

Original Research Paper

Evaluating Short Paper Fiber as a Soil Amendment for Abandoned Mine Land Reclamation in West Virginia

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Abstract: Maximizing the use of onsite material to create topsoil has the potential to reduce costs for mine reclamation in the eastern United States. This study evaluated the addition of short paper fiber (SPF), a by-product of paper mill processing, to coarse coal refuse (CCR) to aid in vegetation establishment. Vegetation growth in two blends of SPF and CCR (80% CCR with 20% SPF; 60% CCR with 40% SPF) was compared to growth in refuse. Ground cover was monitored weekly, and biomass was measured. The SPF/CCR blends resulted in significantly higher ground cover and biomass than the refuse alone. Therefore, the addition of SPF shows potential to support vegetation establishment in CCR. Ground cover reached the minimum level needed for environmental permit release (70%) for both SPF/CCR blends, but ground cover decreased to below 50% on average by the end of the study. Further study should be completed at a large scale.

Keywords: coal refuse; reclamation; ground cover

Introduction

Over 5,000 abandoned mine lands exist in the United States and approximately 60% are located in West Virginia, Pennsylvania, and Kentucky (OSM 2017). The Surface Mining and Control Act of 1977 was established to reduce the environmental impacts from surface mining. To meet regulations, reclamation plans include slope stability with revegetation. The addition of vegetation has been shown to reduced erosion rates (Gray and Sotir 1996; Pan and Shangguan 2006). Vegetation reduces rainfall impact, intercepts runoff, and provides root reinforcement (Albright *et al.* 2010; Fournier 2011).

Coal refuse is the non-combustible material that is separated from coal during the mining and material handling process. The refuse is characterized as having rock fragments from shale, mudstone, and varying amounts of residual coal. Obtaining persistent grass cover following refuse pile reclamation is often difficult due to the quality of the refuse which is characterized by low pH (i.e.

< 5), low nutrient content, and high iron content (see Table 1 for an example).

Topsoil can improve the potential success of revegetation plans (Alday *et al.* 2011), but topsoil is often unavailable or expensive. Cost-effective alternatives are needed, and overall costs could decrease if the refuse could be utilized as a main component of the growth media. This work explores this possibility by examining short paper fiber (SPF), a by-product of pulp and paper mills, as a soil amendment.

SPFs are the solids extracted from the manufacturing of paper and are available at nearly all paper mills (Laubenstein 2004). In 2000, approximately 675 paper, paperboard, and pulp mills existed in the south, west, north central, and northeast regions of the United States (EI 2005). SPF is primarily composed of organic matter, microbial growth solids, and some nutrients (e.g., nitrogen and phosphorus; Laubenstein and Field 1994). Typically, the SPF, a by-product, is transported to a landfill for disposal.

There is evidence that SPF can be an effective

component of manufactured topsoil and used as a soil amendment (Li and Daniels 1997; Carpenter and Fernandez 2000; Evanylo *et al.* 2004). Preliminary work suggests that the residuals may be used in mine reclamation activities when topsoil is not available (Laubenstein 2004; Daniels *et al.* 2013). For example, Daniels *et al.* (2013) reported that mill wastewater sludge improved the establishment of tall fescue in mine spoil, outperforming manufactured topsoil components in biomass (Daniels *et al.* 2013).

In addition, two demonstration sites utilized SPF in West Virginia. The two refuse piles were capped with a low permeability layer composed of compacted SPF (hydraulic conductivity = 10^{-7} cm/s at placement) and covered with a manufactured topsoil made of a mixture of refuse (25%) and SPF (75%). Reduction in acid mine drainage treatment costs occurred at both sites, but the impact on vegetation growth was not documented (Laubenstein 2004).

The overall goal of this work was to evaluate the use of SPF as a soil amendment to be utilized in the reclamation of abandoned mine lands while by maximizing the use of on-site material. Growth characteristics resulting from two mix ratios of expected application rates (based on cost) were evaluated.

Materials and Methods

A small-scale plot study was completed, evaluating the establishment and persistence of grass in three growth media treatments: i) 100% coarse coal refuse (“refuse”), ii) 60% coal refuse blended with 40% short paper fiber (“60/40 blend”), and iii) 80% refuse with 20% paper fiber (“80/20 blend”). All percentages for blending were based on volumes of coarse coal refuse (CCR) and SPF.

The refuse was obtained from the Royal Scot coarse coal refuse pile located near Anjean, WV. Prior analysis characterized the refuse as a poorly graded sand with gravel (USCS classification SP; Stevens 2016) that is nutrient deficient and deemed an unsuitable growth media (see Table 1). The SPF (i.e., MGro™ donated by WestRock paper mill in Covington, Virginia, USA) are solid residuals (e.g., wood fiber, carbon, boiler ash, calcium phosphate precipitate, lime, and additives) resulting from paper mill treatment and carbon plant wastewater.

Twelve growth containers were constructed for

the three soil media treatments (four replications of the three treatments, Figure 1a). The growth containers consisted of vertically oriented PVC pipes (diameter = 15 cm; length = 35 cm). Growth media treatments were mixed by volume, inserted into the pipes at 11% standard Proctor energy (67.85 kJ/m^3), and added to a depth of 30 cm. The SPF was mixed at saturated state, and the coarse coal refuse was at a dry state. Final unit weight of the pipes ranged from 6.4 kN/m^3 to 7.9 kN/m^3 .

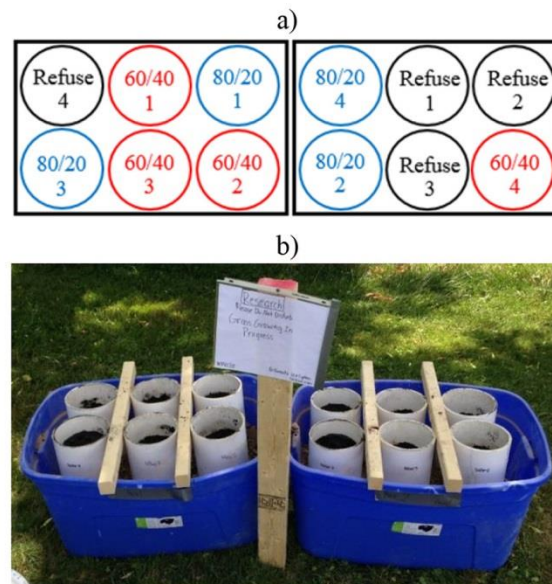


Figure 1. a) Random distribution of three soil media treatments between two soil boxes; b) field application of test containers

The pipes were randomly distributed among two plastic containers (65 cm x 55 cm x 50 cm); six were in each box (Figure 1b). Approximately 30 holes (diameter = 3 mm) were randomly installed to permit drainage within each container. The pipes were placed above a 12 cm sand layer. The pipes were surrounded with sand to simulate in-ground placement (Figure 2).

Each sample was seeded with a locally available contractor’s mix that consisted of 48% annual rye (*Lolium multiflorum*), 38.76% perennial rye (*Lolium perenne*), and 9.75% red fescue (*Festuca rubra*). Seeding methods followed recommendations by the West Virginia Division of Highways (WVDOH 2010). The WVDOH (2010) seeding rate was (3.4 kg/ha) resulting in 0.01 grams of seed for each pipe (approximately 5 seeds). This rate was increased to 0.1 g per pipe (approximately

10 seeds) due to the small surface area of the pipes. The top 0.5 cm of soil was scraped, the seeds were scattered, and the seeds were covered. Seeds were watered with 250 mL of water the day of planting (July 14, 2016). To provide protection to the seeds outside, a polypropylene turf reinforcement mat was placed on each box as a protective layer that permitted water and sunlight to pass. The material was removed two weeks after planting, following seed germination. The samples were watered (250 mL) three times a week if sufficient rainfall did not occur (30 minutes of steady rain) the day of or day before scheduled watering.

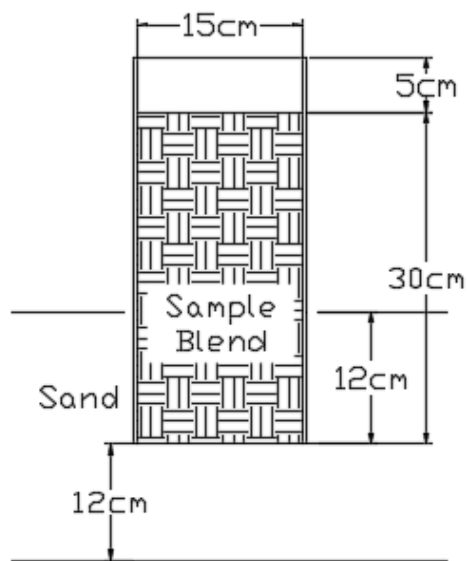


Figure 2. Soil housing dimensions.

Ground cover was monitored weekly throughout the study period (July 21, 2016 – October 27, 2016). Photographs were taken at a height of 0.5 m from the soil surface. The photographs were analyzed for ground cover by area using Adobe Photoshop. Stem height was measured for 10 random live stems from each sample weekly. When fewer than 10 stems existed, as in the case for the refuse samples, all available live stems were measured.

At the conclusion of the growing season, above-ground biomass was collected and weighed. Live, dead, and total biomass amounts were measured following guidance of Franks and Goings (1997). In addition, soil samples (500 g) were collected from each pipe. Soil samples were

analyzed at AgSource Laboratories-Harris (Lincoln, NE) for pH, organic matter (OM), N, P, K, Fe, Mg, Ca, and Na. Analytical methods followed the methods reported by AgSource Laboratories (2006).

Comparisons of ground cover and total biomass among treatments were made using the non-parametric Dunn’s test. An α value of 0.05 was assumed for all tests, and statistical tests analyses were conducted using JMP software (v. 13.0.0).

Results

Results suggest that the use of SPF as a soil amendment may improve growth conditions (Table 1) and be beneficial in mine reclamation to support the growth of grasses. Ground cover values for the blended samples were consistently at least an order of magnitude greater than the samples with only refuse; mean ground cover ranges were 2.6%-77.1%, 3.3%-71.4%, and 0.0%-1.3% for the 80/20, 60/40, and refuse treatments, respectively (Figure 3). No statistical differences in ground cover were determined between the 80/20 and 60/40 blend treatments (p -value = 0.0845), but both blends resulted in ground cover values greater than the refuse treatment (p -value < 0.001) (Figure 4). Stem height results were similar to observations of ground cover (Figure 5).

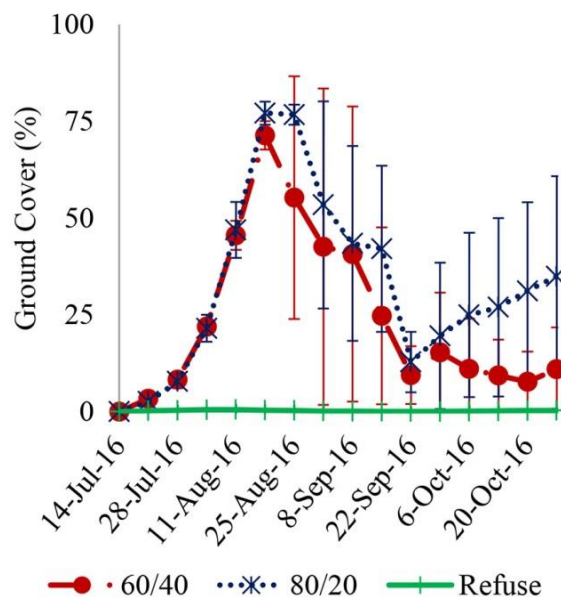


Figure 3. Mean ground cover of the three blends (60/40, 80/20, and refuse); error bars denote standard deviation.

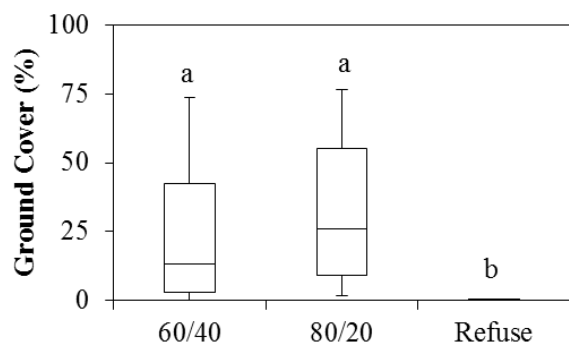


Figure 4. Distribution of ground cover for each blend. Summary values for tenth percentile, first quartile, median, third quartile, and ninetieth percentile. Letters above plots denote statistical significance.

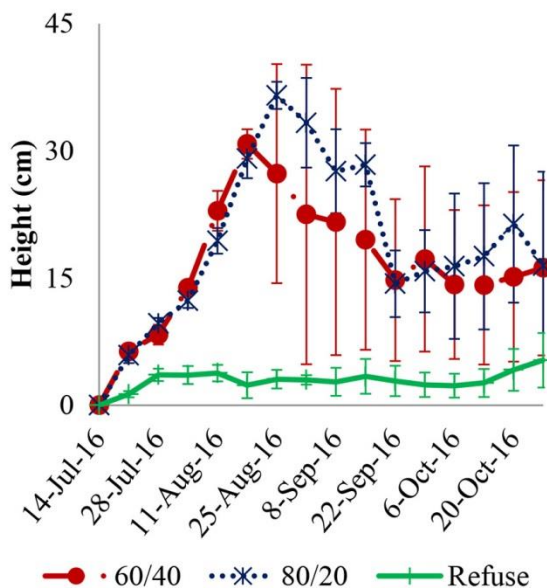


Figure 5. Mean stem height of the three blends (60/40, 80/20, and refuse); error bars denote standard deviation.

The 80/20 blend resulted in total biomass amounts greater than those observed in the refuse samples (p -value = 0.0134); mean total biomass was 12.75 g and 0.10 g for the 80/20 and refuse samples, respectively. However no statistical differences were observed between the 60/40 (mean total biomass = 4.78 g) and refuse samples (p -value = 0.2866). Similarly, mean biomass observed in the 60/40 blend and 80/20 blend were statistically similar (p -value = 0.8422) (Figure 6). The 80/20 blend and refuse biomass samples had 74% and 80% of live biomass, respectively. Only 39% of the biomass measured in the 60/40 blend was live (Figure 6).

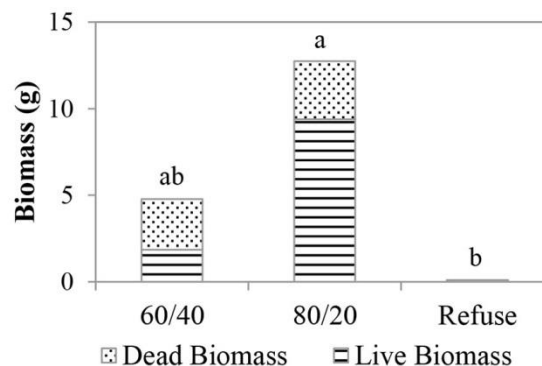


Figure 6. Mean biomass for the three blends (60/40, 80/20, refuse); letters denote statistical significance.

Table 1. Agronomic characteristics of refuse and refuse amended with MGro™ (mean and standard deviation reported).

	CCR	80/20	60/40
pH	4.5	7.6	7.5
	±0.22	±0.08	±0.07
OM (%)	16.0	12.4	15.3
	±2.4	±3.34	±0.88
N (ppm)	1.75	16.5	29.0
	±0.43	±2.69	±7.31
P (ppm)	21.8	194.0	484.5
	±0.83	±20.4	±54.2
K (ppm)	39.8	50.8	70.5
	±4.44	±13.0	±14.3
Fe (ppm)	100.4	19.7	31.3
	±3.41	±2.12	±6.35
Mg (ppm)	19.0	40.0	70.0
	±4.18	±7.18	±9.62
Ca (ppm)	226.0	2589	2932
	±40.2	±140	±167.6
Na (ppm)	4.50	22.8	17.0
	±0.50	±1.09	±0.71

Discussion

The SPF was evaluated to serve as a component of manufactured topsoil for a disturbed site that has little access to quality topsoil. Manufactured topsoil typically consists of organic matter, a mineral base, fertilizer, and lime (Carpenter and Fernandez 2000). SPF in this study was intended to increase organic matter, provide nutrients, increase pH, and support substantial ground cover.

Results suggest that the addition of SPF will not lead to deficiencies in organic matter content. There were few differences in organic matter levels among treatments (Table 1). Both the refuse material and SPF blends were composed of greater than the 2% level desired for growth (Espinoza *et al.* 2006).

While the SPF provided nutrients in the form of P and K, the levels of P were considered very

high (>30 ppm, AgSource 2017) and the levels of K were considered less than adequate (<160, AgSource 2017). These results suggest that additional fertilizer will be necessary and the SPF cannot be used alone as a soil amendment.

Presence of highly acidic soils (i.e. pH < 5.0) is a common limitation of engineered sites, particularly when working with spoil. Acidic soils limit growth because aluminum and magnesium increase to toxic levels and reduces the availability of phosphorus (Coppin and Richards 2007). The low pH of the refuse (4.5) is a limitation for establishing growth, and the SPF was intended to increase pH. The addition of SPH was successful in increasing the pH of the growth media (≥ 7.5) as compared to the refuse alone (Table 1). However, the optimal pH for grass mixtures is slightly acidic, suggesting that better refinement of the blend ratios needs to be considered.

The addition of SPF increased both ground cover and biomass as compared to the refuse treatments (Figure 4 and 6). This result is promising because vegetation cover is the main factor in erosion severity (Fournier 2011). Above-ground biomass, both live and dead, reduces raindrop impact, shields soils, increases infiltration, reduces runoff flowrates, decrease surface wind velocity, and filters sediment from runoff (Albright *et al.* 2010). The intent is to increase live biomass amounts with time to achieve the full benefits of vegetation cover.

Seventy percent ground cover is needed for the National Pollutant Discharge Elimination System (NPDES) general water-pollution-control permit (USEPA 2007). Both blend treatments (60/40 and 80/20) met this minimum criteria during a portion of study period, but the ground cover decreased to below 50% on average by the end of the study (Figure 3).

These results suggest support previous work that the use of SPF in mine reclamation shows promise (e.g. Li and Daniels 1997; Daniels *et al.* 2013). However, further study is needed. In addition, several limitations of this study need to be considered:

- Small vegetated area: In this first study, four replications of each treatment were evaluated and the surface area of each study sample was 183 cm². Due to the small area, few seeds were

included to meet the seed density recommended by WVDOH (2010). Further study at a larger scale is needed.

- Time of planting: The seed mixture utilized in this study is a commonly used contractor's mix composed of annual and perennial ryegrass, and red fescue. The recommended time of planting for this mix is between the dates of March 1 to June 15 and August 1 to October 15 (WVDOH 2010). Due to outside project factors, the seeds were planted during July for this study. In practice, re-seeding would occur during the appropriate time of planting for optimal growth.

- Selected seed mixture: There was low diversity in the commonly used contractor's seed mixture utilized in this study. Recent research suggests the use of site-specific mixtures. When using grasses, the inclusion of 6–10 species is recommended (Kirmer *et al.* 2012). Nitrogen fixing legumes should also be incorporated (Salon and Miller 2012). A site-specific mix may promote future success.

- Additional soil amendments: In this initial study, the only soil amendment included was the SPF. It was applied at two set rates: 60/40 and 80/20. No additional fertilizer or lime was included and should be considered in future studies. In practice, the seeds would be applied by a hydroseeding procedure, and a mulching component would be included (i.e., straw mulch or hydraulic erosion control product). Mulch can reduce erosion effects and increase vegetation cover (Dunifon *et al.* 2011; Storey *et al.* 2011). The mulch may also improve infiltration rates and retain moisture (Smets *et al.* 2008) that would aide in vegetation establishment.

- Soil blend ratios: Two blend ratios were studied based on expected implementation rates. The 60/40 blend was studied as a best case and the 80/20 blend was considered to reduce the cost needed to implement the soil amendment. Further study could identify optimal blend ratios for vegetation germination and persistence.

Conclusions

This preliminary study suggests that SPF may be a cost-effective component of reclaiming abandoned mine lands in West Virginia. Minimum ground cover levels needed for permit release were achieved using both tested blends: 60% coarse coal refuse with 40% short paper fiber and 80% coarse coal refuse with 20% short paper fiber; however further study is needed to address study limitations. A large-scale test is in development that will evaluate vegetation germination and persistence in the proposed blend ratios, evaluate water quality of runoff, and evaluate surficial stability on 3(H): 1(V) slopes.

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