measured in $H_2O$ were indicative of the acid nature of these spoils. Initially the pH was slightly below the minimum standards for reclamation, but with time, the pH decreased significantly as sulfide minerals underwent oxidation. The largest amount of lime needed at any date being 9 metric tons/ha which was associated with the SMP buffer reading of 6.4.

Changes in available phosphorus with time are given in Table 12. Data shown here in comparison with that from the slightly acid shale site given in Table 8 are considerably different. Even though 84 kg/ha of phosphorus was applied, only a very small change was observed in the subsequent samplings. Unfortunately, spoil samples were not

Table 11. Changes in pH values following establishment of tillage-legume treatments in September at the Acid Shale Site.

| Time after establishment in months | pH measured in | | |
|---|---|---|---|
| | $H_2O$ | KCl | SMP buffer |
| 0 | 5.0 | 4.6 | 7.2 |
| 5 | 5.5 | 5.2 | 6.7 |
| 8 | 4.4 | 4.0 | 6.8 |
| 13 | 3.7 | 3.4 | 6.4 |

Table 12. Changes in Bray-1 phosphorus levels following the establishment of tillage-legume treatments in September at the acid shale location.

| Time after establishment in months | Tillage Treatment | | |
|---|---|---|---|
| | Chiseled | Disked | Smooth Graded |
| | kg/ha | | |
| 0* | 5 | 6 | 5 |
| 5 | 6 | 11 | 7 |
| 8 | 7 | 6 | 7 |
| 13 | 4 | 5 | 4 |

* Sampled prior to applying 84 kg/ha of phosphorus.

collected one month after establishment at this site hence the rate of fixation of the applied phosphorus cannot be characterized. The large amounts of iron released in conjunction of sulfide weathering undoubtedly reacted with the phosphorus resulting in an insoluble iron phosphate compound. Verification of this product with phosphorus fractionation was not done.

The samples were not analyzed by exchangeable cations. The levels of potassium, based on analyses from other areas and a few samples tested by the soil testing laboratory, should have been adequate throughout the duration of this study. The level of Ca, and Mg may have been low relative to those reported earlier for the neutral shale site, but on the other hand should have been high enough so that these elements would not have restricted plant growth. It is believed that the levels of Mn and Fe would have been high at this site and this may have caused an imbalance for the other plant nutrients. Such high levels, if they did in fact occur, would have reduced the utilization of phosphorus in the plant tissue.

Forage response to tillage treatments. As the result of poor legume stands, only the alfalfa and sweet clover legume-tillage combinations were harvested in May. The yield data from these harvests are given in Table 13. In August, it was decided that we would harvest all legume-tillage combinations, data presented in Table 14, hence the yields for the alfalfa and sweet clover plots were cut the second time. Combining the yield values for the latter two mentioned species would be more reflective of the true differences in vegetative yield, however, this was not done since we do not know the effect cutting would have on the stimulation of regrowth of both the legume and grass components.

It is apparent that even the total yields from either alfalfa or sweet clover legume treatment were at least two orders of magnitude less for the acid shale site than for the other location. The reason for the reduction in yields from the more acid area is at least two fold. First, the phosphorus levels were much lower and hence the legume contribution to yield was greatly affected. These lower yields may be also caused by the more acid conditions, however, more likely these two factors are both contributing to yield depression and the relationship may be a multiplying effect rather than a simple addition.

There was a significant difference between the average yields obtained from the chiseled and smooth graded plots for the May harvest. For the August harvest, significant differences in yields were obtained between all three tillage treatments. Considering the effect of tillage for any specific legume-fescue treatment, none of the tillage treatments resulted in significant differences for either harvest although a few approached the 5% significance level.

Table 13. Effect of the tillage treatments on fescue-legume forage yields* for the May harvest at the acid shale site.

| Legume - Ky 31 Fescue Mixture | Tillage Treatment | | |
|---|---|---|---|
| | Chiseled | Disked | Smooth Graded |
| | - - - - - - - - - kg/ha | - - - - - - - - - - - - | |
| Alfalfa | 1555 | 1074 | 585 |
| Sweet Clover | 846 | 737 | 501 |
| Mean | 1201 | 905 | 543 |

*Yields adjusted to 10 percent moisture.

$LSD_{.05}$ for tillage treatment means in 485 kg/ha

Table 14. Effect of the tillage treatments on fescue-legume forage yields* for the August harvest at the acid shale site.

| Legume - Ky 31 Fescue Mixture | Tillage Treatment | | |
|---|---|---|---|
| | Chiseled | Disked | Smooth Graded |
| | - - - - - - - - - - | kg/ha - - - - - - - - - - - | |
| Alfalfa | 429 | 231 | 143 |
| Birdsfoot trefoil | 528 | 453 | 340 |
| Red Clover | 615 | 432 | 332 |
| White Clover | 481 | 437 | 333 |
| Sweet Clover | 294 | 169 | 210 |
| Crownvetch | 573 | 372 | 484 |
| Sericea Lespedeza | 666 | 587 | 338 |
| Mean - all legumes | 512 | 383 | 262 |

* Yields adjusted to 10 percent moisture.

$LSD_{.05}$ for tillage treatment means is 117 kg/ha.

## VERY ACID SANDSTONE SITE

Establishment of vegetative cover. A poor stand of both fescue and the legume mixture was obtained on all plots regardless of lime application rate if the lime had been incorporated. Those plots on which lime was not incorporated were essentially void of plants. The legume portion of the stand was dominated with alfalfa seedlings with a few isolated plants of sweet clover, red clover, and birdsfoot trefoil. Sericea lespedeza and crownvetch plants were not observed on any of the lime treatments.

Changes in chemical properties of the spoils. The effect of lime and the method of incorporation on pH levels as a function of sampling depth as well as the vegetative yield are given in Table 15. These data are means derived from four replications. Several trends are noted; the most striking is that lime doesn't move appreciably below the zone of incorporation even on sandy spoils. The pH of even the 5-10 cm depth was not as high as expected as both the disk and chisel plow was operated to this depth. The 10-15 cm increment represents spoil materials below the zone of incorporation. Upward movement of water from the acid underlying zone into the 5-10 cm depth increment may account for the low pH values obtained. It is also quite apparent that incorporation is absolutely necessary and even the upper 5 cm of the non-incorporated lime plots are acid.

The yields obtained from all plots are very low. There were no significant differences between lime rates or methods of incorporation with the exception of the no-till treatment. The acid nature of these spoils is of course the major contributor to the poor vegetative growth but this is probably not the major cause of the low yields,

Table 15. Effect of lime rate and method of incorporation on pH levels sampled at three depth increments and forage yields.

| Lime Rate and Incorporation Method | | Sample Depth in Centimeters | | | Yield*** |
|---|---|---|---|---|---|
| | | 0-5 | 5-10 | 10-15 | kg/ha |
| mt/ha | | | | | |
| 67.2 | Disked | 6.8 | 5.1 | 3.4 | 162 |
| 134.4 | Disked | 6.7 | 5.2 | 3.6 | 139 |
| 67.2 | Chiseled | 5.7 | 5.0 | 4.0 | 189 |
| 134.4 | Chiseled | 6.7 | 4.7 | 3.6 | 187 |
| 67.2 | Disked* | 6.1 | 4.5 | 3.2 | 200 |
| 134.4 | Disked* | 6.8 | 4.9 | 3.2 | 132 |
| 67.2 | Chiseled** | 6.6 | 5.2 | 3.5 | 196 |
| 134.4 | Chiseled** | 6.9 | 5.0 | 3.2 | 231 |
| 67.2 | No-tillage | 5.4 | 3.8 | 3.0 | 0 |
| 134.4 | No-tillage | 5.1 | 3.5 | 3.2 | 0 |

* Legume seeded in March whereas all other plots, legumes were seeded in September.

** One-half lime applied, chiseled, followed by remaining lime applied to the surface.

*** Yields adjusted to 10 percent moisture.

at least not directly. The lack of moisture may be much more important. The acid zone prevents deep rooting and as the result of the sandy nature of the spoils, the water holding capacity is very low and plants should be under a moisture stress almost constantly. Other plant species will be required on this spoil type if successful reclamation is to be expected. Bermudagrass, *Cynodon dactylon L. Pers.*, which is tolerant to both high temperatures and associated droughty conditions may be a suitable substitute for Ky-31 tall fescue.

## VI. REFERENCES


Barnhisel, R. I. and H. F. Massey. 1969. Chemical, mineralogical and physical properties of eastern Kentucky acid-forming coal spoil materials. Soil Sci. 108:367-372.

Berg, W. A. and W. G. Vogel. 1968. Manganese toxicity of legumes seeded in Kentucky strip-mine spoils. U.S. Forest Service Research Paper 119.

Berg, W. A. and R. F. May. 1969. Acidity and plant-available phosphorus in strata overlying coal seams. Mining Congress Journal. 55:31-34.

Berg, W. A. and W. G. Vogel. 1973. Toxicity of acid coal-mine spoils to plants In *Ecology and Reclamation of Devastated Lands*. Gordon and Breach, N.Y. Vol. 1. pp. 57-68.

Bray, R. H. and L. T. Kurtz. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Chang, S. C. and M. L. Jackson. 1957. Fractionation of soil phosphorus. Soil Sci. 84:133-144.

Cummins, D. G., W. T. Plass and C. E. Gentry. 1967. Chemical and physical properties of spoil banks in eastern Kentucky coal fields. U.S. Forest Service Res. Paper CS-17. Central States For. Exp. Sta. Columbus, O. 12 pp.

Curtis, W. 1971. Strip mining and sedimentation. Transactions of the Amer. Soc. Agr. Engin. 14:434-436.

Curtis, W. R. and W. O. Cole. 1972. Micro-topographic profile gauge. Agric. Eng. 53(1):17.

Czapowskyj, M. M. 1976. Annotated bibliography on the ecology and reclamation of drastically disturbed areas. USDA For. Serv. Gen. Tech. Rep. NE-21.

Funk, D. T. 1962. A revised bibliography of strip-mine reclamation. USDA Forest Serv. Central States For. Exp. Sta. Misc. Pub. 35.

Massey, H. F. 1972. pH and soluble Cu, Ni and Zn in eastern Kentucky coal mine spoil materials. Soil Sci. 114:217-221.

Massey, H. F. and R. I. Barnhisel. 1972. Copper, nickel and zinc released from acid coal mine spoil materials of eastern Kentucky. Soil Sci. 113:207-212.

Plass, W. T. 1969. Pine seedlings respond to liming of acid strip-mine spoils. USDA Forest Serv. Res. Note NE - 103.

Plass, W. T. and W. G. Vogel. 1973. Chemical properties and particle-size distribution of 39 surface-mined spoils in southern West Virginia. USDA Forest Serv. Res. Paper NE-276, 8 pp.

Shoemaker, H. E., E. O. McLean and P. F. Pratt. 1961. Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminum. Soil Sci. Soc. Amer. Proc. 25:274-277.

Sutton, P. 1973. Reclamation of toxic strip-mine spoil banks. Ohio Report. 58:18-20.

Vimmerstedt, J. P. 1970. Strip-mine reclamation. Ohio Report. 55:60-61.

Vogel, W. G. 1973. The effect of herbaceous vegetation on survival and growth of trees planted on coal-mine spoils. Research and Applied Tech. Symp. on Mined-Land Reclamation. pp. 197-207.

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO. EPA-600/7-77-093 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE Reclamation of Surface Mined Coal Spoils | | 5. REPORT DATE August 1977 issuing date |
| | | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) Richard I. Barnhisel | | 8. PERFORMING ORGANIZATION REPORT NO. CSRS 1 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Kentucky Agricultural Experiment Station, Agronomy Department, University of Kentucky, Lexington, Kentucky 40506 | | 10. PROGRAM ELEMENT NO. 526 |
| | | 11. CONTRACT/GRANT NO. CSRS 684-15-3, EPA-IAG D6-E762 |
| 12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory - Cin., OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268 | | 13. TYPE OF REPORT AND PERIOD COVERED Final Report |
| | | 14. SPONSORING AGENCY CODE 600/12 |

15. SUPPLEMENTARY NOTES

Project was in cooperation with the U.S.D.A. Cooperative States Research Service (CSRS)

16. ABSTRACT

A project was conducted to demonstrate the effect of tillage including: subsoiling or ripping, disking, chisel plowing as a means of creating a rough micro-relief as compared to smooth graded surface mined coal spoils. It was found that when the surface was rough, increased plant growth occurred at all levels of applied phosphorus. Yields were also improved with the use of a mulch and when used in combination with phosphorus and subsoiling, approach those yields of nonmined land.

Lime additions should be made according to soil tests in which both active as well as total potential acidity as the result of oxidation of sulfide minerals are determined. When required, lime should be incorporated into the spoils by disking, etc.; this practice increases the rooting depth and thus reduces the droughty nature of acid spoils.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Ecology, Environments, Earth Atmosphere, Environmental Engineering, Geography, Hydrology, Limnology, Biochemistry, Earth Hydrosphere, Combustion, Refining, Energy Conversion Heat Sources, Materials Handling, Inorganic Chemistry, Organic Chemistry, Chemical Engineering | Coal | 6F 8A 8F 8H 10A 10B 7B 7C 13B |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT Release to the Public | 19. SECURITY CLASS (This Report) Unclassified | 21. NO. OF PAGES 67 |
| | 20. SECURITY CLASS (This page) Unclassified | 22. PRICE |

EPA Form 2220-1 (9-73)



☆ U.S. GOVERNMENT PRINTING OFFICE: 1977—757-056/6553