EFFECTS OF COVER SOIL THICKNESS ON REVEGETATION OF ACIDIC APPALACHIAN COAL REFUSE[1]

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Abstract. Appalachian coal processing wastes are typically acid forming with potential acidities in Virginia ranging from an average of 12 Mg CCE demand/1000 Mg waste up to > 50 Mg/1000 Mg where higher sulfur coal seams are cleaned. Direct seeding of these materials is further complicated by high rock fragment content, low water-holding capacity, and high summer surface soil temperatures. In Virginia, conventional revegetation protocols established by the Virginia Division of Mined Land Reclamation (DMLR) in the early 1980's required the return of 1.2 m of soil cover over all actively permitted coal wastes. Unfortunately, most active piles at the time had no available topsoil reserves, so the only alternative was to disturb adjacent properties via blasting to generate spoil derived topsoil substitutes. Between 1982 and 1990, we investigated a number of direct seeding and reduced topsoil cover alternatives in an effort to determine the optimal combination of soil amendments and cover soil thickness for the successful revegetation of varying coal waste acidity conditions. The centerpiece of this research effort was a series of topsoil wedge experiments established over three different coal waste materials where cover soil depth was varied from 0 to 125 cm, with and without lime (15 to 25 Mg/ha) at the soil/coal waste contact. Multi-year vegetation and soil sampling results indicated that a minimum of 45 to 75 cm of cover soil was required over highly acid-forming refuse (47 Mg CCE demand/1000 Mg), with the shallower depth sufficient when a lime layer was applied at the contact zone. Over moderately acid-forming materials (15 to 35 Mg CCE /1000 Mg), as little as 25 cm of cover soil was adequate as long as lime was added to the soil/waste contact zone. Coal waste materials that are < 15 Mg CCE/1000 Mg net acid forming can be direct seeded if high P applications are coupled with heavy mulch or organic amendments, especially when the fill faces are not south-facing. These results were implemented into permit review and oversight by Virginia DMLR in the early 1990's and over the past 15 years, a wide range of active coal waste piles have been successfully revegetated with soil covers of 50 cm or less.

Additional Key Words: Potential acidity, direct seeding, liming, coal waste, gob.

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Introduction

Stabilization and reclamation of coal refuse disposal piles and fills is a costly and challenging problem facing the Appalachian coal industry. Coal refuse disposal areas are also known as "gob piles," "slate dumps," "waste piles," and "refuge." The exact land area of coal refuse in the Appalachian coal fields is difficult to estimate, but active disposal facilities (see Fig. 1) cover thousands of ha and abandoned refuse piles dot the landscape in almost every major watershed. Annual production of coal refuse exceeds 15 million Mg in Virginia alone.

Figure 1. Large (> 200 ha) coal refuse disposal area in southwest Virginia. The material in the foreground is unreclaimed coarse refuse currently being filled while the light green materials in the background are recently revegetated materials with a thin (25 cm) topsoil plus lime cover.

Modern coal cleaning technologies have allowed coal preparation facilities to become quite efficient at pyritic sulfur (S), waste rock and low-grade coal from run-of-mine coal. Up to 50 % of the raw mined product may end up as refuse, particularly when the coal originates from longwall mining operations or is high in partings, rock, and impurities. The refuse materials vary from coarse fragments removed by physical screening to very fine particles removed by flotation and density separation processes (Stewart, 1990). Clean Air Act compliance, particularly the demand for low S emissions from power plants has led to greatly improved efficiencies in pyritic-S removal from cleaned coals. The inevitable result of these engineering improvements, however, is an increasing amount and reactivity of pyritic-S in Appalachian coal refuse disposal facilities. The average coal refuse in Virginia is at least 0.5% pyritic-S with an average potential acidity of 15 Mg lime requirement per 1000 Mg waste (Stewart & Daniels, 1992).

The potential hazards of improperly reclaimed refuse include contamination of surface and ground water by acidic leachates and runoff, erosion and sedimentation into nearby water bodies, spontaneous combustion, and damage from landslides. While these problems were common on refuse piles constructed prior to the 1970’s, recent regulations attempt to minimize the environmental impact of coal refuse disposal via prompt revegetation. Establishment and maintenance of permanent vegetation on refuse, however, is complicated by physical, mineralogical, and chemical factors, particularly high levels of potential acidity, soluble salts, and very high summer temperatures (Davidson, 1974; Schramm, 1966). Conventional reclamation approaches before the mid-1980’s usually involved topsoil covers (Jastrow et al., 1981), although some success was reported with various direct seeding approaches, both with (Joost et al., 1987) and without (Nickerson, 1984) heavy lime and organic amendments.

Reclamation standards for refuse disposal in Virginia are set forth in the Permanent Regulatory Program of the Virginia Division of Mined Land Reclamation (VDMLR), based upon requirements of the federal Surface Mining Control and Reclamation Act (SMCRA) of 1977. Before permit liability and bond monies are released, refuse disposal areas must support self-sustaining vegetation and meet water quality performance standards for a minimum period of 5 years. Once the fill is completed, regulations require that "the site shall be covered with a minimum of 4 feet (1.2 m) of the best available non-toxic and non-combustible materials." However, those same regulations also allow for use of less than 4 feet (1.2 m) of alternative materials if chemical and physical analyses indicate its properties are conducive to establishing a permanent vegetative cover, and the applicant can prove that the standards for revegetation success can be met. Thick topsoiling is quite costly and may be impractical in areas where native soils are shallow. Extensive topsoiling also creates the problem of reclaiming the borrow areas.

The work reported here was conducted as one component of a larger coal refuse revegetation research effort (see Daniels et al., 1996) in the 1980’s to assess the necessary thickness of topsoil covers over potentially phytotoxic coal waste materials. At that point in time (mid 1980’s), SMCRA had been implemented for less than a decade via VDMLR’s Permanent Regulatory Program, and the vast majority of coal refuse disposal areas did not have sufficient topsoil stockpiles or locally available topsoiling materials to meet the mandated 1.2 m covers. The “topsoil wedge” research designs employed here were based largely on previous efforts by Schroeder et al. and other researchers in the western coal mining states, but were adapted for local conditions and logistics as discussed later. A summary of our overall program was presented at the 1987 ASMR meeting (Dove et al., 1987), but this paper provides greater detail on the topsoil wedge experiments.

<u>Original Research Objectives</u>

1. To evaluate the minimal topsoil depth necessary for the successful reclamation of acid-forming coal refuse materials.

2. To determine the effect of lime additions to the refuse/topsoil contact zone upon minimal topsoil depth requirements for successful reclamation of coal waste piles.

Research Methods and Materials

Three study sites in Wise and Buchanan counties, Virginia, were established in cooperation with Westmoreland (Bullit Mine Refuse Area - BMR), Paramont (Ramsey Refuse Area - RRA), and the Jewell Smokeless Coal Company (JSR - Harper's Branch Refuse Area). Each study site was located on an active coal waste disposal area. In 1983, all research wedges were constructed over relatively flat portions of coarse coal refuse fills. The coal waste materials employed varied from very toxic (net potential acidity = 47 Mg/1000 Mg at JSR) to moderately acid forming (net potential acidity = 25 Mg/1000 Mg at BMR), to relatively low potential acidity (12 Mg/1000 Mg at RRA). Topsoil materials used consisted of a mixture of all natural soil horizons above hard rock plus softer underlying overburden that could be removed with a bulldozer. These materials were considered to be typical for the reclamation of these areas, with an average pH of 5.5 to 6.5 and 25% to 35% rock fragments.

Soil depth wedges were constructed (Figs. 2 and 3) such that cover thickness increased from 0 to 120 cm over a distance of 16 m. At two locations, BMR and JSR, south-facing plots were established to maximize water stress effects. At RRA, four identical sets of plots were constructed with opposing aspects (N-S-E-W: Fig. 4). Prior to plot construction, agricultural lime was applied to the refuse:topsoil interface beneath half of each topsoil wedge area. At JSR, we applied 25 Mg/ha, and at BMR and RRA lime was applied at 12 Mg/ha. The lime was bladed in with a dozer, but not incorporated per se. All plots were seeded with a uniform seed mixture (primarily *Festuca arundinacea, Festuca Ovina, Lotus corniculatus, and Lespedeza striata*) with routine reclamation rate N-P-K applications (Dove et al., 1987).

All plots were non-destructively sampled on a yearly basis for vegetative cover using the point frame method. Additionally, plots were destructively sampled in fall 1987 for determination of species composition, plant nutrient analysis and standing biomass yield. We replicated our vegetation sampling transects (n= 3 each limed and unlimed) up each side of each wedge, and the overall depth and lime effects reported as "different" were all significant ($P < 0.05$) for each wedge studied. In 1987, we excavated soil trenches (Fig. 5) down each side (limed vs. unlimed) of all wedges to collect bulk soil samples and performed detailed descriptions of mine soil morphology and rooting depth at each 15 cm cover soil depth increment.

Results and Discussion

Topsoil Thickness and Lime Effects on Vegetation Density

Four years after vegetation establishment at JSR the effect of subsurface lime application was readily apparent. At a topsoil thickness of 15 cm or less, the percent ground cover was sharply reduced in those plots that had not received sub-lime (Table 1). As the topsoil thickness increased, ground cover was excellent in all plots.

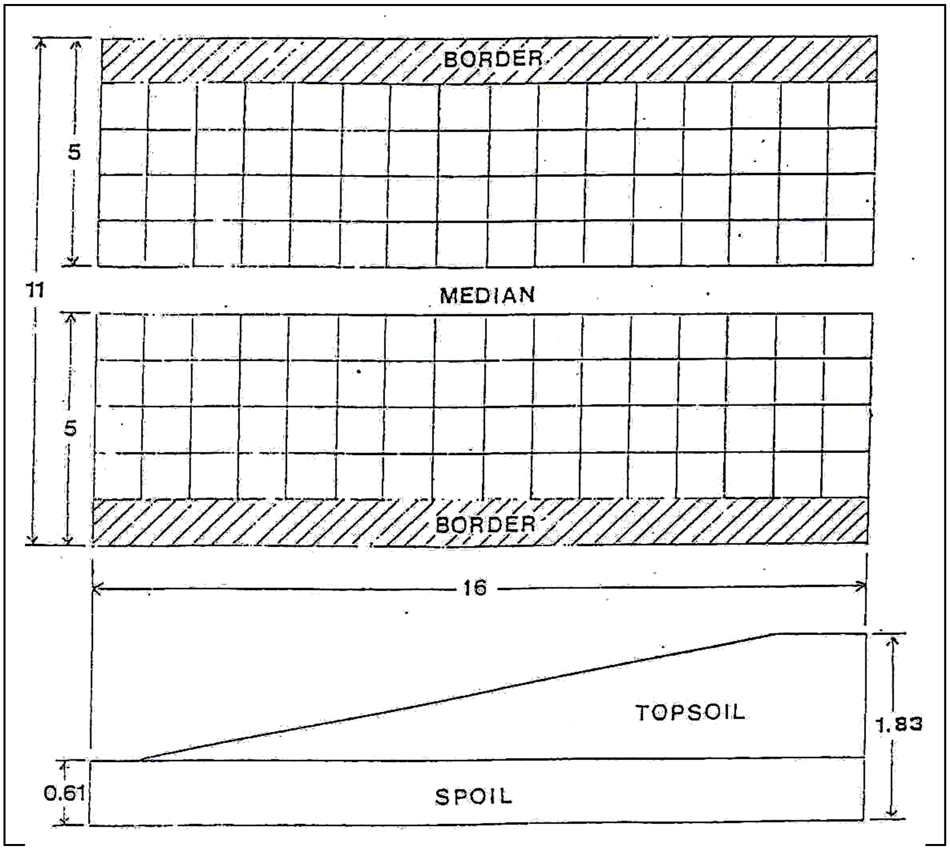

Figure 2. Plan and side views of topsoil wedge design implemented at all research locations. Lime was applied under one half of each wedge. The areas shown as "border" were sloped away to avoid a sharp sloping edge. While not shown here, the high end of the wedge was similarly sloped away. Measurements shown in meters.


Figure 3. View of recently constructed and seeded topsoil wedge at Jewell Smokeless Coal (JSR) in 1983. This view is from the rear (high side) of the wedge, looking down from 1.8 m to 0 cm in front of red pickup.

Figure 4. Four-sided wedge designed installed at the Ramsey Refuse Area (RRA) in 1983. Each wedge was oriented directly along N-E-S-W aspects, respectively. This picture clearly shows how the topsoil cover material was feathered out to 0 thickness at the base of each wedge. However, the respective lime, fertilizer, seed and mulch treatments extended 1.0 m out onto the bare refuse as if it were being direct seeded.

Figure 5. Trench excavated in 1987 through the limed half of the topsoil wedge at the Ramsey Refuse Area (RRA). The area in lower right-hand corner contains approximately 10 cm of topsoil cover. Note the relatively thick and diverse vegetation here at relatively thin topsoil cover depths over this moderately acid- forming material (P.A. = 12 Mg/1000)

Table 1. Percent ground cover at JSR in September 1987. Mean values for limed vegetation followed by a * are significantly different than their corresponding un-limed depth class.

	Topsoil Depth (cm)					
	0	15	30	60	90	120
	---% Cover -------------------------------------					
Lime	25.0*	92.5*	95.0	92.5	95.0	100
No Lime	5.0	62.5	97.5	97.5	92.5	97.5

Overall ground cover was lower at BMR (Table 2), but a similar response to subsurface liming was apparent at the shallower topsoil depths. Plots with 0 to 15 cm of topsoil, which had received subsurface lime, had higher cover estimates than plots which did not. A similar trend was apparent at thicker topsoil depths as well. As topsoil thickness increased, ground cover also increased in the limed plots. However, unlimed plots demonstrated an inconsistent vegetation response to increasing soil depth, which was indicative of a much "patchier" cover condition as observed in the field.

Table 2. Percent ground cover in August 1987 at BMR. Mean values for limed vegetation followed by a * are significantly different than their corresponding un-limed depth class.

	Topsoil Depth (cm)					
	0	15	30	60	90	120
	---% Cover -------------------------------------					
Lime	55.0*	62.5*	75.0	82.5	85.0	95.0
No Lime	37.5	47.5	85.0	65.0	90.0	77.5

Percent ground cover was good to excellent at all topsoil depths at RRA (Table 3) which was the least acidic of the refuse materials studied. Plots with a north aspect had lower ground cover at topsoil depths of < 60 cm. When lime was applied at the soil:refuse interface, ground cover was good at all topsoil depths on all aspects except north. Overall, those wedge halves at RRA which received subsurface lime supported higher percent ground cover at all topsoil thicknesses (Table 4). These data are readily explained at the thinner topsoil depths where shallow rooting is apparent but are not as intuitively obvious at thicker depths.

Subsequent plant rooting and soil morphological investigations (unpublished; summarized here by Daniels) at all three locations revealed a number of explanatory findings for the observed variations in plant response discussed above. First of all, on the more acidic refuse materials (JSR and BMR) where lime was not applied at the topsoil/refuse contact zone, evidence of pyrite oxidation (e.g. jarosite, red Fe-oxides and white sulfate salts) in the upper 15 cm of refuse was obvious regardless of soil cover depth. No plant roots penetrated the refuse. On the limed half of each wedge, however, the acid oxidation products were observed well below (10 to 15 cm) the topsoil/refuse contact, and roots proliferated into the limed portion of the refuse even though a significant accumulation of whitish sulfate salt materials (gypsum from S neutralization?) was also apparent in this zone. Soil pH and EC measurements confirmed that the underlying refuse materials, regardless of their potential acidity or lime treatments, had little effect on the bulk chemical properties of the overlying topsoils, even at the 15 cm depth. This is presumably due to the relatively high seasonal leaching found in this region. Finally, all topsoil wedges did contain moderate compaction in their subsoils at depths between 45 and 90 cm due to the bulldozer grading process. This may explain why a distinct vegetation/soil depth response was not seen at soil depths > 50 cm at several locations, and why we actually saw a decline in cover % at intermediate depths in several experiments. However, in most instances, grass roots were observed to penetrate to depths > 80 cm where topsoil cover depth was thicker.

Table 3. Percent ground cover in September 1986 at RRA. Mean values for limed vegetation followed by a * are significantly different than their corresponding un-limed depth class.

		Topsoil Depth (cm)					
	Aspect	0	15	30	60	90	120
		% Cover					
Lime	South	90.0*	97.5*	100	97.5*	97.5	97.5
No	South	77.5	82.5	90.0	62.5	92.5	82.5
Lime	North	62.5	67.5*	35.0	45.0	85.0	85.0
No	North	62.5	32.5	42.5	50.0	77.5	87.5
Lime	East	80.0	62.5	57.5	65.0	72.5	87.5
No	East	67.5	72.5	70.0	82.5	75.0	95.0
Lime	West	75.0	82.5	82.5	82.5	85.0	92.5
No	West	80.0	75.0	85.0	92.5	77.5	92.5

Table 4. Mean percent ground cover versus topsoil depth across all wedges at RRA in September 1987. Mean values for limed vegetation followed by a * are significantly different than their corresponding un-limed depth class.

	Topsoil Depth (cm)					
	0	15	30	60	90	120
	% Cover					
Lime	76.9	77.8	68.7	72.2	85.0	90.6
No Lime	71.9	65.6	71.8	71.9	80.6	90.0

Research Implementation

Overall, our multi-year studies at these three wedge sites led us to the conclude that (1) no more than 50 cm of topsoil cover was justifiable on even highly acid forming refuse; (2) by adding a moderate amount of agricultural lime (typically 50% or less of determined potential acidity) the required topsoil thicknesses could be reduced by 50% or more; and (3) regardless of the refuse material's potential acidity, adding even 15 cm of topsoil cover has a profound positive effect on multi-year revegetation success (Fig. 6). Parallel work on direct-seeding (Daniels and Stewart, 2000) indicated that utilization of heavy P and organic matter treatments ($\geq$ 50 Mg/ha biosolids or compost, or very heavy straw + wood fiber mulch) was required for successful direct-seeding of coal refuse materials successfully, particularly on south-facing slopes. However, direct seeding was only successful on relatively low acid producing materials, even when limed.

In the early 1990's we synthesized our results to generate a set of soil thickness vs. lime requirement guidelines (Table 5) for VDMLR that have been used for over 10 years as a general tool for permit review and final revegetation compliance prescriptions. However, VDMLR retains the right to require a complete 1.2 m cap of topsoil if a given site does meet 5-year vegetation performance criteria. Over the past 15 years, we have assisted in the application of this system over a wide range of refuse sites, and we have found that utilization of 25 cm of topsoil cover materials coupled with 25 Mg/ha agricultural lime at the refuse/soil contact has been successful for long term revegetation success on even highly acid forming materials.

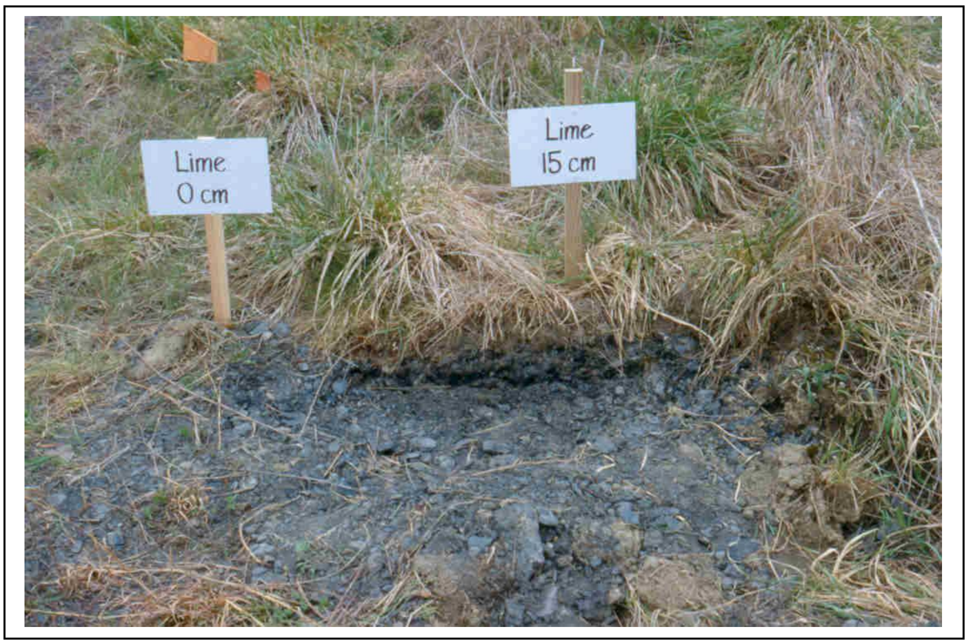

Figure 6. Contact zone between 0 and 15 cm of topsoil cover over limed refuse at the Bullit Mine Refuse (BMR) area in 1987. The area to the right of the 0 cm stake (and in front of the 15 cm stake) was shaved back to reveal the soil cover while no soil or vegetation removal occurred to the left of (or in front of) the 0 cm line. Note the stark effect here of even several cm of topsoil on vegetation cover after 4 years on moderately acid-forming refuse (25 Mg/1000 net acid).

Table 5. Integrated topsoil thickness and liming recommendations for coal refuse. Table adapted from Daniels et al. (1996) and Daniels and Stewart (2000).

Potential acidity by Acid-Base Account. (ABA)	Lime Recommendation	Amendments and seeding strategies
<20 Mg ha^{-1} net acid	Lime to ABA need	Direct-seed with heavy P, straw mulch, and organic[1] amendments if possible. Use refuse seed mixture.
20-50 Mg ha^{-1} net acid	Lime to ABA, split if necessary	Direct-seed with heavy P, straw mulch, and organic[1] amendment (required). Use refuse seed mixture.
50-100 Mg ha^{-1} net acid	Add lime (ABA need) at refuse-soil contact	Topsoil cover with 15-30 cm of final depth. Use conventional lime, fertilizer, and seed.
50-100 Mg ha^{-1} net acid[2]	Without lime	Topsoil cover with 50 cm or greater final depth. Use conventional lime, fertilizer, and seed.
>100 Mg ha^{-1} net acid	Add lime (ABA need) at refuse-soil contact	30-50 cm of final topsoil depth. Use conventional lime, fertilizer, seed.

[1] Organic amendment consisting of stabilized biosolids, papermill sludge, composted wood chips or similar material with C/N <30 at a rate of at least 50 Mg ha^{-1}, incorporated with a chisel plow.

[2]On flat and gently sloping surfaces (<20%), lime and organic amendments may be applied in several treatments. Splitting lime applications, so as to allow it to react with the acidic refuse prior to seed application, may allow direct seeding on materials of up to 100 Mg ha^{-1} net ABA acidity. This is allowable only on near-level to moderately sloped areas.

Note: These recommendations do not take sideslope seeps and springs into account. Such seeps are usually acidic; affected areas will need to be spot treated.

Complications of the Wedge Design

As noted earlier, our wedge design was based upon earlier western USA research studies, and necessarily modified for what we could realistically expect from our mine operators in Virginia in the mid 1980's. As you will note in Tables 1-4, our vegetation response data is presented with minimal statistical analysis based on repeated measures of single wedges without true "replication". This is due to the fact that our cooperators were only "willing" to construct one such wedge at the JSR and BMR sites, and the four back-to- back wedges installed at RRA had contrasting aspects. Ideally, with 20-year hind-sight, it would have been worth our added effort to insist upon at least 3 replicated wedges at each site.

Finally, an obvious design complication of these wedges was the fact that they were established "above grade" which potentially could produce excessive water drainage through the topsoil layers relative to their behavior if placed in an excavated "at grade" installation. However, by the time we installed these experiments we had extensive field observations indicating that most coarse refuse materials once compacted to routine placement densities had significant internal drainage problems. Therefore, we were convinced that if we excavated the wedges to allow the topsoil surface to be at grade for all cover depths, the deeper ends of the wedges would more likely become periodically saturated at –50 cm or less, greatly complicating the intended design. To accommodate for the presumed excessive water drainage effect, we located our vegetation sampling transects at least 1 m away from the lateral edge of each sides slope. In fact, over multiples seasons, we never observed any difference in vegetation vs. soil depth response that appeared to be due to this presumed "edge effect".

Overall Conclusions

The long-term stabilization and revegetation of acid-forming coal refuse materials continues to be the single most challenging revegetation problem in the Appalachian coal fields. Regardless of the long term implementation of SMCRA, most coal refuse disposal facilities do not have sufficient topsoil or topsoil substitute resources on hand to meet the mandated 1.2 m topsoil cover requirements. Therefore, reasonable and verifiable procedures for determining essential cover depths were required. Implementation of the topsoil wedge design at three locations over a range of coal refuse acidity conditions generated a multi-year research data set for this purpose. By coupling these data with a number of common-sense observational findings, we generated a viable and proven effective strategy for determining minimal topsoil thickness requirements for a range of coal refuse conditions (Table 5).

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