Re-Vegetation of Cover Soils and Coal Discard Material Ameliorated With Class F Fly Ash

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Abstract

Coal discard material is a difficult medium to prepare for successful re-vegetation. It is possible to re-vegetate the covering topsoil, but the sustainability of conventional procedures is often poor. This covering topsoil is acidified, over time, by the capillary action of water generated by the underlying coal discard material. Roots are unable to grow properly and vegetation eventually dies. The objective of this experimental work was to identify other amelioration strategies for the cover soil and coal discard, using bituminous coal combustion by product - class F fly ash as a soil ameliorant. Due to the lower $CaCO_3$ equivalent of class F fly ashes compared with agricultural lime, heavier applications are required to neutralize such acidity. This research, concentrated on different combinations of amelioration of both the cover soil and the discard material compared to an untreated control, and the agricultural lime and fertilizer treatment. One treatment also included the use of class F fly ash as a barrier (buffer zone) between the covering topsoil and the coal discard. The cover soil was then planted to two grasses, Rhodegrass *(Chloris gayana)* and Smutsfinger grass *(Digitaria eriantha)* commonly used in rehabilitation in South Africa. Significant increases in yield, have up to 200%, were noticed for class F fly ash treated soil and discards relative to the untreated control in a specific season. Class F fly ash as an ameliorant has, therefore, the potential to be used in creating a more sustainable soil environment to ensure a more stable vegetation to facilitate effective reclamation of coal discards.

KEYWORDS: Coal discard, Class F fly ash, amelioration, acidity, re-vegetation

1. INTRODUCTION

South African coalmines face a major challenge when it comes to the disposal; stabilization and reclamation of coal refuse disposal sites, also known as coal discard dumps. The coal discard materials vary from very fine materials removed by the flotation and density separation processes, also known as coal washing and coarse materials removed by the physical screening of coal. Coal discard dumps are very engineered designs that often make the re-vegetation process difficult.

If coal discard dumps are improperly reclaimed, many environmental hazards can occur. These hazards include the contamination of surface and ground waters by acidic leachates and runoff, erosion and sedimentation into nearby water sources, spontaneous combustion, and damage from landslides if failure of steep slopes occurs. Most of the problems that are associated with coal discard dumps can be mitigated by establishing and maintaining a healthy, adapted, productive and viable vegetation cover. Vigorous root development of identified adapted plant species can reduce the percolation of water and the ingress of oxygen into the coal discard profile. The establishment of a perennial vegetative cover, will also reduce sediment loss and stabilize the surface areas of dumps. Many problems are associated with the stabilization and re-vegetation of coal discards, and this paper introduces preliminary research that highlights the need for more detailed research under South African conditions.

To reclaim coal discards, it is essential that the discard characteristics are known and understood. Very little comprehensive information is available on coal discard properties. Haynes and Klimstra [8], Medvick and Grandt [11], Bland *et al.* [3], Buttermore *et al*. [4], Sobek and Sullivan [16], as cited by Daniels and Stewart, [5] have examined coal refuse characteristics from a reprocessing perspective in the United States, but comprehensive literature on these aspects is scarce especially in South Africa.

Of the few studies conducted globally on coal refuse “discards”, the description of the following characteristics are considered imperative in the planning of the reclamation of coal discards. These include particle size, pH, electrical conductivity, sulphur content, total elemental analysis, and mineralogy and soil solution chemistry. Once the properties of coal discards are known, it remains a challenge to integrate them with reclamation concerns. Many factors influence the reclamation potential of such a dump. A few important factors include the geologic source of the refuse, the processes involved in the preparation of plant establishment, local site conditions such as microclimate, inherent variability of materials, slope and aspect effects of dumps, pyrite oxidation and potential acidity of the materials, spontaneous combustion, low fertility of the cover soils, moisture retention, rooting depth, the compaction of the materials and also the high surface temperature. When taking all these factors into consideration it is necessary that a successful discard reclamation strategy be developed with guidelines for discard area vegetation such as the characterization of the area to determine the re-vegetation potential, the site preparation, fertilization, seeding rates and species mixtures, as well as the consideration of tree planting.

In South Africa soils and discards are conventionally treated with very high levels of lime to create a suitable pH for the establishment of a good vegetation cover. A good vegetation cover ensures stability of the coal discard to prevent any sort of erosion of the cover soil. The problem, however, is that the cover soil becomes acidic as a result of the capillary action of generated acidic water from the underlying coal discard and, with time, the vegetation dies. The objective of this experimental work was to treat the soil and discard with class F fly ash as an alternative amendment, and to determine the ability of this material to improve pH of the soil and discards and maintain it as long as possible, thereby creating a more favourable and sustainable rooting medium. Fly ash is basically an amorphous ferro-alumino silicate, which is also characteristically high in Ca, and many other macro- and micro-nutrients. Virtually all natural elements are present in coal ash in trace amounts. There is a general consensus that most trace elements increase in concentration with decreasing size of fly ash particles (Adriano *et al*., 1980). The alkaline nature of fly ash has led to an examination of its use as a liming agent to supplement the reagent grade $CaCO_3$ on acidic agricultural soils and coalmine spoils[9,12,21].

Furthermore, the enriched macro- and micronutrients contained in fly ash enhances plant growth in nutrient-deficient soils[13,10,20,19,18]. Laboratory studies have shown that an alkaline fly ash was equivalent to approximately 20% of reagent-grade $CaCO_3$ in reducing soil acidity and supplying plant Ca needs[,2,17]. However, depending on the source of fly ash, and the extent to which it is weathered, its neutralizing capacity could range from none to very high [6,2,17]. When spoil areas are reclaimed, the quantities of fly ash, which need to be applied, usually, exceed those required for cropland amelioration. The quantities of fly ash required to reclaim discards, however, will be different and it will depend upon the pH of the fly ash, the degree to which it is weathered, and the pH of the discard to be reclaimed. For example, spoil areas having a pH of 4.4. to 5.0 were reclaimed using fly ash at rates of 70 metric tons ha^{-1} [7,2], while on discards with pH values of 2.0 to 3.5 rates from 335 to 1790 metric tons ha^{-1} were used [1,2].

Previous research has shown that fly ash has residual alkalinity. This supports the use of fly ash as a more sustainable soil ameliorant [17,18]. This residual alkalinity of fly ash is present in the glassy phase of the fly ash particle [14]and with the dissolution of this phase, alkalinity is released to facilitate the neutralization of acidity. With the correction of low pH's, plant nutrients in the soil are more soluble and available for plants. Data obtained in previous research supports the conclusion, that class F fly ash definitely has a much higher $CaCO_3$ equivalent than what was originally assumed [17,18].

Another objective of this study was to investigate the capping of the discard material with a fly ash layer, which would serve as a buffer zone, delaying or preventing the acidification of the soil by the acid generating coal discard, and thereby facilitating better re-vegetation of such materials.

2. MATERIALS AND METHODS

A randomized study, using large pots, was conducted on the Hatfield Experimental Farm, Pretoria, South Africa (25°45'S 28°16'E), 1327m above sea level in 2003, 2004 and 2005.

A 15 cm layer of cover soil, collected from a surface coal mine, was used to cover the coal discard that was placed in 50 *l* pots with different treatments.

The experimental design was a randomized block design with six treatment combinations replicated four times. These included the incorporation of fly ash into the cover soil, the incorporation of fly ash into the discard material, and the use of fly ash as a buffer to cap the discard before soil placement as illustrated in Table 1.

Table 1: Treatment combinations for coal discard study.

Sample	**Treatment**
T1	Fly ash treated cover soil over fly ash treated discard
T2	Untreated cover soil over untreated discard (CONTROL)
T3	Fly ash treated cover soil over untreated discard
T4	Untreated cover soil over fly ash treated discard
T5	Fly ash treated cover soil over fly ash treated discard with fly ash interlayer
T6	Lime and NPK treated cover soil over lime treated discard

The optimum lime application rate for the cover soil and coal discard was based on the buffering capacity of the two substrates. The mine cover soil and the coal discard had a $pH_{(H2O)}$ of 4.3 and 2.8, respectively. It was calculated, from the buffer curve, that the mine cover soil and coal discard, would require 10 and 50 tons ha^{-1} of dolomitic lime, respectively. These lime requirements would raise the pH of the substrates to a $pH_{(H2O)}$ of 6.5, suitable for plant growth. The level of fly ash to be used would thus be five times the amount of lime, which was based on the assumption (from literature) that class F fly ash had a $CaCO_3$ equivalent of 20% [17]. In September 2002, the cover soil treatments received an equivalent of 50 tons ha^{-1} of fly ash, and discard treatments received an equivalent of 250 tons ha^{-1} of fly ash. The fly ash interlayer used in T5, was based on a layer thickness of 15 cm, which equates to 1688 tons ha^{-1} calculated using a calculated bulk density of 1125kg m^3 for fly ash. The quantities of fertilizer and lime used in T6 treatment in the establishment year was 65 kg N ha^{-1}, 200 kg P ha^{-1}, 135 kg K ha^{-1}, in the form of limestone ammonium nitrate, superphosphate and potassium chloride respectively. The equivalent of 10 tons and 50 tons of dolomitic lime per hectare was applied to the soil and discard, respectively. In the following seasons 100 kg N ha^{-1} was applied to all treatments each spring.

Two tufts of each of two popular rehabilitation and forage grasses, Rhodegrass (*Chloris gayana*) and Smuts finger grass (*Digitaria eriantha*), were planted in January 2003, in each of these pots. Biomass production was used to determine the survival and persistence of the vegetation. Monthly harvests were taken in the 2002/2003, 2003/2004 and 2004/2005 growing seasons.

The aim of this study was to determine if potential acidity would enter the growing medium from the underlying coal discard by means of capillary movement, and affect the growth of the two test grass species. This would change the soil conditions for root growth and development and ultimately effect biomass production.

2.1 STATISTICAL ANALYSES

All dry matter production data and soil analyses were statistically analysed using PROC GLM (1996/1997 and 1997/1998). Statistical analyses were performed using SAS (1998). LSD's were taken at $P \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 PLANT MEASUREMENTS

The data collected in this study was used to illustrate to what extent fly ash affected the chemical properties of soil and discard and facilitated plant growth on topsoiled coal discard. In this first summer T3 and T4 were the best treatments for *C. gayana.* The results presented in Tables 2 and 3, show clearly which of the two species was best adapted to the different treatments. The *D. eriantha* proved to be the better species, in terms of yield. Dry matter production data is presented separately for different seasons. This highlights the different growth responses of the two species in the different seasons. The T1 and T5 treatments proved to be the most effective amelioration treatments in comparison to T2 treatment, which served as the untreated control. This observation, however, only held true for *D. eriantha* in the first summer. The results are slightly different when the second year's data (Tables 4 and 5) is interpreted. In the second year it was the *C. gayana,* which was the stronger species, and treatments T4 and T6, which occasionally had the more pronounced effect on the biomass production in the actively growing season.

Table 2 only includes the production data for the first two months (60 days) after establishment. It should be noted that the production of the T1 treatment (Fly ash ameliorated soil and discard) and T5 treatment (fly ash ameliorated soil and discard with fly ash barrier) produced the most significant yields of approximately 90% higher than the control in the case of *D. eriantha*. In the case of *C. gayana* there were not as clear-cut results, although T6 (the lime and fertilizer treatment) yielded, once again, some of the poorest results.

Table 2: Mean biomass production data for *D. eriantha and C. gayana* during the summer of 2003 (after planting in the early summer of 2002/2003 season)

	2003		
	March	April	TOTAL
	D. eriantha **(g / plant)**		
T1	9.64 (+/-3.21)	10.51 (+/-4.3)	**20.15_a**
T2	6.29 (+/-2.34)	4.60 (+/-2.5)	10.89_c
T3	6.75 (+/-2.56)	7.46 (+/-2.13)	14.21_b
T4	5.85 (+/-2.34)	7.18 (+/-2.45)	13.03_b
T5	7.01 (+/-2.98)	12.69 (+/-3.21)	**19.79_a**
T6	6.92 (+/-3.04)	5.75 (+/-3.45)	12.67_b
	C. gayana **(g/plant)**		
T1	5.32 (+/-2.67)	3.76 (+/-1.56)	9.08_{bc}
T2	5.48 (+/-2.99)	4.99 (+/-2.14)	10.47_b
T3	7.28 (+/-3.87)	5.54 (+/-3.56)	12.82_a
T4	6.22 (+/-2.90)	5.66 (+/-3.78)	11.88_a
T5	3.84 (+/-2.21)	5.60 (+/-3.98)	9.44_{bc}
T6	3.17 (+/-2.01)	4.47 (+/-2.78)	7.64_c

***ab** Column means with common alphabetical subscripts do not differ significantly (P> 0.05) (Bonferroni Test)

Table 3: Mean biomass production data for *D. eriantha* and *C. gayana* during the winter of 2003 (after planting in the summer of the 2002/2003 season)

	2003					
	May	June	July	August	September	TOTAL
	***D. eriantha* (g / plant)**					
T1	5.37 (+/-3.24)	5.03 (+/-3.45)	3.87 (+/-2.45)	5.31 (+/-3.03)	5.67 (+/-2.15)	25.25 $_{ab}$
T2	2.82 (+/-1.56)	2.66 (+/-1.33)	2.39 (+/-1.56)	2.88 (+/-1.45)	2.99 (+/-1.43)	13.74 $_{d}$
T3	3.69 (+/-2.87)	2.80 (+/-1.67)	1.90 (+/-0.67)	2.51 (+/-1.99)	2.92 (+/-1.23)	13.82 $_{d}$
T4	4.70 (+/-2.20)	3.43 (+/-2.11)	2.51 (+/-0.78)	3.27 (+/-1.01)	3.23 (+/-1.22)	17.14 $_{c}$
T5	6.11 (+/-3.12)	6.50 (+/-3.87)	4.03 (+/-2.24)	5.10 (+/-2.46)	6.03 (+/-2.12)	27.77 $_{a}$
T6	5.37 (+/-2.98)	5.05 (+/-4.1)	3.42 (+/-1.21)	4.71 (+/-2.45)	5.39 (+/-2.11)	23.94 $_{b}$
	***C. gayana* (g / plant)**					
	05	06	07	08	09	TOTAL
T1	2.32 (+/-0.55)	1.64 (+/-0.99)	1.21 (+/-0.45)	1.94 (+/-0.98)	3.08 (+/-1.87)	10.19 $_{d}$
T2	3.14 (+/-1.87)	2.39 (+/-1.44)	1.62 (+/-1.02)	2.86 (+/-1.45)	4.29 (+/-2.12)	14.30 $_{b}$
T3	3.95 (+/-2.32)	3.01 (+/-1.24)	1.66 (+/-0.78)	2.79 (+/-1.78)	4.02 (+/-1.24)	15.43 $_{a}$
T4	3.57 (+/-1.34)	2.63 (+/-0.74)	1.38 (+/-0.99)	2.51 (+/-1.23)	3.88 (+/-1.22)	13.97 $_{b}$
T5	2.07 (+/-1.45)	2.28 (+/-1.87)	3.89 (+/-1.56)	4.99 (+/-2.01)	3.05 (+/-1.78)	16.28 $_{a}$
T6	2.66 (+/-1.01)	2.37 (+/-1.45)	1.39 (+/-0.64)	2.71 (+/-1.32)	3.63 (+/-1.66)	12.35 $_{c}$

***ab** Column means with common alphabetical subscripts do not differ significantly (P> 0.05) (Bonferroni Test)

It is clear, from Table 3 that the species growth rate declined by approximately 50 % in the winter season of 2003 (despite this work being conducted under greenhouse conditions). However, significant differences in yields were still noted in this season. The T5 treatment continued to provide the best yields for both species. It is evident from these dry matter production data that the *D. eriantha* responded more strongly than *C. gayana* in the first year.

In Table 2 it is noted that T6 was very poor for both species, however, +/- 6 months after initial treatment (Table 3) the lime and fertilizer treatment (T6) now had a very positive effect on *D. eriantha*, while the effect on *C. gayana* still did not reflect a very clear pattern.

In the following 7 months, presented in Table 4, the observation is made that the dry matter production of the *C. gayana* (36.2g plant^{-1}) was improving, and compared well with that of *D. eriantha* (34.3g plant^{-1}). Once again, it is evident that the T5, T1 and T6 treatments were the best for the *D. eriantha*, whereas the T3, T4 and T5 treatments were the better treatments for *C. gayana*.

Table 4: Mean biomass production data for *D. eriantha and C. gayana* during summer growing season of 2003/2004

	2003			2004				
	October	November	December	January	February	March	April	TOTAL
	***D. eriantha* (g / plant)**							
T1	5.00 (+/-2.11)	6.19 (+/-2.87)	7.52 (+/-3.57)	6.08 (+/-3.02)	4.92 (+/-2.54)	8.35 (+/-4.56)	1.48 (+/-0.98)	39.54_b
T2	2.93 (+/-1.11)	2.77 (+/-1.02)	4.38 (+/-2.45)	3.64 (+/-1.78)	2.48 (+/-1.21)	0.43 (+/-0.12)	0.58 (+/-0.21)	17.21_e
T3	3.49 (+/-1.34)	3.54 (+/-1.23)	5.96 (+/-3.21)	5.47 (+/-2.34)	4.92 (+/-2.34)	2.56 (+/-1.33)	0.95 (+/-0.43)	26.89_d
T4	2.48 (+/-1.25)	4.64 (+/-2.11)	7.11 (+/-3.33)	7.02 (+/-3.76)	6.75 (+/-3.54)	2.52 (+/-1.17)	1.40 (+/-0.65)	31.92_c
T5	6.48 (+/-3.02)	8.19 (+/-3.45)	11.07 (+/-4.56)	10.45 (+/-4.32)	9.56 (+/-4.67)	4.77 (+/-2.29)	1.80 (+/-1.01)	52.32_a
T6	4.60 (+/-2.13)	5.72 (+/-3.12)	10.25 (+/-5.67)	8.41 (+/-3.56)	6.88 (+/-3.76)	2.04 (+/-1.00)	0.79 (+/-0.32)	37.97_b
	***C. gayana* (g/plant)**							
T1	2.16 (+/-1.43)	2.87 (+/-1.87)	5.69 (+/-2.43)	5.69 (+/-2.33)	6.39 (+/-3.22)	4.21 (+/-2.31)	4.90 (+/-1.34)	31.91_c
T2	3.70 (+/-2.65)	4.66 (+/-2.56)	6.46 (+/-4.57)	5.00 (+/-2.89)	5.01 (+/-4.71)	4.29 (+/-2.22)	5.61 (+/-2.35)	34.73_b
T3	4.57 (+/-2.74)	4.99 (+/-2.78)	8.77 (+/-4.11)	7.50 (+/-3.47)	6.94 (+/-2.86)	4.80 (+/-3.11)	5.05 (+/-2.09)	42.62_a
T4	3.56 (+/-2.10)	5.43 (+/-3.76)	8.45 (+/-3.88)	7.64 (+/-3.65)	7.21 (+/-3.23)	3.74 (+/-2.02)	4.60 (+/-2.14)	40.63_{ab}
T5	5.50 (+/-3.03)	4.01 (+/-2.67)	6.33 (+/-3.93)	5.18 (+/-2.96)	4.01 (+/-2.76)	5.41 (+/-2.77)	5.94 (+/-2.44)	36.47_b
T6	4.37 (+/-2.78)	5.01 (+/-3.01)	4.71 (+/-2.07)	4.89 (+/-2.31)	4.68 (+/-1.34)	4.21 (+/-1.87)	3.07 (+/-1.26)	30.94_c

***ab** Column means with common alphabetical subscripts do not differ significantly ($P > 0.05$) (Bonferroni Test)

The yields of *C. gayana* in the winter of 2004, as presented in Table 5, indicate a better growth of this grass in comparison with the *D. eriantha* (2.1 2g $plant^{-1}$). This clear reversal in production of the species can possibly be ascribed to the roots of *D. eriantha* reaching the coal discard material and consequent negative effects. The *C. gayana*, however, proved to be better adapted. As a result of the growth form of this species (having the advantage of stolons), new plants were established on the surface. This contributed significantly to a higher dry matter production.

Table 5: Mean biomass production data for *D. eriantha* and *C. gayana* during the winter of 2004

	2004					
	May	June	July	August	September	TOTAL
	***D. eriantha* (g / plant)**					
T1	0.65 (+/-0.21)	0.39 (+/-0.13)	0.73 (+/-0.25)	0.55 (+/-0.21)	0.97 (+/-0.39)	3.22 $_a$
T2	0.03 (+/-0.01)	0.00 (+/-0.00)	0.00 (+/-0.00)	0.30 (+/-0.22)	0.01 (+/-0.01)	0.34 $_d$
T3	0.22 (+/-0.10)	0.08 (+/-0.02)	0.19 (+/-0.09)	0.79 (+/-0.32)	0.31 (+/-0.12)	1.59 $_c$
T4	0.46 (+/-0.12)	0.21 (+/-0.11)	0.42 (+/-0.14)	0.61 (+/-0.34)	1.88 (+/-0.78)	3.58 $_a$
T5	0.74 (+/-0.24)	0.37 (+/-0.18)	0.41 (+/-0.26)	0.43 (+/-0.18)	0.54 (+/-0.32)	2.49 $_b$
T6	0.34 (+/-0.14)	0.22 (+/-0.12)	0.35 (+/-0.15)	0.15 (+/-0.07)	0.51 (+/-0.23)	1.57 $_c$
	***C. gayana* (g / plant)**					
T1	2.38 (+/-0.98)	0.82 (+/-0.46)	1.99 (+/-1.01)	2.55 (+/-1.16)	2.72 (+/-1.04)	10.46 $_b$
T2	2.46 (+/-1.13)	1.06 (+/-0.62)	1.37 (+/-0.65)	1.07 (+/-0.67)	1.97 (+/-0.97)	7.93 $_c$
T3	2.17 (+/-1.09)	0.83 (+/-0.51)	0.89 (+/-0.34)	2.05 (+/-1.34)	2.49 (+/-1.21)	8.43 $_c$
T4	2.02 (+/-1.02)	0.61 (+/-0.32)	1.35 (+/-0.57)	2.95 (+/-1.76)	5.32 (+/-2.45)	12.25 $_a$
T5	1.54 (+/-0.67)	1.49 (+/-0.58)	1.48 (+/-0.89)	1.97 (+/-1.04)	2.26 (+/-1.32)	9.04 $_{cb}$
T6	0.82 (+/-0.54)	0.72 (+/-0.12)	1.95 (+/-1.04)	1.66 (+/-0.65)	0.90 (+/-0.24)	6.05 $_d$

***ab** Column means with common alphabetical subscripts do not differ significantly (P> 0.05) (Bonferroni Test)

Table 6: Mean biomass production data for *D. eriantha* and *C. gayana* during summer of 2004/2005

	2004			2005	
	October	November	December	January	TOTAL
	***D. eriantha* (g / plant)**				
T1	1.15 (+/-0.43)	0.64 (+/-0.33)	0.33 (+/-0.14)	0.14 (+/-0.07)	2.26 $_b$
T2	0.01 (+/-0.00)	0.00 (+/-0.00)	0.00 (+/-0.00)	0.00 (+/-0.00)	0.01 $_d$
T3	0.37 (+/-0.12)	0.13 (+/-0.07)	0.04 (+/-0.01)	0.00 (+/-0.00)	0.54 $_c$
T4	2.23 (+/-1.16)	1.07 (+/-0.43)	0.46 (+/-0.18)	0.24 (+/-0.12)	4.00 $_a$
T5	0.64 (+/-0.34)	0.34 (+/-0.11)	0.10 (+/-0.04)	1.02 (+/-0.78)	2.10 $_b$
T6	0.60 (+/-0.27)	0.82 (+/-0.31)	0.29 (+/-0.10)	0.16 (+/-0.05)	1.87 $_b$
	***C. gayana* (g/plant)**				
T1	3.23 (+/-1.76)	5.10 (+/-2.56)	3.91 (+/-1.06)	3.94 (+/-2.01)	16.18 $_b$
T2	2.33 (+/-1.22)	4.04 (+/-2.21)	3.12 (+/-2.19)	3.00 (+/-1.46)	12.49 $_c$
T3	2.95 (+/-1.65)	5.39 (+/-3.03)	4.07 (+/-2.06)	3.43 (+/-1.97)	15.84 $_b$
T4	6.31 (+/-3.25)	7.06 (+/-3.87)	4.27 (+/-1.56)	3.77 (+/-1.38)	21.41 $_a$
T5	4.68 (+/-1.23)	4.84 (+/-2.14)	3.41 (+/-1.87)	5.20 (+/-1.21)	18.13 $_{ba}$
T6	2.62 (+/-1.87)	2.46 (+/-1.02)	3.46 (+/-1.46)	3.52 (+/-1.11)	12.06 $_c$

***ab** Column means with common alphabetical subscripts do not differ significantly (P> 0.05) (Bonferroni Test)

It is evident from Table 5, that treatments T4, T1 and T5 were overall the better soil ameliorant combinations, providing a better environment for plant growth. It is also clear, from both Tables 5 and 6, that the *D. eriantha* tufts were deteriorating, due to the possible restriction on it's roots. In comparison *C. gayana* becomes relatively better and better. This is a clear reversal of the agricultural situation where, *C. gayana* starts well and fades out, while *D. eriantha* starts slowly and gets better and better. It is, therefore, important that a wider range of species be evaluated for tolerance to discard conditions. The well-known tolerance of *C. gayana* to saline soil conditions may be a possible explanation for these results and saline tolerance might be a basis for the identification of species suitable for the reclamation of discards with class F fly ash.

In summary, *D. eriantha* and *C. gayana* responded differently to the different treatments. Shortly after soil and discard amelioration in the summer season of 2002/2003, until the following summer 2003/2004, *D. eriantha* was the predominant specie on all the treatments. Thereafter, *C. gayana* was the predominant species by far. It is evident from the treatment responses, that *C. gayana* is more adapted to the higher soil pH levels and possible saline conditions, and *D. eriantha* is more adapted to acidic soils.

3.2 SOIL ANALYSIS

The soil analyses presented in Table 7, do not give any indication of possible reasons for the improved growth of the two grasses on different treatments. The improvement in pH (12 & 24 months after treatment – Tables 7 & 8) may to some extent be responsible for the better utilization of nutrients in the soil. It is also noted that the neutralizing effect of L and FA could be expected to be greater on more acid substrates. However, these two ameliorants had similar effects on pH, with FA having a slightly better persistence. The treatment of discard material seemed to have a marginal effect on the pH of the cover soil, which, tended to become stronger with time.

Table 7: Analyses of cover soils 12 months after treatment application

		Bray I	*Ammonium Acetate Extraction*				
	pH water	P	*Ca*	*K*	*Mg*	*Na*	C
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
T1	6.98_a (+/-1.12)	36.8_a (+/-12.31)	551_a (+/-56.89)	27_a (+/-6.5)	93_b (+/-23.11)	48_a (+/-6.75)	0.43_a (+/-0.11)
T2	6.25_b (+/-0.99)	37.0_a (+/-11.72)	528_a (+/-76.32)	25_a (+/-11.21)	87_b (+/-11.23)	49_a (+/-3.56)	0.49_a (+/-0.21)
T3	7.28_a (+/-101)	37.7_a (+/-9.35)	532_a (+/-34.86)	18_b (+/-5.89)	82_b (+/-8.97)	54_a (+/-9.87)	0.54_a (+/-0.34)
T4	6.20_b (+/-0.76)	31.7_a (+/-10.78)	484_a (+/-57.91)	27_a (+/-9.67)	83_b (+/-12.32)	44_a (+/-3.89)	0.48_a (+/-0.25)
T5	7.15_a (+/-0.66)	39.0_a (+/-7.98)	582_a (+/-61.01)	27_a (+/-7.90)	96_{ab} (+/-9.05)	51_a (+/-5.48)	0.51_a (+/-0.19)
T6	7.25_a (+/-0.56)	22.1_b (+/-6.98)	588_a (+/-59.80)	33_a (+/-9.89)	122_a (+/-9.11)	46_a (+/-4.44)	0.47_a (+/-0.26)

***ab** Column means with common alphabetical subscripts do not differ significantly (P> 0.05) (Bonferroni Test)

The possible effect of micro- nutrients, provided by the fly ash should, nevertheless, not be excluded. The topsoil used in this experiment had a relatively good nutrient status, except for K. From Table 7, it can be seen that treatments T1, T3, T5 and T6 had slightly better levels of nutrients and good soil pH levels 12 months after treatment.

It is noted in Table 8, however, that 12 months later all nutrient levels were lower, and that pH had also declined. This is probably as a result of cropping and nutrient removal during harvesting. These data, presented in Tables 7 and 8, show that the pH of the untreated cover soil treatments (T2 and T4) remained relatively constant from 12 months to 24 months. The fly ash treated soils T1, T3 and T5, however, revealed a slight increase in pH, irrespective of the cropping of the soil and the annual N topdressing the plants received. This to some extent, can cause slight acidification of the soil, which is noted in the decline of the soil pH of the lime treated soil, T6.

Table 8: Analyses of cover soils 24 months after treatment application

		Bray I	*Ammonium Acetate Extraction*				
	pH water	P	*Ca*	*K*	*Mg*	*Na*	C
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
T1	7.03_a (+/-1.02)	23.0_a (+/-4.65)	415_a (+/-34.51)	16_b (+/-5.87)	67_b (+/-15.67)	29_b (+/-8.96)	0.52_a (+/-0.12)
T2	6.18_b (+/-0.56)	16.3_a (+/-5.78)	363_a (+/-45.62)	18_b (+/-4.32)	67_b (+/-12.34)	48_a (+/-9.22)	0.51_a (+/-0.23)
T3	7.15_a (+/-0.87)	13.1_b (+/-3.46)	438_a (+/-54.67)	16_b (+/-5.21)	72_b (+/-17.89)	31_b (+/-5.43)	0.56_a (+/-0.18)
T4	6.30_b (+/-0.56)	12.4_b (+/-4.67)	372_a (+/-35.67)	18_b (+/-3.78)	65_b (+/-15.76)	27_b (+/-2.56)	0.52_a (+/-0.31)
T5	7.05_a (+/-0.67)	20.9_a (+/-7.89)	424_a (+/-33.21)	30_a (+/-5.78)	82_a (+/-21.11)	26_b (+/-6.78)	0.49_a (+/-0.21)
T6	6.98_a (+/-0.45)	9.3_b (+/-2.34)	437_a (+/-49.84)	22_{ab} (+/-6.94)	96_a (+/-17.99)	30_b (+/-7.93)	0.55_a (+/-0.27)

***ab** Column means with common alphabetical subscripts do not differ significantly (P> 0.05) (Bonferroni Test)

The data presented on nutrient levels (Tables 7 and 8), indicate that there were no obvious treatment effects on P, K, Ca, Mg, Na and C. The C content, however, remained relatively constant from 12 – 24 months for all the treatments. It is also evident from the data that the P, Ca, Mg and Na contents of the different treatments, all declined significantly 0 –24 months. This can possibly be ascribed to plant uptake, leaching or the immobilization of nutrients. The K content of soils also declined for all the treatments, except T5, which remained relatively constant between 12 and 24 months (Tables 7 & 8). The overall results for T5, poses the question, whether the fly ash interlayer, has an additional advantage of buffering the cover soil from the coal discard effects.

4. Conclusion

It is evident from the preliminary research results presented in this paper, that class F fly ash has the potential to be used as an alternative ameliorant to improve the sustainability of coal discard reclamation. Increased yields were noted for all the monitored seasons where the treatment had class F fly ash as a barrier (buffer zone). This affect can possibly be ascribed to the prolonged counter-action of the alkaline material to the acidic water generated from the oxidization of pyrite present in the discard material, which via capillary action tends to move upward towards the cover soil. It was evident from the data that while *D. eriantha* was the best species initially, the *C. gayana* with a different growth form and saline tolerance became totally dominant as the trial progressed.

pH was the only soil property, which showed a possible affect of the different treatments. A slight reduction in pH was noted over the 24-month period for the untreated control and conventional amelioration treatment, whereas the treatments containing class F fly ash showed no major reduction in soil pH. Many questions remain. How does class F fly ash react with acid generating coal discard? How can it be used to facilitate the reclamation of coal discard dumps? The most important challenge in the reclamation of coal discards, is to ensure stable vegetation, through improved soil conditions as a result of effective amelioration, to allow effective root development to stabilize these soils for sustainable periods to ultimately prevent loss of cover soil.

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