LIME TREATMENT EXPERIMENTS GOB REVEGETATION IN ILLINOIS A TWENTY-FIVE YEAR RECORD

by

Charles Medvick

Abstract. In 1971 and 1972, an attempt was made to achieve direct coal refuse revegetation on an Illinois coal refuse (gob) pile by testing six lime application rates and six grass and legume species. Following achievement of some initial success, a larger plot employing "best" treatment was established. Additionally, a small test was installed using "best" treatment and six-inch thick soil cover. In 1976, early results were published, in which short term success was presented. At that time, the prevailing question seemed to be, how long will the vegetation persist? In 1984 and 1985, the gob pile excluding the research plots, was lime-treated and revegetated, but the research plot area was left undisturbed. In 1997, after a 25-year time lapse, the original plots were re-staked from original records, and plot-by-plot, existing vegetation on the plots was evaluated. Data is presented correlating for each treatment (each treatment repeated three times), sulfur analysis, vegetation status and lime adequacy. Related research is discussed. Ramifications concerning relevant acid mine drainage is addressed. Eleven conclusions are offered at the end of the paper.

Introduction

The Illinois Department of Mines and Minerals, Division of Land Reclamation entered into a cooperative effort with Peabody Coal Company to do some experimentation with the objective of revegetating gob refuse areas, but with a short term aim of determining feasibility of lime application to neutralize acidic conditions so that vegetation could be established. The objectives and rationale for this study are described in the 1970 Annual Report of the Land Reclamation Division which, at that time, was a state governmental unit of the Illinois Department of Conservation. That report erroneously indicates the Will Scarlet gob pile is located in Saline County; however, actual location is in Williamson County, about a mile or two from the Saline County line (Ill. Dept. of Conservation, 1970).

Peabody Coal Company agreed to allow the use of two gob piles (Atkinson in Henry County and Will Scarlet in Williamson County). Both gob sources are surface mine coal refuse, with one being situated in northern Illinois and the other in southern Illinois. Peabody agreed to furnish earthmoving equipment to do a small amount of leveling, grading and landshaping work at each site. The Land Reclamation Division agreed to do the actual field work of plot layout and to apply the agreed treatments, including liming, discing, rototilling, harrowing, and seed application. The University of Illinois, Department of Agronomy provided guidance on experimentation.

At the Will Scarlet site, limited sampling sulfur analysis varied from 4.2 to 7.2%. No volunteer vegetation was found to be growing on the gob pile.

In the spring of 1971, plots were staked out, ten feet by twenty feet for each treatment. Plot design was intended to test six grass and legume species for three lime rates and one control. Each treatment was replicated three times. Lime (agricultural limestone) rates applied were 0, 20, 40 and 60 tons per acre. A small cub tractor with rototiller was used to incorporate the lime. It was hoped to incorporate to a depth of six inches; however, perhaps 3" to 5" was actually achieved.

Grass and legume species used were as follow: Blackwell switch grass, alfalfa, birdsfoot trefoil, tall fescue, smooth brome and Korean lespedeza. Fertilizer at 60 pounds per acre of actual N, P, and K was applied and the plots were mulched with straw and covered with mulch net stapled to the ground.

First Results

At the end of July 1971, survey results showed there was no vegetation survival. Acidic conditions caused deterioration of mulch net and even the metal staples only partially remained.

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[2]Charles Medvick is a Public Service Administrator, Illinois Department of Natural Resources, Office of Mines and Minerals, Land Reclamation Division.

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Retreatment

The 10 x 20-foot plots were each randomly divided into two 10 x 10-foot plots. In this fashion, each half was to receive a second application of lime, in addition to what was already applied. This treatment was made in the spring of 1972. At Will Scarlet, 70 tons per acre was added. This brought total lime treatment rates to 0, 20, 40, 60, 90, 110, and 130 tons per acre.

All plots were thus treated, seeded and fertilized, and straw mulch was applied. Results of vegetative performance will be discussed later.

With the benefit of "20:20 hindsight", this writer now believes that an additional step needs to be observed when gob or other toxic materials are being vegetated while the toxic conditions are also being treated. After lime is applied and incorporated, this writer believes that at least one inch of rainfall needs to occur in order to arrest resident acidity. This is based on my belief that the lime does not perform the needed neutralization until it is in solution (rainwater).

Following the occurrence of adequate rainfall, of course, seedbed preparation and fertilizer incorporation will be required prior to seed sowing. Unless the above-described procedure is employed, this writer believes that seed application in acidic gob material will result in desiccation of the seed and loss of seed viability.

Establishment of Larger Test Plots

In the fall of 1973 larger plots were installed for the purpose of more nearly approaching an actual treatment project as well as to eliminate some confounding influence of "edge effect" commonly experienced along the boundary of a treated area. Plots were to be laid out in the one-half to one acre size category, depending on availability and ease of plot layout. Additionally, the larger plots were to be installed simultaneously on two new gob piles located in different parts of the state. Freeman United Coal Mining Company agreed to allow us to work on the Crown Mine gob pile located near Farmersville in Montgomery County. Also, Peabody Coal Company gave permission to work on the Middlegrove Mine gob pile in Fulton County. Will Scarlet also was to have a larger plot installed.

At this point, some experience of past performance as well as some anticipation about future, large scale gob revegetation possibility began to influence research methodology. Only one treatment was to be applied and economics, expediency and practicality of application was to become a part of research design. Rather than apply mulch, the plan was to grow it at the site.

At the same time that the Farmersville and Middlegrove plots were installed, similar plot also was installed at Will Scarlet. Actual plot was 0.46 acre and rectangular. Ground leveling was done with a road grader. Larger rocks were removed by hand in order to reduce problems with the rototiller. Lime rate applied was 130 tons per acre (highest rate used on small, nearby plots).

After lime was incorporated by rototilling 3 to 5 inches in depth, the procedure then was to await the first good rainfall and then rototill a second time. Immediately thereafter, fertilizer was applied (10-10-10 at 600 pounds per acre). Seeding was done using the same mixture as at Farmersville and Middlegrove. Seed was covered by harrowing. The seeding date was August 30, 1973.

A second plot (0.11 acres) was installed at the same time as the 0.46-acre plot was installed. This second plot was treated identically except that 6 inches of native soil was applied on top of the gob plot after 130 tons per acre of lime had been applied and incorporated by discing.

Results on the soil treated area appear to be superior to areas where only lime was applied. There was no initial grass mortality on the soil treated plot, probably because soil temperature would not be as great as on the black gob surface where only lime was applied. Also, it would be expected that soil treatment depth and lime incorporation depth combined will allow greater rooting depth than will be experienced where only lime was incorporated to a 5 to 6-inch depth.

Occurrences Subsequent to 1976

Results of the above-described research appear in the 1976 proceedings of the Illinois Mining Institute (Medvick et al. 1976). Subsequent to 1976 and prior to 1997, the Atkinson, Middlegrove and Farmersville gob piles have been completely reclaimed by the Abandoned Mined Land Reclamation Program and, in the process, those research plots have been destroyed. However, Will Scarlet did not suffer the same fate. In fact, it is because of the fact that remaining identifiability of much of the original plots along with occurrence of the twenty-five year time lapse, more or less, served as a unique incentive to undertake a re-evaluation to see if some useful information could be discerned. It is in that interest that this paper is aimed.

Plot-Adjacent Reclamation Work

The property owner (Peabody Coal Company) decided to reclaim the gob pile on which subject research plots were located. Beginning in September 1984, the gob pile was limed in three stages with lime rates applied being 35-40 tons per acre, 40-50 tons per acre and 50 tons per acre, respectively (Nawrot et al. 1986; Nawrot et al. 1993; Sandusky et al. 1992, Warburton et al. 1987).

On July 2, 1997, telephone discussion with Jack Nawrot, Associate Scientist at Southern Illinois University, sought to determine effect of Peabody's reclamation work on subject research plots. Nawrot indicated that an effort was made to avoid disturbance of the research plots; however, during lime application by lime spreader trucks, it is probable that some of that lime reached the research plots. He indicated, however, it probably was a negligible amount.

Since the 0.46-acre and 0.11-acre soil covered plots were not staked (no markers to delineate them), confounding lime application, no doubt, did occur there. In fact, in 1997, this writer cannot relocate the 0.46-acre plot area.

In 1985, Peabody planted black locust trees on the gob pile area they limed and some hardwood trees and shrubs were planted in 1986 (Nawrot et al. 1986). The Peabody reclamation project also included the sowing of winter rye, sweet clover, red clover and Blackwell switch grass.

1997 Study

This writer has clear recollection of appearance of the Will Scarlet gob pile during the period 1972 to 1981. Except for the lime-treated plots, the gob pile was barren and there was no difficulty identifying the research areas.

In 1997, the gob pile looks like a young forest. Many locust trees are fence post size and Blackwell switch grass predominates as ground cover. Amazingly, several of the 2" x 2" x 4' oak stakes were still standing after 25 years. Many more stakes were laying on the ground where they fell and, in some cases, partially rotted stake stubs could be located where the stake was driven into the gob. Even more surprising was the discovery of a metal pipe, standing erect, as both a plot marker and also a marker designating the boundary between the north replicate and middle replicate. This writer believes that the gob pile, apparently, does not contain the ubiquitous insect and decay organisms found on natural land areas.

Although, admittedly, in a few instances, it was necessary to relocate a few plot stakes from where we originally placed them (during plot relocation work), eventually, by a combination of measurement and alignment between markers still standing, it was possible to, with confidence, reestablish the location of all plots.

1997 Study Methodology

A 1975 Ph.D. thesis by Aschan Sukthumrong (Sukthumrong, 1975) contains a great deal of data on this site, especially chemical analysis data. Sulfur analysis, by plot, appears in Table 2. No chemical analysis work was done in 1997.

Given the fact that we now have had experimental treatments involving six lime rates, a control and six vegetation species, what can we conclude after a 25-year test period? Response to this question is the focus of the 1997 study.

Following remarking (with wooden stakes) of all plots, plot evaluation was initiated in July. The first step was to develop a protocol for evaluating vegetation. This was done to assure that all plots were evaluated consistently. Following is the protocol employed:

Plot Observation Parameters

(1) Indicate species seeded there. Then list species present.
(2) If prominent, mention species dominance.
(3) Describe apparent vegetation vigor.
(4) Is there observable difference between limed vs. unlimed?
(5) Would determination of actual cover % yield meaningful information?
(6) Describe any unvegetated areas -- approx. % barren.
(7) Describe approximate amount of cover (cover %).

Parameter Number 4 could be misleading to the reader if not properly understood. By referring to Figure 1, one can observe that, originally, there were 72 10' x 20' plots that each were later subdivided into two 10' x 10' plots. In 1972, half of each original 10' x 20' plot received an additional 70 tons per acre on top of what originally was applied. This is why, at parameter Number 4, the term limed vs. unlimed is intended to designate the plot half (limed) which received the added 70 tons per acre rate (shaded part on Figure 1) and the term unlimed designates the plot half receiving only the original lime application rate (unshaded part of Figure 1). In the case of the control plot (treatment designation D) the term limed vs. unlimed would not be relevant, since neither half was limed.

Parameter Number 3 is a rating system that, in effect, combines both cover and vigor by appearance of the vegetation. A classification of "good" is intended to designate good or excellent vigor and cover; whereas, a classification of "poor" designates poor vigor. Cover is really not relevant because, in 1997, cover is good in all plots. Plots not rated either good or poor can be presumed to have moderate or fair vegetation.

If one presumes that sulfur analysis (see Table 2) adequately represents sulfur amount for the entire plot, then a lime application rate of 30 tons per acre for each 1% total S would be an adequate rate of lime to assure revegetation success. On this basis, the code @ appears on Figure 1 to designate those plots which are deemed to have been adequately limed.

Numerical Data Analysis

Table 5 in our original publication (Medvick, 1976) shows that, in 1972, all control plots had zero vegetative cover. However, in 1997, there are no plots with zero cover. In fact, Table 1 shows 11 control plots were rated to have good vegetation.

If lime rate applied alone were presumed to correlate with vegetation success (more lime yields correspondingly better vegetation), Table 1 should show increasingly greater number of plots with good vegetation as lime rate increased. However, Table 1 data show this to be not so. Especially anomalous is the fact that the highest number of "good" plots occurs under zero (no lime) treatment.

As stated above, there are no plots with zero vegetative cover in 1997; however, there are some small barren patches. Raw data field notes show there are three plots with estimated 25% barren area, the 15% to 20% barren category occurred in ten plots and there were eight plots estimated to have 9% or 10% barren area. Although some areas classified as barren were, in fact, completely barren, probably half of those patches had some, albeit thin, vegetation.

Table 2 data shows total sulfur analysis by plot, based on analysis published in 1975. If one compares data from Table 2 with Figure 1, it is possible to identify sulfur analysis for each plot. For example, Table 2 Treatment C for brome grass in the north block shows 8.4% sulfur (the highest rate encountered). By referring now to Figure 1, one can see that brome grass Treatment C in the north block is Plot Number 60.

To the extent that averages are meaningful, Table 2 shows that the north block had the highest average sulfur content (4.3%) and the middle block had the lowest (3.1%). Interestingly, the D (control) treatment had the lowest average sulfur content. One should bear in mind, in evaluating this data, that the treatments (A, B, C, D) were selected randomly as to location of each treatment.

Figure 2 shows actual location of each plot and corresponds with Figure 1. Purpose of Figure 2 is to facilitate correlation of vegetation results (Figure 1) with sulfur analysis (Figure 2).

Lime Treatment vs. Lime Requirements

Premised on the presumption that total sulfur content (Table 2) is unoxidized pyrite (ferrous iron disulfide), this experimental design attempted to provide neutralization of total potential acidity for the upper six-inch layer of gob material. Resulting stoiciometric requirement (Sukthumrong, 1975) is 30 tons of lime per acre for each 1% sulfur content. Thus, where this procedure is employed and, based on sulfur analysis, the calculated amount of lime is applied (calculated amount or greater), such area can be deemed to have been "adequately" limed.

Table 3A shows adequacy of lime treatments for the specific treatments employed in this experiment. The treatment code A+ means A Treatment + 70 tons per acre, B+ means B Treatment + 70 tons per acre and C+ means C Treatment + 70 tons per acre. This table shows clearly that, for the highest lime rate applied, C+ (130 tons per acre), the highest sulfur content adequately limed was 4.3%. Consequently, based on sulfur analysis data in Table 2, with sulfur content in one plot being 8.4% and 8.3% in another, it was predictable that some plots would not be adequately limed.

Utilizing the methodology discussed above in an attempt to evaluate the matter of liming adequacy to, hopefully, also reflect vegetation adequacy (good vegetation), Table 3B is presented to show results of this research. Immediately apparent is the fact that adequate liming did not occur below the 90 tons per acre rate. Although, for plots with good vegetation, there was a

TABLE I

NUMBER OF PLOTS WITH INDICATED VEGETATION STATUS, BY LIME RATE

		Lime Rate (Tons/Ac.)							Total	
	Veg. Status	0	20	40	60	90	110	130	Good	Poor
Block #1 (N)	Good	6	2	4	3	2	3	2	22	
	Poor	2	2	0	2	1	1	2		10
Block #2 (M)	Good	4	1	1	2	2	0	1	11	
	Poor	3	2	3	1	3	4	1		17
Block #3 (S)	Good	1	2	1	0	1	1	2	8	
	Poor	8	3	5	4	5	5	3		33
Total Good		11	5	6	5	5	4	5	41	
Total Poor		13	7	8	7	9	10	6		60

Clarification:
Total number of plots is 144.
Plots not rated good or poor, not tallied.
If both halves of zero treatment were rated, both halves were tallied.
The "out" plots were excluded (7 plots) due to fire extinguished by soil dumping in 1971.

Block Designation. There are three treatment replicates (blocks). The blocks of plots are oriented in a north-south direction. Block #1(N) is the north block, #2(M) is the middle block and #3(S) is the south block.

TABLE 2

TOTAL SULFUR ANALYSIS (PERCENT), BY PLOT*

Species	Treatment A	B	C	D	
Brome	7.5	5.6	8.4	8.3	
Fescue	3.9	4.7	4.7	3.8	
Trefoil	3.3	4.0	3.9	2.9	
K.Lespedeza	3.4	3.5	3.6	3.0	
Alfalfa	2.8	4.1	3.8	2.7	
Switch Grass	3.8	5.1	4.2	2.5	
	4.1	4.5	4.8	3.9	Ave.
					4.3 Block Ave. (North)
Brome	2.4	3.0	3.4	3.3	
Fescue	4.2	2.8	3.8	2.6	
Switch Grass	2.4	2.8	3.0	2.7	
K.Lespedeza	3.2	3.1	3.7	2.0	
Trefoil	3.1	3.5	4.0	2.1	
Alfalfa	3.6	3.4	3.3	3.1	
	3.1	3.1	3.5	2.6	Ave.
					3.1 Block Ave. (Middle)
Fescue	2.4	3.9	3.2	2.4	
Trefoil	3.6	2.7	3.2	0.7	
K.Lespedeza	5.0	3.9	3.7	2.1	
Switch Grass	3.1	3.8	7.9	1.6	
Brome	3.1	3.5	2.5	4.1	
Alfalfa	2.4	4.4	4.1	3.8	
	3.3	3.6	4.1	2.4	Ave.
					3.3 Block Ave. (South)

Summary	
Treatment	Average
A	3.5
B	3.7
C	4.1
D	2.9

*From Sukthumrong, 1975

TABLE 3A

COMPARISON OF LIME TREATMENTS WITH LIME REQUIREMENTS, BASED ON 30 T/AC. PER EACH 1% S

Treatment Code	Treatment (Tons/Ac.)	Maximum % S for Indicated Treatment to be Adequate
D	0	0
A	20	0.67
B	40	1.3
C	60	2.0
A+	90	3.0
B+	110	3.7
C+	130	4.3

TABLE 3B

NUMBER OF PLOTS BY INDICATED VEGETATION STATUS, WHERE THOSE PLOTS WERE ADEQUATELY LIMED*

Treatment Code	Treatment (Tons/Ac.)	Vegetation Status	
		Good	Poor
A	20	---	---
B	40	---	---
C	60	---	---
A+	90	2	3
B+	110	1	7
C+	130	5	4

*A total of 29 plots were adequately limed (Table 2 and 3A and Figure 1).

④	54 *	60 *	66 #	72 #
	A *	C *	B	D *
⑤	53	59 #	65	71
	D	B #	A #	C #
②	52 #	58 #	64 #	70 #
	D #	B	A #	C # @
③	51	57 * @	63 * @	69
	D #	B #	C *	A
①	50	56 #	62 #	68
	A # @	B #	C # @	D #
⑥	49 #	55 @	61	67
	D *	C	A *	B
④	30	36	42	48 *
	A # @	D #	C # @	B * @
⑤	29 #	35 #	41 #	47 #
	B @	D #	A #	C @
⑥	28 X	34 X	40 @	46 * @
	B X	D X	C X	A *
③	27 X	33 X	39 *	45
	B * @	C @	D *	A *
②	26 * @	32	38	44 * @
	B *	A	D	C *
①	25 #	31 *	37 *	43 *
	C @	D #	A *	B * @
⑤	6 #	12	18 *	24 *
	A * @	D	B *	C @
②	5 * @	11 # @	17 *	23 #
	B *	C	A #	D
③	4 *	10 # @	16 # @	22 #
	D *	B #	C	A
⑥	3 *	9 *	15 *	21 *
	D *	C *	A *	B *
④	2 *	8 *	14 *	20 *
	C * @	B * @	A *	D *
①	1 *	7 *	13 *	19 *
	A * @	C * @	B *	D

Figure 1.

VEGETATION STATUS, BY PLOT;
BY INDICATED LIME AND
SPECIES SEEDED TREATMENT
AFTER 25-YEAR TIME PERIOD

WILL SCARLET REFUSE LIME PLOTS

	1971		1972		TOTAL LIME
A -	20 TONS	+	70	=	90 TONS
B -	40 TONS	+	70	=	110 TONS
C -	60 TONS	+	70	=	130 TONS
D -	0 TONS	+	0	=	0 TONS

SHADED 1/2 REPRESENTS 1972 LIME ADDITION FOR TOTAL APPLICATION SHOWN IN TABLE.

UNSHADED 1/2 REPRESENTS ORIGINAL 1971 LIME APPLICATION.

- GOOD VEGETATION
* - POOR VEGETATION
@ - ADEQUATELY LIMED
X - EXCLUDE (CONTAMINATED)

① - ALFALFA
② - BIRDSFOOT TREFOIL
③ - LESPEDEZA
④ - BROME
⑤ - FESCUE
⑥ - SWITCH GRASS

←EXAMPLE:
PLOT 43 WITH TREATMENT B * MEANS POOR VEGETATION ON 40 T/AC LIME RATE AND ON 110 T/AC RATE.
@ INDICATES 110 T/A LIME RATE HERE REPRESENTS ADEQUATE LIME RATE.
① INDICATES ALFALFA SEEDED HERE.

④	54 A 7.5	60 C 8.4	66 B 5.6	72 D 8.3
⑤	53 D 3.8	59 B 4.7	65 A 3.9	71 C 4.7
②	52 D 2.9	58 B 4.0	64 A 3.3	70 C 3.9
③	51 D 3.0	57 B 3.5	63 C 3.6	69 A 3.4
①	50 A 2.8	56 B 4.1	62 C 3.8	68 D 2.7
⑥	49 D 2.5	55 C 4.2	61 A 3.8	67 B 5.1
④	30 A 2.4	36 D 3.3	42 C 3.4	48 B 3.0
⑤	29 B 2.8	35 D 2.6	41 A 4.2	47 C 3.8
⑥	28 B 2.8	34 D 2.7	40 C 3.0	46 A 2.4
③	27 B 3.1	33 C 3.7	39 D 3.9	45 A 3.2
②	26 B 3.5	32 A 3.1	38 D 2.1	44 C 4.0
①	25 C 3.3	31 D 3.1	37 A 3.6	43 B 3.4
⑤	6 A 2.4	12 D 2.4	18 B 3.9	24 C 3.2
②	5 B 2.7	11 C 3.2	17 A 3.6	23 D 0.7
③	4 D 2.1	10 B 3.1	16 C 3.7	22 A 5.0
⑥	3 D 1.6	9 C 7.9	15 A 3.1	21 B 3.8
④	2 C 2.5	8 B 3.5	14 A 3.1	20 D 4.1
①	1 A 2.4	7 C 4.1	13 B 4.4	19 D 3.8

Figure 2.

WILL SCARLET REFUSE LIME PLOTS

	1971		1972		TOTAL LIME
A -	20 TONS	+	70	=	90 TONS
B -	40 TONS	+	70	=	110 TONS
C -	60 TONS	+	70	=	130 TONS
D -	0 TONS	+	0	=	0 TONS

① - ALFALFA
② - BIRDSFOOT TREFOIL
③ - LESPEDEZA
④ - BROME
⑤ - FESCUE
⑥ - SWITCH GRASS

TOTAL SULFUR ANALYSIS (PERCENT) BY PLOT [2] higher number for the 130 tons per acre rate than for lower lime rates, there is a greater number (total of 14) of plots with poor vegetation than there is with good vegetation (total of 8). This is so despite the fact that all of those plots were deemed to be adequately limed.

Figure 1 identifies a total of 29 plots to be adequately limed. Thus, since 22 of those plots have either good or poor vegetation, this means that seven plots (adequately limed plots) have fair or moderate vegetation, since they did not qualify as good or poor.

By comparing Table 1 with Table 3B, of the total 41 plots rated to have good vegetation, 33 plots were inadequately limed. Especially surprising is the fact that (Table 1) eleven plots with good vegetation received zero lime treatment. Even more surprising (Figure 1 and Figure 2) is the fact that the north half of Plot No. 72 has good vegetation with no lime treatment and sulfur content there is 8.3%.

As indicated in Table 5 of our original publication (Medvick et al. 1976), all control plots (zero lime treatment) had zero vegetation after the first growing season. However, with no lime treatment, twenty-five years of weather effects appears to have ameliorated gob toxicity and resulted in eleven plots with good vegetation (Table 1). More detailed discussion on this issue will be presented later on in this paper.

Vegetation Species Presence

Of the six species seeded in 1972, the only species which persisted for the 25-year period are switch grass and smooth brome. Raw data notes show that, of the eighteen plots on which each species was originally seeded, switch grass was found on twelve plots and brome was found on one plot. An interesting anomaly is that brome also was found on two plots where switch grass was originally seeded even though switch grass also was found on those two plots.

Table 4 shows species present in July 1997. The ten most frequently occurring species are listed in the order of occurrence by number of plots containing that species. Notice that, of the six species seeded, only switch grass is listed among the "top ten" species; however, switch grass is also the single most frequently occurring species. Thus, a great deal of existing vegetation is "volunteer" vegetation.

In terms of species dominance, visual appearance of these research plots reveals that switch grass stands out. Much of the area appears to be a solid stand of switch grass that is lush (tall and dense stand) with secondary species noticeable only upon close inspection.

From the advantage of 20:20 hindsight, one can conclude now that only switch grass should have been seeded in 1972.

0.11-Acre Soil Covered Plot

Approximately 200 feet west from the south end of the 72 experimental plots, a 0.11-acre plot was installed in early fall of 1973. This area was limed at 130 tons per acre rate and ripped two ways with a road grader ripper about eighteen inches deep and then a six-inch thick soil cover was applied and the area was then fertilized and seeded. Initial seeding was with fescue, alfalfa and perennial rye grass. In March 1974, Sericia lespedeza, alfalfa and fescue were broadcast seeded.

As mentioned earlier in this paper, Peabody undertook reclamation of the whole gob pile in 1984 and 1985. James Sandusky, reclamationist with Peabody, informed this writer they did not avoid the 0.11-acre soil covered plot area when they limed and planted the gob pile. Thus, although the 72 plot area was avoided by Peabody's work, the soil covered plot area, no doubt, received the additional lime, discing and planting that was done on the gob pile at large.

Observation of the 0.11-acre soil covered plot in July 1997 resulted in classifying the area as having excellent vegetative cover. Species observed were foxtail, ragweed, Serecia lespedeza, side-oats grama, goldenrod, one black locust and one unidentified legume species.

A standard soil sampling tube was employed to determine if the soil cover might be experiencing upward diffusion of acidity from the underlying gob. Results were as follow:

ACIDITY (pH) OF SOIL-COVERED GOB

Hole	Surface	Soil at Gob/Soil Interface (6" - 7" Depth)
1	7.4+	7.4+
2	7.4	6.2 - 6.4
3	7.4	7.4
4	7.4	5.4 - 5.8

TABLE 4

VEGETATION SPECIES PRESENCE
BY INDICATED NUMBER OF PLOTS*

Species	Number of Plots Containing that Species
Blackwell switch grass	64
Side-Oats gramma	62
Broom sedge	58
Goldenrod	54
Sweet Clover	46
Black locust	42
Ragweed	40
Mullein	23
Black eyed Susan	16
Astor	13

List of other species observed which were found in twelve plots or less:

Annual rye
Brome grass
Nut sedge
Evening primrose
Red top
Smooth sumac
Spanish needle
Three-awn grass
Wild lettuce
Shingle oak
Foxtail
Red cedar
Jo-pye-weed
One forb and two wild flowers unidentified.

*For this table, total number of plots is 72 10' x 20' plots.

Adjacent Peabody Reclamation Work

Details of Peabody's work on this gob pile have been published (Nawrot et al. 1986; Nawrot et al. 1993; Sandusky et al. 1992; Warburton et al. 1987). In July 1997, the area reclaimed by Peabody (direct liming of gob material) has the appearance of a young forest. Many locust trees are fence post size. The trees have not yet developed to where there is crown closure. Thus, there is adequate sunlight at ground level for herbaceous vegetation to flourish.

The steep gob pile outslopes have not yet been reclaimed and there is significant acidic water seepage from the toe of the gob pile in various places.

General Discussion

Prior to the initiation of the Will Scarlet work in 1971, it was not known if it would be possible to successfully vegetate gob material without first covering with soil. However, it has been established that soil cover placed on acidic gob material can become acidified by upward diffusion (Sukthumrong, 1975). It has also been demonstrated that, without liming gob prior to soil covering, as much as twelve inches to eighteen inches of overlying soil cover is lost due to acidification (Warburton et al. 1987). One study showed that application of 150 tons per acre and incorporated in the gob prior to soil covering prevented upward diffusion of acidity.

One study concluded that there was no difference in results from one-foot, two-foot and three-foot soil cover thickness placed on a gob pile (Kosowski, 1973); however, ten years later, this conclusion changed and found that soil cover became acidified (Warburton et al. 1987). Some workers have concluded that covering gob with four feet of soil does not preclude pyrite oxidation under the soil cover (Warburton et al. 1987).

It is generally known by informed land reclamationists that the source of acidity at coal mine refuse disposal sites (gob piles) is pyrite (ferrous iron disulfide). Absent oxidation, pyrite is a stable material. However, exposure to oxidation results in the generation of acidity, in addition to other reactions. This is why it has been popularly believed for many years that soil cover would exclude oxygen exposure and thereby, "stop the process" of acidity formation. That this is factually not so will be discussed in greater detail later.

Where acidity is a problem, it is an ancient idea that application of neutralizing agents such as lime can arrest acidity. On land areas such as toxic spoil or coal waste refuse, limestone has been the most economical and most readily available neutralizing agent. Thus, why it took so long for someone to attempt to vegetate a gob pile by lime treatment is interesting to ponder.

This writer speculates that his own thinking may have been shared by others. This thinking was that lime treatment would be probably a short term matter largely because, in the neutralization process, a byproduct produced (solid ferric hydroxide) forms a rusty colored coating on lime particles and, in effect, serves to armor the lime from functioning further to continue its neutralizing role. Thus, in a short period of time, the lime would become armored and cease to function, resulting in the lime treatment being only a short-term treatment.

A phenomenon which this writer believes may have been overlooked by most researchers, however, may be the fact that lime particles are not the only particles that become coated with solid ferric hydroxide. In fact, two researchers working with sanitary sewage sludge in controlled experiments with pyritiferous coal mine spoil found that:

"----solid ferric hydroxide is the stable form of iron and precipitates freely from solution, coating both the sludge and pyrite and reducing the effective surface area of the pyrite fragments which, in turn, reduces the rate of acid mine drainage production." Also:

"----oxygen is prevented from adsorbing onto the surface of the pyrite and the organic component of sludge by the ferric hydroxide precipitate." (Loomis et al. 1984)

Another researcher found:

"Review of our data suggests that liming appeared to be retarding pyrite oxidation."

"----The suggestion of a possible suppressing effect of lime on pyrite oxidation is not original with me. It has been known for some time and I merely saw what appeared to be confirmation of the fact in the data." (Tyner, 1974)

Other researchers have stated: "----near-neutral pH causes ferric iron to precipitate, with possible effects including coating of reactive pyrite surfaces and disruption of the ferric oxidation pathway---".

Additionally, "----Heavy surface covers of limestone, initially used to facilitate revegetation, also show some promise for inhibiting AMD formation---". (Kleinmann et al. 1986)

This writer believes that the above-described phenomenon (pyrite fragments becoming inactive due to coating by solid ferric hydroxide) may help explain why our research plots that were treated twenty-five years ago have not reacidified and, conceivably, never will. thus, if vegetation establishment alone is the target of gob pile reclamation, this research has established that direct liming without soil cover is technologically achievable.

With regard to the existence of poor vegetation in some plots at Will Scarlet, even in places where lime rate was deemed to be adequate, this is a critical issue which this writer urges the reader to ponder and attempt to fully understand the ramifications of this fact. Simply stated, gob materials are highly heterogeneous and, in reality, no sample should be considered to be truly "representative" of the whole. For example, sulfur analysis of Sample A might contain two or three times the sulfur analysis of Sample B located just two or three feet away. Thus, where such data is subjected to averaging, one should recognize a relatively large confidence interval for the average number.

Researchers in Scotland quantified the erratic distribution of pyrite in gob material. In that study, one hundred samples were analyzed on a 0.25 meter square area, within which the sample points were located 5 cm. apart. With the units expressed as % FeS_2, the analysis for lowest sample was 0.2 and the highest analysis was 6.6%. Three samples located 5 cm. from the 6.6% sample location contained 0.8%, 0.6% and 1.4%, respectively. This is a difference in pyrite content greater than tenfold in a space of 5 cm. (Pulford et al. 1986).

In practice, if a gob pile is to be limed to establish vegetation, calculating lime rate based on 30 tons per acre for each one percent sulfide sulfur analysis is a fair way to determine lime rate adequacy. However, after liming is done and vegetation established, visual appearance of the vegetation will serve to, in effect, delineate areas where vegetation is unsatisfactory and facilitate identification of the areas which need to have more lime applied. This process can be repeated until no unsatisfactory vegetated areas remain.

Water Quality Discussion

In the final analysis, a successfully reclaimed gob pile will be well vegetated, stable (not experiencing erosion), and water, both from surface runoff and from seepage, will not be acidic (pH 6-9).

Although treatment of the gob pile surface is logical, because the initial ferrous iron disulfide (pyrite) oxidation process requires oxygen, unfortunately, one of the byproducts of pyrite oxidation is the formation of ferric iron. Even more unfortunate is the fact that ferric iron will oxidize pyrite even in the absence of oxygen (Shumate et al. 1971).

Consequently, where a gob pile has been exposed to surface oxidation for a period of time, it is likely that ferric iron has accumulated in subsurface areas. Thus, pyrite materials in subsurface areas that come in contact with ferric iron will be oxidized and acidity will be generated. It has been established (Shumate et al. 1971), however, that the source of ferric iron is the aerobic oxidation of pyrite. Thus, if all aerobic oxidation is arrested and alkaline environment created, there will be no more ferric iron produced.

There are two underground mine gob piles that have been reclaimed in southern Illinois at mines closed in recent years. In both cases, the gob was heavily limed before covering with soil. In both cases, the vegetation is satisfactory, the slopes are stable and acidic seeps at the toe of these gob piles have not occurred. This writer believes that, to be adequate, the lime applied prior to soil covering needs to neutralize the acidity in the gob surface layer and also percolate as alkaline water to subsurface areas to where ferric iron may have migrated. Where these conditions are found, subsequent acidification should not recur unless surface erosion occurs and unoxidized gob material becomes exposed.

Gob Materials Weathering and Aging Discussion

Discussion of this research project cannot be considered complete without due attention to effects of weathering and aging on gob materials. Twenty-five years of freezing and thawing cycles, rain, snow, hot sun and oxidation have affected the surface, and leaching by water insoak has effects below the surface.

This writer believes his experience with reclamation of toxic spoils (surface mine spoils) is relevant in understanding the effects of aging and weathering on toxic materials. Going back to the period of the 1960's, it was not uncommon to have to delay tree planting on some spoils areas due to spoil toxicity. Where this occurred, these areas were checked (for pH and presence of volunteer vegetation) annually to determine if they were "plantable". Commonly, two or three years of aging and weathering resulted in many areas becoming plantable. By actual, personal recall, some sites had to undergo eight or nine years of time lapse after which they became "plantable".

This writer believes the same phenomenon involving toxic spoils also applies to gob materials with the caveat that gob materials likely would be expected to contain greater amount of pyrite and, consequently, for such materials to completely oxidize and become non-acidic through natural aging and weathering, a longer time period would be required.

It is essential to recognize that, for "beneficial" weathering and aging to occur, the site must be stable. If erosion occurs and subsurface, unoxidized materials become exposed by erosion, the aging and weathering effects are, in effect, undermined and, on such sites, the aging and weathering period takes on what one might term "moving target".

In the light of immediately-above discussion, let us now turn to subject gob research plots. Figure 1 shows all plots identified with D Treatment received no lime. Yet, if we tally all D Treatment plots with vegetation code # (good vegetation), there are eleven such plots. The numbers also are tallied on Table 1. It seems fair to ask, how is that possible?

This writer believes the answer must be that twenty-five years of aging and weathering action has exerted its influence and those sites have become "plantable". It is important to understand that the topography of these research plots is level, or nearly so, with possibly as much as 2% slope at most. Thus, the site is stable. Prior to applying lime treatments, a road grader was employed to construct a diversion along the east side of the plots to prevent surface runoff from outside the plot area which might contaminate the plot treatments.

In July 1997, the only evidence of erosion observed on the lot areas was found at Plot 19 (the extreme southeast corner plot) and that plot is identified (Figure 1) as D Treatment (no lime applied). Raw data field notes for that plot indicate a small erosion gully in exposed gob material immediately up-gradient from corner of the plot and an estimated 20% of that plot is barren (no vegetation). Portion of this plot not affected by erosion has vegetation, but is classified as poor vigor.

Finding good vegetation growing on eleven gob plots with no lime treatment represents the single most unexpected result from the 1997 study.

This writer sought to determine if a literature review might reveal other research which documented a change from toxic conditions on coal refuse such that, with the passage of time, conditions improved and vegetation became established. In fact, such research has occurred. In a study at Southern Illinois University, coal refuse sites ranging in age from 20 years to 90 years, involving 26 unburned gob sites, 5 burned gob sites and 5 slurry sites were evaluated. Refuse materials were evaluated where vegetation had become established and compared results with adjacent unvegetated areas. The study found:

"These results would indicate that natural amelioration through weathering and leaching of the surface layers of refuse disposal areas may result in conditions favorable (higher pH, lower conductivity, and acidity) to initial vegetation establishment." (D'Antuono, 1979).

Unfortunately, in that study, the sulfur analysis of the study refuse sites prior to aging is not known.

One additional item deserves to be mentioned, since this writer has not seen the matter mentioned in the literature. This matter involves a possible soil texture beneficial role involving ferric hydroxide precipitate material. At the time (1972) when rototilling was being done to incorporate the added lime treatments, it was noticeable that, contrasted with color of surface gob material (black color), there were a great deal of brown particles scattered throughout the tilled material. These brown particles probably are ferric hydroxide precipitate materials which, being soil-size particles, probably could be expected to serve a soil component function such as water and nutrient retention. This could have an especially beneficial role, given that gob materials consist of a high proportion of coarse texture material.

These observations appear to corroborate with findings by researchers whose studies with sewage sludge and lime treatments of gob showed that, over time, sand-size particles increased while clay decreased. This was attributed to the formation of sand-size, water stable aggregates. During vegetation establishment, straw mulch provided protection from high temperatures, but after establishment, vegetative cover was responsible for surface temperature regulation (Joost et al.1987).

Conclusions

(1) With adequate procedure and lime rate, the stable (non-eroding) parts of a coal refuse pile can be permanently vegetated.

(2) Erodible slopes on coal refuse piles must be adequately limed and soil covered in order to

establish vegetation permanently.

(3) It remains yet to be demonstrated if it is possible to both establish vegetation and eliminate acidic mine drainage by direct liming.

(4) Alfalfa, fescue, Korean lespedeza and birdsfoot trefoil failed to survive a 25-year test period. However, switch grass survived on twelve out of eighteen seeded plots; whereas, brome grass survived on one out of eighteen seeded plots.

(5) Switch grass is an excellent grass species to employ for coal refuse revegetation.

(6) The amount of lime needed for coal refuse revegetation is 30 tons per acre for each one percent of sulfide sulfur in the refuse.

(7) If both vegetation establishment and land use capability [pre-mining capability per SMCRA Section 515(b)(2)] are to be established on a reclaimed gob pile, both lime treatment and soil cover adequate to facilitate land tilling (plowing, etc.) by conventional farming equipment will be required.

(8) Soil covering of a coal refuse pile will not acidify from upward diffusion from gob material if, prior to soil covering, the gob is adequately limed.

(9) Sulfur analysis of coal refuse samples are not necessarily representative of the total refuse pile, unless a large number of samples are analyzed.

(10) Where no erosion (wind or water erosion) occurs, aging alone may ameliorate coal refuse toxicity since, after a 25-year time period, eleven plots with no lime application had good vegetation established.

(11) Tree planting appears to provide favorable ecological benefits for coal refuse pile revegetation, even where herbaceous cover establishment is the objective (wind protection and partial shading).

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APPENDIX

LIST OF SPECIES

COMMON NAME	SCIENTIFIC NAME
Blackwell Switch grass	Panicum virgatum
Broom sedge	Andropogan virginicus
Goldenrod	Solidago spp.
Side Oats gramma	Bouteloua curtipendula
Sweet clover	Melilotus alba
Ragweed	Ambrosia spp.
Mullein	Verbascum thapsus
Black Eyed Susan	Rudbeckia hirta
Black locust	Robinia pseudoacacia
Aster	Aster spp.
Annual rye grain	Secale cereale
Smooth brome grass	Bromus inermis
Nut sedge	Cyperus spp.
Evening primrose	Oenothera spp.
Redtop	Agrostis alba gigantea
Smooth sumac	Rhus glabra
Three-awn grass	Aristida oligantha
Wild lettuce	Lactuca spp.
Shingle Oak	Quercus imbricaria
Foxtail grass	Setaria spp.
Red cedar	Juniperus Virginiana
Jo-pye-weed	Eupatorium spp.
Spanish needle	Bidens bipinnata

One forb and two wild flowers unidentified.

Figure 3. View of revegetation plots from north end looking south. The entire plot tract is visible from left ot right. To the right and left of the research plots, black locust trees, planted by Peabody in 1984, are visible. Some trees are encroaching on the plots. Person in the photograph is resting his hand on a wooden lath which is four feet long.