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Classification of Coal Surface Mine Soil Material for Vegetation Management and Soil Water Quality

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CLASSIFICATION OF COAL SURFACE MINE SOIL MATERIAL FOR VEGETATION MANAGEMENT AND SOIL WATER QUALITY

by

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FOREWORD

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

This report discusses the classification of five Alabama minesoil classes. Based on the characteristics of these minesoils, limestone and fertilizer recommendations are made. In addition a method of calculating the potential erodibility of Alabama minesoils is presented. This report should be of interest to those persons planning mine land reclamation projects in Alabama and other states that have similar minesoils. The method developed for predicting erosion should be of assistance to those developing erosion control system and evaluating the impacts of surface mining on water quality.

Further information may be obtained from the Resource Extraction and Handling Division.

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ABSTRACT

An Alabama minesoil classification system was developed based on soil texture, soil color value and soil pH. Only five different soil classes were found in this study. However, the classification scheme allows for the inclusion of any minesoil that occurs on the basis of its texture, color value and pH.

Limestone and fertilizer recommendations are given for soils of the five minesoil classes. Research evidence showed that the limestone recommendations will maintain a pH favorable to plant growth and surface soil water quality for a period of at least one year. The scope of this project did not allow determination of water quality where the water had leached downward through the minesoil. The recommended fertilizer rates should supersede those of a soil testing laboratory if the laboratory recommends lesser amounts of fertilizer. Also, the recommended rates can be used if soil test recommendations are unavailable.

A method of calculating the potential erodability of Alabama minesoils, by use of a modified form of the Wischmeier universal soil loss equation, is described and potential erodabilities are calculated for several minesoils. Also, a method of estimating yearly soil loss from Alabama minesoils is described and the soil losses to be expected from selected Alabama minesoils are calculated. These minesoil erosion prediction methods can be used to help prevent excessive sedimentation of fluvial systems, to simplify the task of surface mine reclamation and to reduce the costs of reclamation. Both of the methods described can be used anywhere for soil erosion predictions by following the methods described and developing applicable equation factors.

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ACKNOWLEDGEMENTS

The Drummond Company of Jasper, Alabama provided equipment and assistance in establishing field plantings. The assistance of Mr. Dwight R. Hicks of The Drummond Company is recognized in particular. This help is gratefully acknowledged.

Dr. Stanley P. Wilson, Associate Director of the Alabama Agricultural Experiment Station served as Project Officer for the experiment station. Dr. Eilif V. Miller of Cooperative Research, United States Department of Agriculture served as coordinator for the project.

I. INTRODUCTION

Well over 405,000 hectares (1 million acres) have been surface mined for coal in 29 of the United States. This acreage is being increased at a rapid rate as the nation develops a greater need for the energy provided by coal. This is a small amount of land when the country is considered in its entirety, but since the coal is concentrated in relatively small areas the effects of surface mining in these restricted areas become disturbing. However, detrimental effects of surface mining can be prevented or alleviated if known reclamation techniques are applied and research keeps pace as new information is needed.

Surface mine reclaimers often approach their job with little information about the minesoil to be vegetated. They have developed standard techniques and plants that they tend to use indiscriminately on all minesoils regardless of the differing minesoil characteristics. Operational reclamationists do practically all planting without the preliminary surveys that would assure the success of their plantings. Most of the past revegetation of surface mines in Alabama has been with pine trees. Pines provide a future source of income from the mined areas but they do not provide erosion control immediately after mining when it is most needed. There has been no attempt to classify minesoils for planting pines because most of the older minesoils are more or less acid and pines usually survive and grow well. However, many of the recent mines are producing neutral or alkaline minesoils and pines do not survive or grow well on these minesoils.

Previous research in Alabama indicated that a minesoil classification system was feasible and desirable. The minesoils appeared to group themselves into classes with differing characteristics affecting plant establishment and growth. Experiments and ongoing reclamation have shown that the detrimental minesoil characteristics can be ameliorated by cultural treatments such as the application of limestone, fertilizers, discing and mulching. Of course, none of these cultural treatments avail when weather extremes occur. This point has been difficult for many people to accept if they have not had experience in the production of field crops.

Under present state and federal laws, minesoils must be stabilized quickly with grasses and legumes. These crops require more planning and soil treatment than the past pine tree crops. The purpose of the research work described in this report was to characterize and classify those features of coal surface mines in Alabama that could affect plant establishment, plant growth and soil water quality. It is believed that the classification system developed in this study can be used to predict cultural treatments necessary for plant production on coal surface mines. The use of this system could save millions of dollars in reclamation costs and promote faster and more complete revegetation. This promotion of revegetation would mean less minesoil erosion and stream sedimentation. Another benefit from erosion control by vegetation is the lowered cost of sediment pond maintenance. Quick and complete revegetation would reduce the amount of soil material moving into sediment ponds and the ponds would not have to be cleaned as often. Finally, a successful revegetation operation means the return of lands to continuing economic returns for the good of the local and national economy.

II. CONCLUSIONS

Light colored minesoils (Munsell color value of the soil sized fraction > 4 when moist) of Alabama are similar in a majority of their physical and chemical characteristics. Therefore, they have been grouped as a single minesoil class in this study.

The dark colored minesoils (Munsell color value < 4 when moist) had several differing characteristics and were divided into four classes according to groupings of characteristics. After comparing the chemical and physical properties of these minesoils it was obvious that they could be divided into an acid group and a neutral or alkaline group. These two broad groups were further separated into two sub-groups on the basis of soil characteristics and vegetation management practices.

The minesoil classification scheme developed in this study is shown on the following page. The actual classes that were found in this study are underlined. It is possible that more classes of minesoil will be found in Alabama. Therefore, the entire classification scheme is shown and any new minesoils can be given the appropriate designation.

The necessity for limestone when revegetating minesoil classes IIB2 and IIA2 was demonstrated in a field experiment and the need on class IIA1 minesoils by a greenhouse experiment. Fertilizer recommendations from the soil testing laboratory as used in this study were found to be adequate except in the case of phosphorous. Phosphorous in high pH Alabama minesoils (classes IA4 and IIA4) is plentiful according to the usual soil test but apparently unavailable to plants according to field tests.

The pH of some class IIA1 minesoils can be increased and maintained for at least one year by the application of 11.2 metric tons/ha (5 T/A) of limestone. The pH of other class IIA1 minesoils can be increased temporarily but not maintained by the same amount of limestone. However, it was found that the next level of limestone (22.4 metric tons/ha) used in this study will maintain a favorable pH on all class IIA1 minesoils for at least one year. Under these conditions, it is concluded that a minimum of 22.4 metric tons/ha (10 T/A) should be applied to IIA1 minesoils for successful revegetation and water quality maintenance. The water quality of IIA2 and IIB2 minesoils should be maintained easily for at least one year with an application of 11.2 metric tons/ha of limestone.

The other minesoil classes do not require liming. There is a possibility that the large amounts of sulfur in some of these soils will oxidize and lower the pH of these presently near neutral to alkaline minesoils. However, this study has shown that they maintain a favorable pH for at least one year

ALABAMA MINESOIL CLASSIFICATION

I. Lithoclast - More than 50% of the minesoil particles are > 2 mm in their smallest diameter. These particles are characteristically composed of clay, silt and sand, and cannot be broken with hands alone. Gravel fragments are angular, flaggy or blocky.

A. Dark colored (Munsell color value of soil sized fraction ≤ 4 when moist)

1. Extremely acid (pH ≤ 3.5)
2. Very acid (pH 3.5-5.5)
3. Near neutral or neutral (pH 5.5-7.5)
4. Alkaline (pH > 7.5)

B. Light colored (Munsell color value of soil sized fraction > 4 when moist)

1. Extremely acid (pH ≤ 3.5)
2. Very acid (pH 3.5-5.5)
3. Near neutral or neutral (pH 5.5-7.5)
4. Alkaline (pH > 7.5)

II. Pedoclast - More than 50% of the minesoil particles are ≤ 2 mm in their smallest diameter.

A. Dark colored (Munsell color value of soil sized fraction ≤ 4 when moist)

1. Extremely acid (pH ≤ 3.5)
2. Very acid (pH 3.5-5.5)
3. Near neutral or neutral (pH 5.5-7.5)
4. Alkaline (pH > 7.5)

B. Light colored (Munsell color value of soil sized fraction > 4 when moist)

1. Extremely acid (pH ≤ 3.5)
2. Very acid (pH 3.5-5.5)
3. Near neutral or neutral (pH 5.5-7.5)
4. Alkaline (pH > 7.5)

and should present no surface water quality problems for at least this period of time.

The results and conclusions presented in this paper are concerned with the top layer of soil to a maximum depth of approximately 30.48 cm (12 in). Therefore, the effects of deeper layers of minesoil on plant growth are not known. There is a significant degree of soil variation within any area of minesoil. However, this does not appear to significantly effect growth when the recommended limestone and fertilizer applications are used.

Several research workers have worked with the problem of predicting erosion on agriculture soils and highway slopes. There is no reason why this information cannot be modified and applied to minesoils, although, field experiments with soil erosion prediction and minesoils is meager. It is believed that the results shown in this work can be used for erosion prediction on minesoils until field research can be used to refute or confirm these results. The relative erodability index, (REI) developed in this study can be used to compare minesoils in Alabama and make decisions regarding time of regrading, speed and completeness of revegetation and degree of erosion control needed. The soil loss prediction method developed in this study can be used to estimate the size and number of sedimentation ponds needed for a particular drainage area.

III. RECOMMENDATIONS

The minesoil classification system developed in this study can be used by Alabama reclamationists to increase their chances for successful revegetation operations. The only equipment needed to apply the system is a 2mm sieve, Munsell soil color charts and an instrument or kit for pH determination. After the minesoil class has been identified, soil samples should be sent to a soil testing laboratory for limestone and fertilizer recommendations. These recommendations will be valid for use in Alabama except for phosphorous and limestone recommendations on some soils. Table 1 shows the minimum initial amounts of fertilizer to use on Alabama minesoils. These values will probably agree closely with those obtained from a soil testing laboratory. However, as the minesoil pH increases toward 6.0 and above, the soil testing laboratory will often obtain a high phosphorous determination. Field plantings on these minesoils indicate that this phosphorous is unavailable to forage plants, and additional phosphorous in plant available form must be added. Also, undisturbed surface soils seldom become as acid as some minesoils. For this reason, the soil testing laboratory may only recommend their maximum amount of limestone for agriculture soils, and this is often not enough for acid minesoils. The recommendations in Table 1 should supersede those of the soil testing laboratory when those of the laboratory are less than the Table 1 recommendations. Also, the recommendations in Table 1 can be used when laboratory tests are unavailable.

It is known that limestone and fertilizers for agronomic crops should be incorporated into the soil by discing or other means. This holds true for minesoils. Present research work in Alabama shows that the sequence of minesoil cultivation for best plant establishment and growth should be: (1) application of soil amendments, (2) incorporation of amendments into minesoil, (3) application of seed to freshly turned minesoil, and (4) mulch.

The Relative Erodability Index (REI) described in the Experimental Methods section can be used by coal mine reclamationists in Alabama to estimate the relative erodability of the various minesoils. This information can be used to estimate the allowable slope, optimum slope length, speed of revegetation needed and amount of mulch needed. All of these factors affect minesoil erosion and can be modified to help prevent excessive erosion when the erosion potential is high. In order to calculate this index, the percent sand, percent silt + very fine sand, soil structure, soil permeability, soil erodability factor and percent soil sized material (< 2mm dia.) for the minesoil must be known or estimated. The percent sand, percent silt + very fine sand, soil structure, soil permeability and percent soil sized particles can be determined in the field. The soil erodability factor, K, can then be estimated by using the nomograph from Figure nine. These operations will provide all values needed for calculating the REI as described in the Exper-

Table 1. Minimum initial limestone and fertilizer recommendations for forage crops grown on the indicated Alabama minesoil classes.

Minesoil Class	N		P_2O_5		K_2O		Limestone	
	kg/ha	lbs/A	kg/ha	lbs/A	kg/ha	lbs/A	metric T/ha	T/A
IA4	67.2	60	224.0	200	56.0	50	0	0
IIA1	67.2	60	134.4	120	134.4	120	22.4	10.0
IIA2	67.2	60	112.0	100	56.0	50	11.2	5.0
IIA3	67.2	60	224.0	200	56.0	50	0	0
IIB2	67.2	60	112.0	100	56.0	50	5.6	2.5

imental Methods subsection, entitled Relative Erodability Index.

Minesoils to be reclaimed should be examined in the light of known erosion factors. If the Relative Erodability Index (REI) described in this study indicates that a minesoil is highly erodable, the reclamationist should use all the techniques at his disposal to prevent the movement of sediment from that minesoil into streams or lakes. This is especially true in Alabama where rainfall intensity is greater than in the rest of the eastern coal fields. Minesoils with a low REI should not require as much effort or expense in order to prevent soil loss and sedimentation.

The method for predicting soil loss developed in this study can be used on any minesoil so long as the correct values are used in the soil loss equation defined in Materials and Methods (Soil Loss = RKLSVM). Values used in Table 8 apply to Alabama and the LS values are for an assumed 10% slope and slope length of 30.47m (100 ft.). However, all of the factors can be calculated for any set of conditions. This soil loss prediction can be used for sediment pond information needs such as: size of pond, wet or dry pond, number of ponds and amount of pond cleaning that will be necessary.

IV. MATERIALS AND METHODS

MINESOIL SELECTION AND COLLECTION

Twenty-seven active mines and six abandoned mines were examined in the coal mining region of Alabama. The purpose of these examinations was to include at least one mine that would be representative of each of the different minesoil classes to be found in Alabama. In selecting sites for detailed study, the primary concern was to include at least one representative of each apparently different minesoil that could be identified by such field and laboratory techniques as color determination, reaction, texture, mineralogy, and nutrient element content. A particular effort was made to include minesoils that would afford the greatest difficulties to revegetation efforts. Test plantings had been established on many of the mines in the course of previous research. The results from this earlier work were of incalculable value to the selection procedure. Ten active mines were chosen for detailed study. Table 2 shows the number, name and location of all mines studied in detail. An additional mine (location no. 28) was later sampled in less detail. This minesoil had the lowest pH found at any site but no significant differentiating characteristics could be found between it and a previously selected minesoil of low pH.

In the active mining areas samples were collected immediately adjacent to plots where experimental plantings were made. These samples were collected from parallel rows 3.66m (12 ft.) apart and every 3.66m (12 ft.) along the rows. Samples contained from 500g to 1500g and were collected from the upper 10.16cm (4 in.) of minesoil.

It seemed reasonable to collect samples from an area comparable in size to the planting area. Therefore, the sampling area formed a rectangle or square depending on the number of rows sampled.

MINESOIL ANALYSIS

Minesoil samples were dried at 105°C until they reached a constant weight. Each sample was then crushed lightly with mortar and pestle until the material was segregated into fairly cohesive particles. This operation required subjective evaluation for the final particle size determination.

After the samples were crushed, the relative amounts of coarser materials were determined by passing them through sieves and weighing the fractions. Soil sized materials (< 2mm in diameter) were sent to the Auburn University Soil Testing Laboratory where the following analyses were performed: pH, buffered pH, Ca, Mg, P, K, CEC, % base saturation, percent Ca, Mg, and K saturation. Soil pH was determined by adding 20ml of distilled

Table 2. Locality number, name of mine and Alabama location of minesoils studied in this project.

Locality Number	Mine Name	Location
2	Burgess	Sec 4 R5W T22S about 3 miles NW of West Blockton in Bibb County
5	Adger	Sec 13 R6W T19S near western edge of Jefferson County
10	Winston	Sec 15 R10W T12S, S.W. corner of Winston County
16	Robertson RA61	Sec 2 R8E T3S about 1 mile S. of Fabius in Jackson County
20A	Fort Payne A	Both Fort Payne A and B are located in same area. Sec 31 R8E T5S. DeKalb County.
20B	Fort Payne B	
21	Sunlight	Sec 7 R6W T13S, about 4 miles N. of Jasper in Walker County.
25	Kellerman 4	The Kellerman and Blue Goose localities are located in a large mining area in Tuscaloosa County including sections 29, 30, 31, R7W T19S and Sections 25, 35, 36 R8W T19S.
26	Kellerman 3	
27	Kellerman 5	
28	Blue Goose	

water to 20cc of oven dry soil that had been sieved through a 10-mesh screen. A standard glass and calomel pH meter was used. The same water and soil mixture was used to obtain buffered pH by adding 20ml of Adams-Evans buffer solution and interpreting the resulting pH obtained from a standard pH meter (1). A double acid of 0.05 N HCL and 0.025 N H_2SO_4 described by Mehlich (4) was used for P, Ca, K and Mg extraction. Phosphorous was determined by the method of Watanabe and Olsen (6). Calcium, potassium and magnesium were determined by reading absorbance on a Perkin-Elmer model 330AA with flame adjusted for maximum sensitivity. Sulfur content was determined by Leco analyzer. Three determinations were made for each sample and the average used as the final value.

EXPERIMENTAL PLANTINGS

Field Plantings

The first series of field plantings was made in the spring of 1977. At this time, the minesoil classification system was not sufficiently developed to choose proven planting sites by applying the classification system. Six sites of differing characteristics were chosen and six plots of 2.01m x 2.01m (6.6 ft. x 6.6 ft.) were established at each site. Three of the plots were randomly chosen for lime and/or fertilizer applications. The three remaining plots received no lime or fertilizer. All plots were cultivated to a depth of approximately 15.24cm (6 in.). Forage seed appropriate for the minesoil were then sown on all plots and raked lightly.

Table 3 shows the amount of limestone applied to each minesoil. All fertilized plots received 72.8 kg/ha (65 lbs/A) nitrogen, 107.5 kg/ha (96 lbs/A) P_2O_5 and 107.5 kg/ha (96 lbs/A) K_2O. All plots were seeded with common bermuda (*Cynodon dactylon*) and serala sericea (*Lespedeza sericea*) except those of mine number 26 which were seeded with dallisgrass (*Paspalum dilatatum*) and alfalfa (*Medicago sativa*) because of the minesoil alkalinity.

The second series of field plantings was scheduled for February 1978. However, drought conditions delayed plantings until March 1978. The minesoil classification system was sufficiently developed at this time to choose representative minesoils for experimental plantings. One minesoil for each of the classes was selected and a field experiment established to test revegetation recommendations.

Five treatments were used at each of the sites. Limestone and fertilizer were applied to all plots except control plots. All plots were then disced, including control plots, and cottonwood cuttings and loblolly pine seedlings were planted in March 1978. Table 4 shows soil amendments and forage seed applied to the different minesoils. It appeared in March that the drought had ended but it continued and practically all loblolly and cottonwood were dead by the end of April. All loblolly seedlings, both dead and alive, were replanted at the end of April. There were no cottonwood cuttings available for replanting. All plots were raked in May 1978 and forage crop seed planted on all plots. Finally, all plots were mulched with hay.

Soil cover was determined by dividing the entire plot into 5.08 cm x

Table 3. Limestone added and soil cover obtained on Spring 1977 plots.*

Locality No.	Soil Cover Fert.	Soil Cover Unfert.	Limestone Added
	---------%----------		metric T/ha
21	77.7	46.7	0
26	71.0	37.0	0
5	0	0	11.2
27	0	0	15.7
25	90.0	61.0	0
10	87.3	67.7	4.48

* All fertilized plots received 72.8 kg/ha N, 107.5 kg/ha P_2O_5, 107.5 kg/ha K_2O. All plots were planted with common bermuda (*Cynodon dactylon*) and serala sericea (*Lespedeza sericea*) except those on mine no. 26 which were planted with dallisgrass (*Paspalum dilatatum*) and alfalfa (*Medicago sativa*).

Table 4. Soil amendments and seed applied to Spring 1978 plots.

Locality No.	Treat.	Soil Amendments N	P_2O_5	K_2O	lime	Seed Planted
		------------kg/ha-----------				
21	1	42.6	268.8	128.8	0	Sorghum-sudan (Sorghum bicolor x Sorghum sudanensis)
	2	42.6	128.8	128.8	0	Johnsongrass (Sorghum halepense)
	3	42.6	268.8	0	0	Alfalfa (Medicago sativa)
	4	42.6	0	0	0	Sweet clover (Melilotus offinalis)
	5	0	0	0	0	
28	1	42.6	128.8	128.8	44800	Browntop millet (Panicum fasciculatum)
	2	42.6	128.8	0	44800	Common bermuda (Cynodon dactylon)
	3	42.6	0	0	44800	Serala sericea (Lespedeza sericea)
	4	42.6	128.8	128.8	0	Crimson clover (Trifolium incarnatum)
	5	0	0	0	0	
2	1	42.6	128.8	128.8	22400	Browntop millet (Panicum fasciculatum
	2	42.6	128.8	0	22400	Common bermuda (Cynodon dactylon)
	3	42.6	0	0	22400	Serala sericea (Lespedeza sericea)
	4	42.6	128.8	128.8	0	Crimson clover (Trifolium incarnatum)
	5	0	0	0	0	
25	1	42.6	268.8	128.8	0	Browntop millet (Panicum fasciculatum)
	2	42.6	128.8	128.8	0	Johnsongrass (Sorghum halepense)
	3	42.6	268.8	0	0	Alfalfa (Medicago sativa)
	4	42.6	0	0	0	Serala sericea (Lespedeza sericea)
	5	0	0	0	0	
10	1	42.6	128.8	128.8	11200	Browntop millet (Panicum fasciculatum)
	2	42.6	128.8	0	11200	Johnsongrass (Sorghum halepense)
	3	42.6	0	0	11200	Alfalfa (Medicago sativa)
	4	42.6	128.8	128.8	0	Serala sericea (Lespedeza sericea)
	5	0	0	0	0	

5.08 cm (2" x 2") squares and counting each square that contained live vegetation. This figure was then converted to percent cover. This method probably yields a valid estimate of soil cover for erosion control so long as the plants are growing close to the soil surface. However, the method probably underestimates the soil coverage of taller plants.

Forage crop yield was determined by removing all plants from the central $0.368 m^2$ ($4 ft^2$) of each plot. Plants were clipped at approximately 1 cm from the soil surface and oven dried at 70^oC.

Greenhouse Planting

A greenhouse study was established in August 1977 in order to test some of the soil amendment recommendations without having to contend with the vagaries of local weather. The same six minesoils were used as in the 1977 field plantings. Each minesoil received four treatments and each treatment was replicated six times. The randomized complete block design was used with each treatment replicated once in each of six blocks.

Common bermuda and Kobe lespedeza (Lespedeza striata) were planted together and the minesoils limed and/or fertilized for treatment one (Table 5). Treatment two was the same as treatment one except that no amendments were added to the minesoil. Treatment three was the same as treatment one except that Johnsongrass and alfalfa were planted instead of bermuda and lespedeza and in treatment four Johnsongrass and alfalfa were planted with no soil amendments. Table 5 shows soil analyses for each of the minesoils before soil amendments, after amendments, after plants were grown in the soils, and the amendments added.

The soil material used in this experiment was obtained by sieving each of the minesoils through a 2.54 x 2.54 cm (1 x 1 inch) screen and discarding all material that did not pass through the screen. The results of these sievings are shown in Table 6. Soils for both amended and unamended treatments were placed in pots of 20.32 cm (8 inch) diameter to a depth of 19.05 cm (7.5 inches) and seeded and watered. All legume seed were inoculated. The prepared pots were placed in a greenhouse equipped with a wet wall to prevent extremely high ambient temperatures. All pots were watered twice each week unless incipient wilting indicated need for a more frequent watering. All plants were harvested at the end of four weeks and the oven dry weight for each species was obtained for each pot.

LIMING EFFECTS

Five minesoils were chosen for a study to determine the effects of liming on soil water reaction over a period of time. Two of these minesoils were extremely acid, two were alkaline, and one was neutral in reaction. Soil sized fractions were obtained from each minesoil by sieving with a 2 mm mesh sieve.

For the two extremely acid sites, sixteen 100 g samples from each site were placed in separate 1000 ml beakers. For each of the other sites, four 100 g samples were placed in separate 1000 ml beakers. These beakers were

Table 5. Soil analyses and amendments for minesoils used in greenhouse experiment.

Mine Location No.	Treatments	pH	N	P	K	Mg	Ca	Dolomitic limestone
			-----------------kg/ha-----------------					metric T/ha
27	Before amendments	3.4		7.8	40.8	341.6	376.3	
	Amendments		67.2	134.4	134.4			15.7
	After amendments	5.6		28.0	181.4	894.9	3512.3	
	F-BK*	6.7		26.9	84.0	1118.9	4076.8	
	F-JA**	6.7		31.4	109.8	1118.9	4849.6	
	C-BK#	3.4		15.7	22.4	957.6	795.2	
	C-JA†	3.4		14.5	17.9	974.4	739.2	
5	Before amendments	4.5		138.9	106.4	838.9	1854.7	
	Amendments		67.2	56.0				11.2
	After amendments	6.2		50.4	147.8	894.9	2844.8	
	F-BK	7.2		51.4	106.4	1118.9	3169.6	
	F-JA	7.1		59.4	121.0	1118.9	3080.0	
	C-BK	4.3		60.5	87.4	885.9	1064.0	
	C-JA	4.3		65.0	84.0	891.5	1108.8	
10	Before amendments	4.9		2.2	32.5	90.7	134.4	
	Amendments		67.2	67.2	33.6			4.5
	After amendments	6.6		40.3	49.3	380.8	750.4	
	F-BK	7.7		28.0	38.1	366.2	722.8	
	F-JA	7.5		26.9	40.3	387.5	806.4	
	C-BK	4.6		3.4	45.9	95.2	134.4	
	C-JA	4.4		3.4	43.7	90.7	112.0	
21	Before amendments	7.0		113.1	123.2	838.9	3682.6	
	Amendments		67.2	112.0	112.0			0
	After amendments	7.5		184.8	254.2	894.9	4309.8	
	F-BK	8.3		159.0	149.0	1013.6	4569.6	
	F-JA	8.2		154.5	166.9	1067.4	4916.8	
	C-BK	8.3		118.7	137.8	1034.9	4188.8	
	C-JA	8.2		113.1	126.6	1055.0	4491.2	

Table 5 (cont.). Soil analyses and amendments for minesoils used in greenhouse experiment.

Mine Location No.	Treatments	pH	N	P	K	Mg	Ca	Dolomitic limestone
			-----------------	-------------------	kg/ha	-------------------	-----------------	metric T/ha
25	Before amendments	7.0		128.8	50.4	332.6	1012.5	
	Amendments		67.2	0	56.0			0
	After amendments	7.1		154.5	118.7	422.2	1084.2	
	F-BK	6.7		152.3	87.4	526.4	1321.6	
	F-JA	6.7		161.3	88.5	499.5	1243.2	
	C-BK	6.7		149.0	73.9	458.1	1097.6	
	C-JA	6.8		137.8	65.0	472.6	1086.4	
26	Before amendments	8.1		70.6	100.8	838.9	8422.4	
	Amendments		67.2	112.0	56.0			0
	After amendments	7.7		142.2	215.0	894.9	6089.4	
	F-BK	8.1		108.6	134.4	1118.9	7212.8	
	F-JA	7.9		118.7	124.3	1118.9	6630.4	
	C-BK	8.3		71.7	143.4	1118.9	6563.2	
	C-JA	8.1		81.8	143.4	1118.9	5429.6	

* Soil amendments, common bermuda, Kobe lespedeza.

** Soil amendments, Johnsongrass, alfalfa.

No amendments, common bermuda, Kobe lespedeza.

† No amendments, Johnsongrass, alfalfa.

Table 6. Amount of rock retained and passed by a 2.54 cm x 2.54 cm (1 in. x 1 in.) mesh screen.

Locality No.	Minesoil					
	> 2.54 cm dia.			< 2.54 cm dia.		
	kg	lbs	%	kg	lbs	%
27	77.3	69	26.9	209.4	187	73.1
5	265.4	237	53.6	229.6	205	46.4
10	50.4	45	18.6	220.6	197	81.4
21	49.3	44	18.5	217.3	194	81.5
25	236.3	211	54.2	199.4	178	45.8
26	70.6	63	25.2	209.4	187	74.8

then used to arrange a complete randomized block design of four blocks with one replication of each treatment in each block.

Two hundred ml of distilled water were added to each beaker. Three of the beakers containing extremely acid minesoils from each site were limed with powdered ACS grade $CaCO_3$. The rates of liming were 0, 11.2, 22.4, and 44.8 metric tons per hectare. The same rates of $CaCO_3$ were added to 200 ml of distilled water to serve as controls. All beakers were then stirred and the first pH readings recorded.

The beakers were completely covered with a flexible plastic cover except when stirring or pH readings were required. Reaction readings were taken immediately after water and $CaCO_3$ were added and all beakers were stirred. The second pH reading was taken the following day and a third reading 27 days later. A final pH reading was taken 331 days after the initial reading. The beaker contents were stirred weekly for the first month and then monthly thereafter.

EROSION

Wischmeier and his associates (7, 8, 9, 10) developed a universal soil loss equation for the prediction of soil loss. A modification of this equation developed by Utah Research Laboratory was used in this study (5).

The universal soil loss equation modified by the Utah Research Laboratory is as follows:

$$A = RKLSVM$$

where A = the amount of soil lost per unit area
R = rainfall factor
K = soil erodability factor
LS = topographic factor (length and steepness of slope)
VM = vegetative and mechanical control factors (equivalent to Wischmeier's CP factors)

Values of R have been calculated for most areas in the United States and maps that give plots of R values for the various regions are available. The R value of 375 for the Northern Alabama mining area was obtained from Erodent (R) value maps from the Utah Research Laboratory Study (5).

Wischmeier (11) reports that silts and very fine sands (particles 0.05 to 0.10 mm in diameter) are the most easily eroded of all soil size particles and that soils become less erodable as their sand or clay content is increased. Also, the rate of decrease in erodability with increased clay content declines even further with higher concentrations of organic matter. In addition, Wischmeier found that while there was an increase of erodability with additional increments of silt size material; the rate of increase of erodability became less as either the organic matter or clay to sand ratio increased.

These relationships were correlated quantitatively by Wischmeier (10) and expressed in a nomograph reproduced here in Figure 1. By determining the

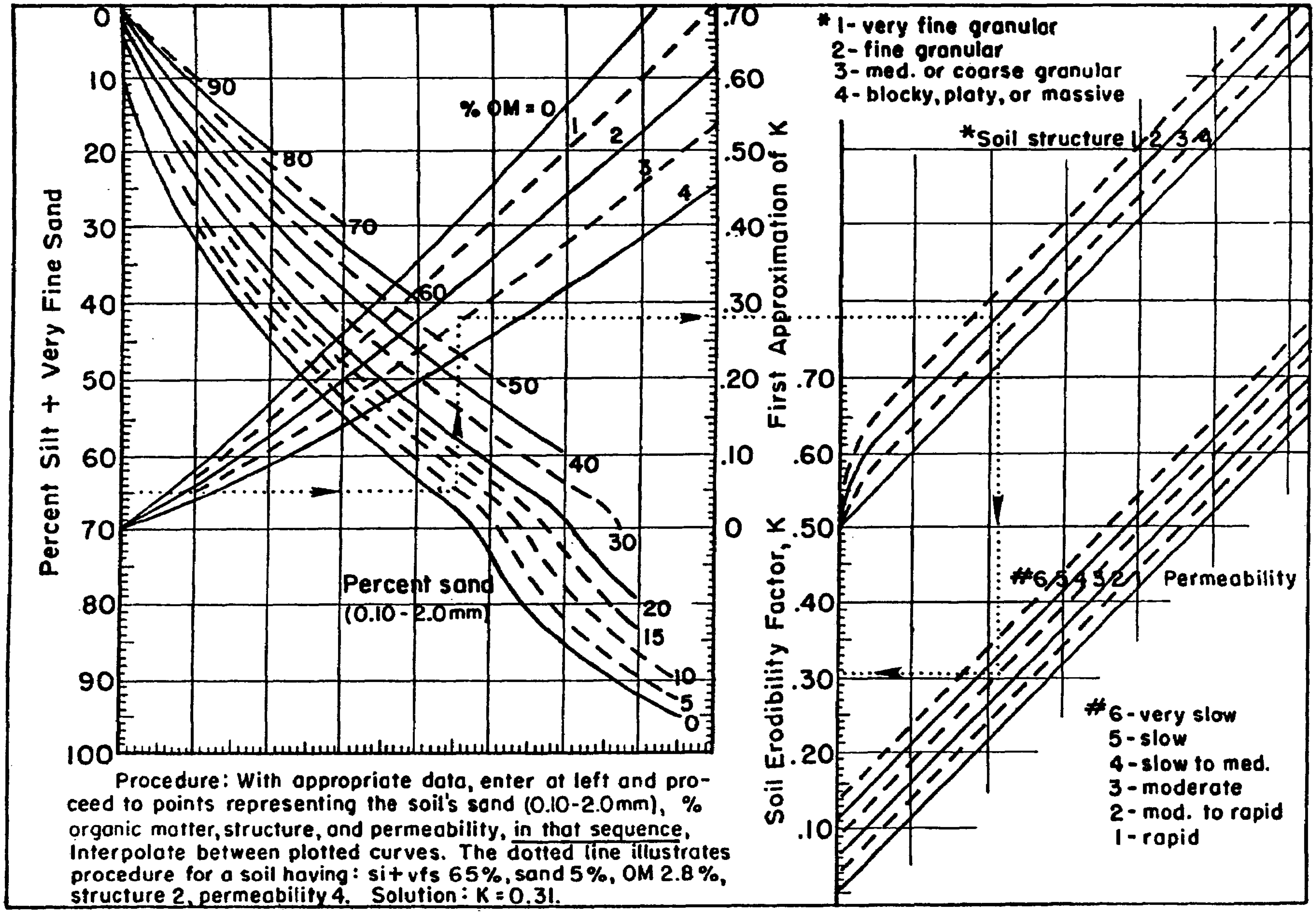

Figure 1. Nomograph for determination of soil erodability factor K (10).

percent of silt and very fine sand, the organic matter (generally nil in minesoils), the soil structure and permeability and by following the procedure outlined in Figure 1 a soil-erodability factor (K) can be determined and applied in the universal soil loss equation. Soil structure and permeability are not always easy to estimate. However, the nature of the nomograph is such that an estimation error of one structure or permeability class will not seriously affect the K value estimate.

The topographic factor (LS) was determined with an equation from Utah Research Laboratory (5) after Wischmeier (12) and Foster and Wischmeier (2)

$$LS = \left(\frac{0.43 + 0.3 + 0.43\ S^2}{6.613}\right) \left(\frac{\lambda}{72.6}\right)^m \left(\frac{10{,}000}{10{,}000 + S^2}\right)$$

where: λ = slope length in feet
S = steepness of slope in percent
m = exponent dependent upon slope steepness

0.3 for slopes < 0.5%
0.5 for slopes 0.5 to 10%
0.6 for slopes > 10%

The VM factors are also applied in the universal soil loss equation as a single unit. Included in this unit are such factors as type of vegetation, mechanical manipulation of soil (not including such features as ditches and berms which are included under LS factors) and the presence of mulches.

The Utah Research Laboratory (5) study observed that mulches have VM values of about 0.01 until RKLS values exceed a certain critical level at which point the mulch partially fails. Figure 2 illustrates the relationship existing between the RKLS factor and the quantity of stone mulch that is required to maintain the VM factor at a level of about 0.01 or one ton per acre per year. The amounts of rock shown in Figure 2 for each RKLS value are the minimum amounts needed to hold soil loss to a point below one ton per acre per year. The erosion control effect of any lesser amounts of rock would be so small that it could be considered wasted.

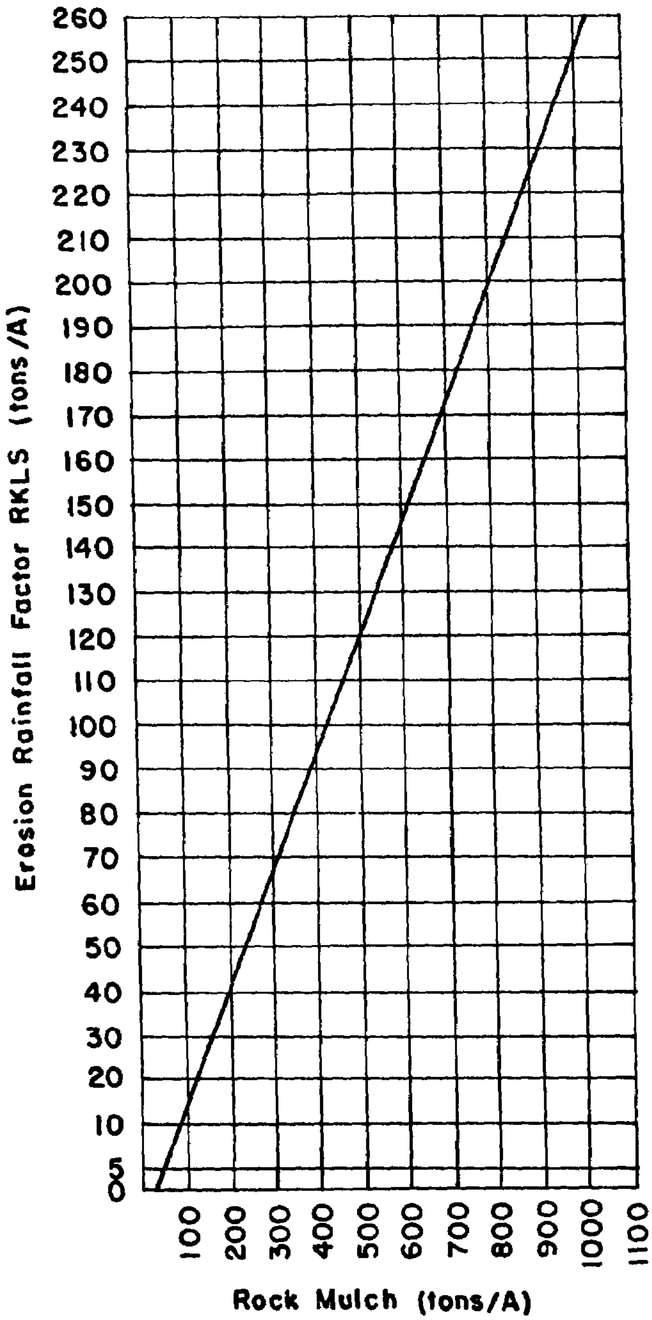

Figure 2. Minimum amounts of rock mulch required to provide a VM value of 0.01 at varying RKLS values (5).

V. RESULTS AND DISCUSSION

MINESOIL CLASSIFICATION

An Alabama minesoil classification system was developed based on soil texture, soil color value and soil pH. Only five different soil classes were found in this study. However, the classification scheme allows for the inclusion of any minesoil that occurs on the basis of its texture, color value and pH.

Light colored minesoils (Munsell color value of the soil sized fraction > 4 when moist) of Alabama are similar in a majority of their physical and chemical characteristics. Therefore, they have been grouped as a single minesoil class. The dark colored minesoils (Munsell value < 4 when moist) had several differing characteristics and were divided into four different classes according to groupings of characteristics. After comparing the chemical and physical properties of these minesoils it was obvious that they could be divided into an acid group and a neutral or alkaline group. These two broad groups were further separated into two sub-groups each on the basis of soil characteristics and vegetation management practices.

The minesoil classification scheme shown on the following page was developed and all classes that were identified in the field are underlined. It is possible that more classes of minesoil will be found in Alabama. Therefore, the entire classification scheme is shown and any new minesoils can be given the appropriate designation.

MINESOIL ANALYSIS

Light and Dark Colored Minesoil Comparisons

A summary of fourteen properties for eleven different minesoils is presented in Table 7. The light colored (value >4 when wet) minesoils (IIB2) exhibit much lower concentrations of magnesium and sulfur than dark minesoils (value ≤4 when wet). The calcium, potassium and phosphorous content of light colored minesoils are either lower than any of the dark minesoils or equivalent to those dark minesoils having the least concentration of these elements. The pH of light colored minesoils ranges from 4 to 5 and the buffer pH is above 7.6. These same values are also commonly found in dark minesoils. There are no apparent textural differences between dark and light minesoils.

Light Colored Minesoil Characteristics

Of the two light colored minesoils (IIB2) studied, one probably represents C-horizon material related to modern soils (locality 20B) and the other

ALABAMA MINESOIL CLASSIFICATION

I. Lithoclast - More than 50% of the minesoil particles are > 2 mm in their smallest diameter. These particles are characteristically composed of clay, silt and sand, and cannot be broken with hands alone. Gravel fragments are angular, flaggy or blocky.

   A. Dark colored (Munsell color value of soil sized fraction ≤ 4 when moist)

      1. Extremely acid (pH ≤ 3.5)
      2. Very acid (pH 3.5-5.5)
      3. Near neutral or neutral (pH 5.5-7.5)
      4. Alkaline (pH > 7.5)

   B. Light colored (Munsell color value of soil sized fraction > 4 when moist)

      1. Extremely acid (pH ≤ 3.5)
      2. Very acid (pH 3.5-5.5)
      3. Near neutral or neutral (pH 5.5-7.5)
      4. Alkaline (pH > 7.5)

II. Pedoclast - More than 50% of the minesoil particles are ≤ 2 mm in their smallest diameter.

   A. Dark colored (Munsell color value of soil sized fraction ≤ 4 when moist)

      1. Extremely acid (pH < 3.5)
      2. Very acid (pH 3.5-5.5)
      3. Near neutral or neutral (pH 5.5-7.5)
      4. Alkaline (pH > 7.5)

   B. Light colored (Munsell color value of soil sized fraction > 4 when moist)

      1. Extremely acid (pH ≤ 3.5)
      2. Very acid (pH 3.5-5.5)
      3. Near neutral or neutral (pH 5.5-7.5)
      4. Alkaline (pH > 7.5)

Table 7. Mean values for chemical and physical properties of eleven Alabama minesoils.

Soil Property	Minesoil Class IA4	IA4	IIA3	IIA3	IIA2	IIA2	IIA1	IIA1	IIA1	IIB2	IIB2
	Locality Number 26	21	20A	25	16	2	5	27	28	20B	10
pH	7.83	7.64	6.74	5.75	5.00	4.22	3.79	3.20	2.82	5.05	4.35
Buffer pH	7.96	7.93	7.97	7.92	7.79	7.55	7.40	6.98	6.90	7.64	7.86
Ca, ppm in Soil*	2531.00	1452.00	446.00	397.00	202.00	152.00	185.00	123.00	91.00	182.00	52.00
Mg, ppm in Soil	520.00	340.00	264.00	160.00	130.00	245.00	159.00	352.00	292.00	56.00	49.00
K, ppm in Soil	70.00	73.00	80.00	43.00	65.00	45.00	49.00	35.00	19.00	46.00	31.00
P, ppm in Soil	49.80	70.22	50.61	71.88	9.57	5.68	15.87	4.16	2.75	5.18	1.29
CEC of Soil (meq/100g)	8.23	5.65	2.55	2.34	2.60	4.92	5.99	10.01	9.67	3.63	1.49
CEC of Clay (meq/100g)	48.82	28.96	17.67	15.85	14.77	18.98	18.69	36.58	29.17	19.36	13.03
Acidity (% of CEC)	3.10	10.70	8.80	25.90	51.40	70.40	78.50	81.90	91.50	79.10	66.30
Ca% of CEC	70.60	62.50	43.90	43.00	20.90	8.20	8.50	3.50	2.50	12.70	11.60
Mg% of CEC	24.60	29.70	41.50	28.10	22.60	19.90	11.30	13.60	5.20	6.30	17.60
K% of CEC	1.10	1.60	4.10	2.00	3.20	0.80	1.10	0.40	0.00	1.30	3.20
S, (ppm in Soil)	1083.00	499.00	692.00	930.00	500.00	900.00	2011.00	4502.00	4065.00	142.00	204.00
S/Ca	0.43	0.34	1.55	2.34	2.46	5.92	10.87	36.60	32.29	0.62	4.12
% >4 mm in minesoil**	67.00	52.00	39.00	34.00	28.00	29.00	37.00	31.00	24.00	11.00	34.00
% >2 mm in minesoil	77.00	61.00	46.00	36.00	32.00	36.00	44.00	42.00	28.00	13.00	37.00
% >0.05 mm in minesoil	89.00	76.00	67.00	80.00	67.00	64.00	64.00	59.00	53.00	56.00	83.00
% 4-2 mm in minesoil	9.00	9.00	6.00	3.00	4.00	7.00	7.00	11.00	5.00	2.00	3.00
% 2¼ mm in minesoil	10.00	8.00	7.00	21.00	25.00	16.00	14.00	11.00	20.00	23.00	17.00
% VFS in minesoil	2.00	7.00	14.00	16.00	10.00	12.00	6.00	6.00	5.00	20.00	29.00
% silt in minesoil	7.00	16.00	25.00	11.00	21.00	20.00	18.00	24.00	20.00	28.00	11.00
% clay in minesoil	4.00	8.00	8.00	10.00	13.00	15.00	18.00	18.00	27.00	17.00	7.00
% sand in soil	53.00	39.00	39.00	68.00	51.00	43.00	35.00	30.00	36.00	50.00	72.00
% silt in soil	29.00	42.00	46.00	17.00	31.00	32.00	39.00	40.00	27.00	31.00	17.00
% clay in soil	18.00	19.00	15.00	15.00	18.00	24.00	33.00	30.00	37.00	19:00	11.00
Ca % CEC / Mg % CEC	2.92	2.67	1.14	1.52	0.96	0.43	0.78	0.26	0.65	2.23	0.72
% >2 mm / % clay in minesoil	1.50	1.03	1.00	0.36	0.53	0.89	0.38	0.48	1.04	0.42	0.58

* Soil material <2 mm in dia.

** Includes all material regardless of size.

(locality 10) probably represents very deeply weathered, material that was first weathered during the late cenozoic period. The evidence for this is as follows: at the Fort Payne site (locality number 20) some individual minesoil piles were light colored while, immediately adjacent ones were dark. The overburden material in the highwall had a 5 to 7 meter capping of light colored material that was relatively friable (it could be broken by hand). This overburden also contained occasional tree roots and graded gradually downward into unweathered rock material. At the Winston site (locality number 10, class IIB2) the highwalls exhibited 17 or more meters of light colored material that was too coherent to break by hand but would break relatively easily by hammering. No ferromagnesium minerals were observed and the common cement was hydrated iron oxides. Such a deeply weathered zone which has been secondarily cemented clearly predates recent conditions.

To summarize, there are at least two types of light colored minesoil materials; (1) a younger, relatively friable, surficial type related to modern soils, (2) an older, non-friable, often very thick sequence resulting from a long interval of weathering and cementing.

Dark Colored Minesoil Characteristics

The mean values for fourteen different properties of the eight dark colored spoils were compared by Duncan's new multiple-range test. The results are given in Tables 8 and 9. Nine of these characteristics are used in comparing the spoils in Table 8 and on the basis of these comparisons the spoils may be classified as belonging to either an acid or an alkaline group. Differences are considered to be significant at the 5% level.

The alkaline group (pH $\geq$5.5) is identified as the upper four localities listed under the column giving the pH values in Table 8 and includes localities numbered 26, 21, 20A, and 25; the other four localities are in the acid group. Each of the localities exhibits a pH which is significantly different from the pH value of any locality from the opposite group. The same general grouping occurs in the upper and lower parts of the columns listing the values for buffer pH, phosphorous, ppm, and Ca% of CEC. With regard to these properties each of the members of the alkaline group is significantly different from any member of the acid group. The particular sequence within the groups and the relationships within the groups varies but for each of these four categories the same localities constitute two separate and distinct groups.

Two localities in the alkaline group, numbered 26 and 21, are different from any member of the acid group in eight of the nine categories listed in Table 8. One acid locality, number 27, is different from any member of the alkaline group in all nine properties. With regard to the five characteristics represented by the five columns on the right side of Table 8, five of the localities are sometimes transitional or intermediate in value between the acid and alkaline groups in that they have values which are not significantly different from one or two members of the opposite group. These localities are listed in each of the right hand columns between the dotted lines. Of the localities in the alkaline group, locality 20A is transitional two times and locality 25 four times; in the acid group locality 16 is

Table 8. Comparisons of nine minesoil characteristics among eight minesoils.

Group	pH			Buffer pH			P ppm			Ca % CEC			Ca % CEC / Mg % CEC			% Clay			% >2mm / % clay			Ca ppm			S/Ca		
	loc.	Mean	SP*	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP
ALKALINE GROUP	26	7.83	A	20A	7.97	A	25	71.88	A	26	70.6	A	26	2.92	A	26	4.23	A	26	19.43	A						
ALKALINE GROUP	21	7.64	A	26	7.96	A	21	70.22	A	21	62.5	B	21	2.57	A	21	7.75	B	21	9.78	B	26	2531	A	21	0.35	A
ALKALINE GROUP	20A	6.74	B	21	7.93	A	20A	50.61	B	20A	43.9	C	25	1.52	B	20A	8.16	B	20A	6.56	C	21	1452	B	26	0.46	A
ALKALINE GROUP	25	5.75	C	25	7.92	A	26	49.80	B	25	43.0	C										20A	446	C			
																									20A	1.53	AB
													20A	1.14	C	25	9.64	BC	25	3.92	D	25	397	CD	25	2.40	AB
													16	0.96	CD	16	12.54	C	2	3.12	DE	16	202	DE	16	2.62	AB
																						5	185	DE	2	6.14	B
ACID GROUP	16	5.00	D	16	7.79	B	5	15.87	C	16	20.9	D															
ACID GROUP	2	4.22	E	2	7.55	C	16	9.57	CD	5	8.5	E	5	0.78	D	2	15.0	D	27	2.85	E						
ACID GROUP	5	3.79	F	5	7.40	D	2	5.68	CD	2	8.2	E	2	0.43	E	27	17.53	D	16	2.83	E	2	152	E	5	15.14	C
ACID GROUP	27	3.20	G	27	6.98	E	27	5.16	D	27	3.5	E	27	0.25	E	5	18.40	D	5	2.60	E	27	123	E	27	37.85	D

* SP (statistical population) minesoils with the same letter are not significantly different from each other at 5% level. Analysis was made by Duncan's New Multiple Range Test.

Table 9. Comparisons of five minesoil characteristics among eight minesoils.

S, ppm			CEC clay			% Particles > 4 mm			K, ppm			Mg ppm		
loc.	Mean	SP*	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP	loc.	Mean	SP
21	499	A	16	14.77	A	26	67.23	A	20A	80.4	A	26	519.9	A
16	500	A	25	15.85	A	21	51.93	B	21	72.5	B	27	352.3	B
20A	692	AB	20A	17.67	A	20A	39.16	C	26	70.4	BC	21	340.1	B
2	900	AB	5	18.69	A	5	36.10	CD	16	64.4	C	20A	263.8	C
25	930	AB	2	18.98	A	25	33.57	CD	5	49.3	D	2	244.9	C
26	1083	B	21	28.96	B	27	30.73	CD	2	44.9	D	25	159.9	D
5	2011	C	27	36.58	C	2	29.11	CD	25	42.8	DE	5	159.2	D
27	4502	D	26	48.82	D	16	27.64	D	27	35.5	E	16	129.7	D

* SP (statistical population) minesoils with the same letter are not significantly different from each other at 5% level. Analysis was made by Duncan's new multiple-range test.

transitional four times, locality 2 twice, and locality 5 once. In all nine categories, when the mean values of the properties are listed in ascending or descending order the four alkaline and acid localities always occur adjacent to each other, in other words, the value for an acid locality never intervenes between two alkaline values nor does the value for an alkaline locality intervene between two acid values.

The other five properties that were not listed in Table 8 but were used in comparing the dark spoils are listed in Table 9. These properties can not be related directly to the alkaline or acid groups but they are useful in comparing the various localities. In three of the five categories the values for locality 21 are significantly different from the values of all other localities except for those of locality 26 and in three of five categories the values for locality 26 are significantly different from those of all other localities except those of locality 21. Thus, the two most typical of the alkaline localities (numbers 21 and 26) are significantly different from all other localities in eleven out of fourteen characteristics used in comparison (eight listed in Table 8 and three in Table 9). The most acid locality, number 27, exhibits values significantly different from those of all other localities in two of the five characteristics listed in Table 9 and so locality 27 has values significantly different from those of all other localities in eleven of the fourteen categories studied (nine listed in Table 8 and two in Table 9). Each of the other five localities also exhibit values that are different from those possessed by all the other localities. The localities and the total number of significantly different features that each locality has are as follows: locality 20A, three unique values; locality 25, two unique values; locality 16, four unique values; locality 5, four unique values.

Evidence has been presented in the paragraphs above that an alkaline and an acid group exists within the dark colored spoils and the differentiating value between these two groups is between the values found for localities 25 and 16. The pH of the soil at locality 25 is 5.75 and for locality 16 it is 5.00. A pH value of 5.50 was selected to separate the two groups.

<u>Subdivision of the Dark Colored Basic Minesoils</u>

The two localities numbered 26 and 21 clearly represent a very distinct grouping. They are significantly different from all other localities in eleven of the fourteen categories studied and they never exhibit characteristics that are similar to those of the acid group. The other two localities are much less distinct and often exhibit characteristics similar to those expressed by the alkaline group. The boundary line between these two groups passes between the pH value of 6.74 shown by locality 20A and pH 7.64 exhibited by locality 21. A value of pH 7.5 was selected to separate the neutral or near neutral (pH 5.5-7.5) minesoil class from the alkaline class (pH >7.5).

<u>Subdivision of the Dark Colored Acid Minesoils</u>

Locality number 27 is distinct, in the acid group it is significantly different in eleven of fourteen categories studied and is sharply different from the other three localities in the acid grouping. A differentiating value of pH 3.5 was selected to separate the very acid (pH 3.5-5.5) and extremely acid (pH $\leq$3.5) classes. The value of 3.5 lies between the pH value of 3.20 for locality 27 and pH 3.79 for locality five.

VEGETATION PRODUCTION

1977 Plantings

The percent of soil cover was determined for the 1977 plantings seven weeks after sowing. Table 10 shows the percent of the minesoil surface that contained newly established seedlings. The two planting sites in class IIA1 produced no soil cover due to the drought during this time. There was enough rainfall at the other sites to establish some seedlings but not enough to keep them alive beyond the seedling stage. Shortly after soil cover measurements were taken, all seedlings on all plots were killed by drought. Other research being conducted at this time indicated that mulching would have increased the chances for seed germination and seedling establishment on the class IIA1 sites. It is also possible that mulching would have kept the seedlings alive on the other sites until the drought ended.

The amended plots had significantly better soil cover than the unamended plots in all cases where seedling establishment was obtained. It is possible that germination was the same on all sites but such factors as minesoil acidity, nutrient content and crusting probably prevented seedling establishment on IIA1 sites.

Alfalfa and dallisgrass were planted on one of the IA4 sites. There does not appear to be any reason for the dallisgrass not to become established. However, there was no dallisgrass at the seven week interval, but an adequate stand of alfalfa. The other IA4 site was seeded with common bermuda and sericea. Neither of these species is suited for an alkaline site such as IA4. However, the sericea did survive for the seven week period, but probably would not have grown well even if the drought had not occurred. At the IIA3 site, bermuda became established only on the amended plots while the sericea became established on all plots. At the IIB2 site, bermuda and sericea both became established on all plots. The IIA3 and IIB2 sites were both sandy soils but they differed greatly in acidity. The IIA3 site had a pH of 5.7 and the IIB2 had a pH of 4.3.

1978 Plantings

Percent of soil surface covered and oven dry yield were determined in August, 1978. The mean values for both of these determinations are shown in Table 11. The total yield on the IIB2, IIA3 and IIA2 minesoils was composed of browntop millet. The total yield on the IA4 minesoil was composed of sorghum-sudan. Some of the other seed (Table 4) may have germinated but they did not survive beyond the seedling stage.

The percent cover and yield were both satisfactory for classes IA4, IIB2, and IIA3 when adequate soil amendments were supplied. The failure or

Table 10. Percent of soil surface covered by vegetation seven weeks after germination (1977 plantings).

Mine	Class	Plots					
		Amended*			Unamended		
		1	2	3	1	2	3
		----------------%			----------------		
Kellerman No. 5	IIA1	0	0	0	0	0	0
Adger	IIA1	0	0	0	0	0	0
Kellerman No. 3	IA4**	68	74	71	42	33	36
Sunlight	IA4#	77	74	82	48	47	45
Kellerman No. 4	IIA3†	87	87	89	58	61	64
Winston	IIB2√	92	92	85	76	60	67

* All amended plot soil covers were significantly different from unamended plot soil covers at the 0.01 level within a minesoil class.

** Alfalfa only on all plots.

\# Sericea only on all plots.

† Bermuda on amended plots only and sericea on all plots.

√ Bermuda and sericea on all plots.

Table 11. Mean values for percent of soil surface covered and ovendry yield of forage six months after sowing (1978 plantings).*

	Minesoil Class									
	IA4		IIB2		IIA3		IIA1		IIA2	
Treat.	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
1	98.0[a]	4876.0[a]	99.3[a]	3063.7[a]	100.0[a]	3456.7[a]	0	0	38.0[a]	1459.0[a]
2	77.0[c]	2240.3[c]	95.0[b]	2798.3[b]	99.3[a]	1598.7[b]	0	0	36.3[a]	1164.7[b]
3	88.0[b]	3795.0[b]	55.7[c]	795.0[c]	100.0[a]	1479.7[b]	0	0	9.7[b]	460.0[c]
4	7.7[d]	32.0[d]	18.7[d]	68.7[d]	72.3[b]	66.3[c]	0	0	1.7[c]	28.7[d]
5	5.3[e]	37.7[d]	9.0[e]	21.3[e]	34.0[c]	55.3[c]	0	0	0.7[c]	10.3[e]

* Values in the same column followed by the same letter are not significantly different at the 0.01 level.

partial failure of classes IIA1 and IIA2 is believed to be due to the continuing drought during the growing season. Germinating seed were observed on all plots shortly after sowing. However, soil moisture was inadequate for seedling establishment on classes IIA1 and IIA2. Forage crops have become established on these minesoils in other experiments during periods of adequate soil moisture. Therefore, it is assumed that failure to obtain a stand of forage was due to drought.

Minesoil class IA4 had a significantly higher cover and yield when adequate amounts of phosphorous were added (Tables 4 and 11). Soil test recommendations for this high pH minesoil indicated that no phosphorous was needed. However, cover and yield were significantly increased in treatments 1 and 3 where the greater amounts of phosphorous were added (Table 11). The soil testing laboratory at Auburn University now uses an extracting solution for near neutral to alkaline minesoils that is designed to show a more realistic soil phosphorous content than the extracting solution used for acid minesoils (3, 4). The yield and cover comparisons between treatments 1 and 3 also indicate a need for potassium on this minesoil (Tables 4 and 11). When treatment 5 is compared to the rest of the treatments, the need for nitrogen, phosphorous, and potassium is confirmed.

Soil test recommendations for minesoil class IIB2 are confirmed by cover and yield results shown in Table 11. Results from treatments 1, 2 and 3 show the need for phosphorous and potassium. However, the greatest need appears to be for limestone for soil acidity reduction. Treatment 4 received the maximum amounts of fertilizer but cover and yield were poor when no limestone was added.

Minesoil class IIA3 was near neutral in soil reaction and again the soil testing laboratory recommended that no phosphorous be added. However, results shown in Table 11 reveal that phosphorous is needed on this minesoil. An adequate soil cover was obtained with lesser amounts of phosphorous than were required for class IA4, but yield for class IIA3 was significantly reduced when less phosphorous was applied (Tables 4 and 11). When phosphorous was eliminated completely, both cover and yield were poor (Treatment 4). The elimination of potassium fertilizer from treatment 3 did not significantly reduce cover or yield. However, the extra phosphorous of treatment 3 may have masked the potassium effect.

The addition of potassium fertilizer did not significantly increase the amount of soil cover obtained on class IIA2 minesoil but it did increase the yield (Tables 4 and 11). Phosphorous significantly increased both cover and yield for this class, and nitrogen alone increased yield but did not increase cover. Lime gave a significant increase in both cover and yield when nitrogen was also added (Treatments 3 and 4).

The cottonwood plantings were almost a total failure and they were not replanted. Loblolly pine survived moderately well after the second planting. Survivals for loblolly on IA4, IIB2, IIA3, IIA1, and IIA2 were 87%, 93%, 96%, 37% and 50% respectively. There were no significant survival differences among treatments. It is not believed that loblolly will survive or grow well on the IA4 and IIA3 minesoils due to the alkalinity. Past experience shows that southern pines exhibit extreme iron deficiency symptoms when planted on these minesoils and usually die within one or two years.

Greenhouse Planting

An examination of Table 12 shows that common bermuda produced the best overall yield of the four forage crops sown. Bermuda also showed the greatest response to soil amendments. Kobe lespedeza had the least response to soil amendments. In fact, there was no response if the yield from location 27 is omitted. However, the apparent poor response of Kobe lespedeza was probably due to competition from the fertilized bermuda since they were grown in the same pots. Johnsongrass responded to amendments on four of the six minesoils and alfalfa responded on five of the six minesoils. There is no obvious explanation for lack of response to amendments by Johnsongrass or alfalfa.

The IIA1 minesoil at location 27 showed the greatest response to soil amendments. The lack of yield in the control pots was probably due to the low pH of the unlimed minesoil. However, this minesoil also forms a strong crust after wetting, and this crust may have interfered with seedling emergence. Liming appears to alleviate this crusting problem on IIA1 minesoils.

The IIA1 minesoil at location 5 showed little response to soil amendments. This could have been due to a lack of available phosphorous. Table 5 shows that available phosphorous was reduced significantly after the addition of other fertilizers. This circumstance could be due to the effect of added fertilizers or to a faulty original soil test.

The IIB2 minesoil responded positively to amendments. The yield of all four forage plants was increased by liming and fertilizing. Phosphorous content was low in this minesoil and the addition of phosphorous fertilizer accounts for the increased yield of amended IIB2 minesoils.

The poor yield of the IIA3 minesoil is probably due to the fact that no phosphorous fertilizer was included in amendments. Soil tests indicated that the minesoil phosphorous content was high. It was known at this time that extra phosphorous was needed for IA4 minesoils but not for IIA3 minesoils. Results from this study and other studies now indicate that the standard Alabama test for soil phosphorous is not valid for IIA3 minesoils.

Phosphorous was added to both IA4 minesoils. These minesoils are alkaline and soil tests indicated a high phosphorous content. However, phosphorous was added because past experience had shown the need. All plants responded to the fertilizers except Kobe lespedeza. The reason for the lack of response in lespedeza is not known.

LIMING EFFECTS

The effect of lime and leaching on pH of selected minesoils is shown in Table 13. The pH of the extremely acid minesoil (IIA1) at locality 27 was not changed at the end of 331 days by the addition of 11.2 metric tons/ha of limestone. There was an increase at the end of 28 days but this effect was

Table 12. The effect of limestone and fertilizers on ovendry yield of two forage crop combinations grown in a greenhouse.*

Location No.	Minesoil Class	Bermuda†		Lespedeza†		Johnsongrass√		Alfalfa√		Average	
		F**	C#	F	C	F	C	F	C	F	C
		kg/ha									
27	IIA1	3687[a]	0[d]	279[a]	0[c]	1137[b]	0[d]	1110[a]	0[c]	1578.2	0
5	IIA1	1416[c]	893[a]	185[c]	246[a]	187[d]	248[a]	277[b]	184[a]	516.3	392.7
10	IIB2	2678[b]	338[b]	308[a]	123[b]	2155[a]	30[c]	1141[a]	64[b]	1570.5	138.7
25	IIA3	246[d]	125[c]	243[b]	249[a]	62[d]	155[b]	214[b]	211[a]	191.2	185.0
21	IA4	2156[b]	92[c]	213[b]	275[a]	708[b]	64[c]	1324[a]	189[a]	1100.2	155.0
26	IA4	2340[b]	153[c]	153[c]	270[a]	677[c]	121[b]	1139[a]	215[a]	1077.3	191.5
Average		2103.8	266.8	230.2	195.0	821.0	103.0	867.5	143.8		

* Values in columns followed by the same letter are not significantly different at the 0.01 level.

** Limed and/or fertilized (see Table 5).

\# Controls.

† Bermuda and Kobe lespedeza were grown together in the same pots.

√ Johnsongrass and alfalfa were grown together in the same pots.

Table 13. Changes in soil water pH with time for limed and unlimed minesoils.

Locality No.	Minesoil Class	Limestone Added	Time			
			0 day	1 day	28 days	331 days
		Metric T/ha	pH			
27	IIA1	0	3.23*	3.22**	3.45**	2.58
		11.2	4.45*	4.88*	6.02#	4.57
		22.4	4.90#	5.65**	6.88*	6.70
		44.8	5.12#	5.92#	6.90*	7.12
5	IIA2	0	4.15*	4.08*	4.25**	3.62
		11.2	5.55#	6.15#	6.92*	7.00
		22.4	5.72#	6.30#	7.10*	7.30
		44.8	5.87#	6.40#	7.12*	7.38
25	IIA3	0	6.08*	6.18*	6.35*	6.75
26	IA4	0	8.00*	7.65*	7.90*	7.52
21	IA4	0	7.92**	8.00**	7.98**	7.15

* This pH not different from pH at 331 days at 0.05 level.

** This pH different from pH at 331 days at 0.05 level.

This pH different from pH at 331 days at 0.01 level.

apparently overcome by oxidation of additional sulfides. Limestone additions at the rate of 22.4 and 44.8 metric tons/ha did increase the pH of the minesoil water significantly over a period of 331 days.

Another extremely acid minesoil (IIA1) at locality 5 contained less sulfur than the one at locality 27 and behaved differently. The pH here increased significantly after addition of 11.2 metric tons and remained so.

The pH of the neutral or alkaline minesoils did not change drastically over the 331 day period. However, the alkaline minesoil at locality 21 did show a significant decrease in pH. Sulfides would be expected to cause such a change as this, but the other two high pH minesoils contained more total sulfur (Table 7) and their pH did not fall. Also, the pH at locality 25 did not change even though it had significantly less calcium than the soil of locality 21.

EROSION

Relative Erodability Index

In surface coal mines a large percent of the minesoil is generally composed of particles that are larger than soil size (Table 6). These larger particles are not as readily susceptible to erosion as are soil sized particles. Their rate of erosion is not only less but they constitute a mulch which acts to decrease the erosion rate of the associated soil sized particles.

A method of predicting the erosion potential of a minesoil is needed in order to make decisions concerning the degree of water control needed, season when topographic manipulation is to be performed and amount of mulch needed. The optimum institution and use of these reclamation operations can significantly reduce the amount of erosion and stream sedimentation in the vicinity of a coal surface mine. The following paragraph describes a method, developed in this study, for determination of the potential erodability of coal surface mines in Alabama.

In order to determine potential erodability, the percent soil sized material in the minesoil and the K value are needed. The soil sized fraction is the only part of the minesoil that is likely to erode and the K factor for a particular soil rates the soil's erosion susceptibility. Therefore, these two values can be used to predict the erodability of a bare minesoil. The product of these two values was used in this study to evaluate the potential erodability of minesoils (Table 14). In order to compare erodabilities of minesoils, a relative index is needed. Such a Relative Erodability Index (REI) was developed. The index is calculated by relating the potential erodability values to a common base which was arbitrarily selected.

The potential erodability (PE) and relative erodability index REI were calculated by using the information from Table 7 and the nomograph in Figure one. Table 14 shows the PE and REI for all of the minesoils used in this study. The highest PE value obtained was 26.97 for locality 20B. The next greatest decimal (30) was selected as a datum value to which all minesoil

Table 14. Soil factors and Relative Erodability Index (REI) for eleven Alabama Minesoils and five minesoil classes.

Locality No.	Minesoil Class	% Silt + VFS	Soil Structure	Soil Permeability	K Value	% Soil	Potential Erodability	REI
2	IIA2	51	1	2	.27	64	17.28	0.58
25	IIA3	43	1	1	.24	64	15.36	0.59
21	IA4	60	1	2	.37	39	14.43	0.48
26	IA4	38	1	1	.21	23	4.83	0.14
16	IIA2	46	1	2	.27	68	18.36	0.61
5	IIA1	49	4	5	.44	56	24.64	0.82
20A	IIA3	71	1	2	.45	54	24.30	0.81
27	IIA1	51	4	5	.42	58	24.36	0.81
28	IIA1	34	4	5	.29	72	20.88	0.70
20B	IIB2	53	1	2	.31	87	26.97	0.90
10	IIB2	62	1	1	.42	63	26.46	0.88

PE values were related. If minesoils with PE values above 30 are found, they will have REI values greater than one.

This erodability index can be used to determine the necessity for speed and completeness of revegetation. Localities 2, 25, 21, 26 and 16 have lower indexes than the rest of the localities. Locality 26 had a significantly lower index than any other locality.

The same process used in this study can be used or modified to calculate erodability indexes in other mining regions.

Soil Loss Prediction

A valuable piece of information for reclamationists would be the amount of soil material expected in sedimentation ponds over a yearly period. The following method for estimation of soil loss in Alabama was developed from the Utah Research Laboratory soil loss equation.

Armored minesoils are defined as minesoils that contain sufficient naturally occurring stone at the surface to provide a VM factor of about 0.01. Minesoils with less surface stone are called unarmored. The VM value of soils that are loose to a 12 inch depth, unvegetated and without surface stone is estimated to be about 0.8 by the Utah Water Research Laboratory (4). In Table 15, the slope (S) was assumed to be 10% and the slope length (L) 100 feet. Under these conditions the LS factor is 1.5941. The R value for North Alabama is 375, and the K values were calculated by the method described in the Methods section titled Soil Loss Equations.

Column A values in Table 15 were obtained by applying the RKLS values for each minesoil to Figure 2 and finding the amount of rock mulch needed to provide a VM value of approximately 0.01. Four of the minesoils with the highest mulch requirements call for approximately 1,000 tons of stone particles to provide a VM of 0.01. Since an acre of stone particles six inches deep weighs approximately 1,000 tons, a six inch depth of stone will protect a variety of highly erodable minesoils against erosion. Therefore, it seems reasonable to assume that no significant erosion will occur where there are six or more inches of stone at the minesoil surface. Column B values represent the weight of the stone in tons per acre actually present in the upper six inches of minesoil. These B values were obtained by the formula:

$$B = \left(\frac{\%\ \text{minesoil material} > 4\ \text{mm}}{100}\right)\ (1{,}000\ \text{tons}).$$

Subtracting the values of Column B from Column A indicates whether or not the minesoil can be considered armored.

The column labeled A in Table 15 estimates the minimum tons per acre of rock mulch needed to provide a VM value of 0.01. These values were obtained from Figure 2 using the RKLS values of Table 15. The column labeled B represents the calculated tons per acre of rock mulch present on the minesoil. These values were obtained by calculating the amount of rock mulch > 4 mm in the upper 6'' of minesoil. If the value B minus A is positive, the minesoil

Table 15. Calculated soil loss to be expected from bare Alabama minesoils with 10% slopes of 100 feet length.

Location No.	Minesoil Class	K	RLS*	RKLS	A**	B#	B-A	VM	Soil Loss (T/A/yr.)	Soil Loss (Metric T/ha/yr.)
26	IA4	.21	598	126	520	770	250	.01	1.3	2.8
21	IA4	.37		221	890	610	-280	.8	176.8	396.0
2	IIA2	.27		161	655	360	-295	.8	128.8	288.5
25	IIA3	.24		143	590	360	-230	.8	114.4	256.2
16	IIA2	.27		161	655	320	-335	.8	128.8	288.5
28	IIA1	.29		173	700	280	-420	.8	138.4	310.0
20A	IIA3	.45		269	1,070	460	-610	.8	215.2	482.0
27	IIA1	.42		251	1,000	420	-580	.8	200.8	449.7
5	IIA1	.44		263	1,045	440	-605	.8	210.4	471.3
10	IIB2	.42		251	1,000	370	-630	.8	148.0	331.5
20B	IIB2	.31		185	750	130	-620	.8	148.0	331.5

* R for study area = 375 (from Erodent (R) values map in Utah Water Research Laboratory (5).
LS = assumed slope 10%, assumed slope length 100 feet. Using Utah Research Laboratory Eq.
LS = 1.5941.
RLS = 375 X 1.5941 = 598.

** Minimum tons/acre of rock mulch needed to provide VM of 0.01

\# Tons/acre > 4 mm in minesoil to a depth of 6": $B = \left(\frac{\%\ \text{minesoil material} > 4\ \text{mm}}{100}\right)$ (1,000 tons).

is armored and the VM value is 0.01. If the value B minus A is negative, the minesoil is unarmored and the VM value is 0.8. Table 15 shows the soil loss to be expected from the minesoils studied in this project. These values were obtained by using the Utah Research Laboratory equation (A = RKLSVM) and the RKLS and VM values found in Table 15. Only one minesoil (locality 26), is classified as an armored soil. The soil loss for this minesoil was estimated as 2.8 metric T/ha/yr (1.26 (T/A/yr); whereas, the loss for an unarmored minesoil such as the one at locality 10 was 331.5 metric T/ha/yr (148.0 T/A/yr).

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16. ABSTRACT

An Alabama minesoil classification system was developed based on soil texture, soil color value and soil pH. Only five different soil classes were found in this study. However, the classification scheme allows for the inclusion of any minesoil that occurs on the basis of its texture, color value and pH. Limestone and fertilizer recommendations are given for soils of the five minesoil classes. Research evidence showed that the limestone recommendations will maintain a pH favorable to plant growth and surface soil water quality for a period of at least one year. The scope of this project did not allow determination of water quality where the water had leached downward through the minesoil. The recommended fertilizer rates should supersede those of a soil testing laboratory if the laboratory recommends lesser amounts of fertilizer. Also, the recommended rates can be used if soil test recommendations are unavailable.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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