CHAPTER 6

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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 revegetate the covering topsoil, but the sustainability of conventional procedures is often poor. Liming and fertilizing the covering topsoil, does not necessarily ensure a viable growth medium for plants for prolonged periods. 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. As a result, the covering topsoil becomes unstable, and susceptible to erosion. 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. The effectivity of this material in counteracting the acidic conditions prevalent in the cover soil was observed. 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. This preliminary study focussed on the effect of different treatments on the production of these species and to the extent to which soil chemical status changed over a 24-month period. Significant increases in yield, of up to 200%, were noticed for class F fly ash treated soil and discards relative to the untreated control in a specific season. The pH of cover soil was the most strongly affected soil parameter during the experimental period. 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. This work provides the basis for more detailed follow-up research.

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

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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 (1975), Medvick and Grandt (1976), Bland *et al.* (1977), Buttermore *et al*. (1978), Sobek and Sullivan (1981), as cited by Daniels and Stewart, (2000) 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 (Martens, 1971; Moliner and Street, 1982; Wong and Wong, 1989).

Furthermore, the enriched macro- and micronutrients contained in fly ash enhances plant growth in nutrient-deficient soils (Plank and Martens, 1974; Martens and Beahm, 1978; Wong and Wong, 1989; Truter *et al.,* 2001, Truter, 2002, Truter and Rethman, 2003, Truter 2007). 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 (Phung *et al*., 1978; Adriano *et al*., 1980; Truter 2002). 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 (Doran and

Martens, 1972; Adriano *et al*., 1980; Truter, 2002). 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} (Fail and Wochok, 1977; Adriano *et al*., 1980), while on discards with pH values of 2.0 to 3.5 rates from 335 to 1790 metric tons ha^{-1} were used (Adams *et al*., 1972; Adriano *et al*., 1980).

Previous research has shown that fly ash has residual alkalinity. This supports the use of fly ash as a more sustainable soil ameliorant (Truter, 2002, Truter, 2007). This residual alkalinity of fly ash is present in the glassy phase of the fly ash particle (Reynolds *et al.,* 1999) 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 (Truter, 2002, Truter 2007).

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 (Figure 1) in 2003, 2004 and 2005.

Figure 1: Greenhouse pot study on coal discard reclamation

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. Figure 2 illustrates of how coal discard pots were constructed to simulate coal discard design.

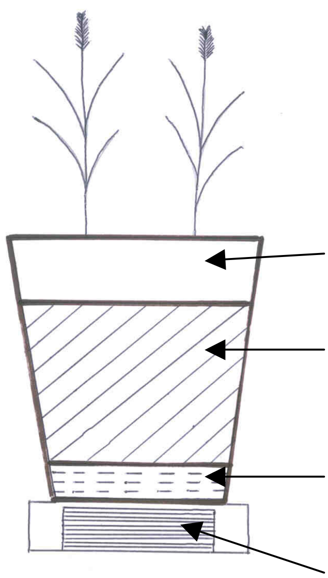

Figure 2: The pot simulation of coal discard dumps

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% (Truter, 2002). 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: 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 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.

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.

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)

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)

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.

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)

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.

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.

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)

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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CHAPTER 7

General Conclusions and Recommendations

7.1 The utilization of soil ameliorants, containing Class F fly ash, to enhance plant production by improving soil chemical properties

The utilization of the micronutrient content and liming qualities of class F fly ash together with the macronutrient and organic content of sewage sludge, can provide an alternative soil ameliorant such as SLASH. SLASH and class F fly ash definitely have agricultural potential. For optimal crop production specific soil conditions are required for a specific crop, it is , therefore, important that soil pH and nutrient levels meet crop requirements. It is concluded from this study that the class F fly ash and SLASH soil ameliorants had a significant effect on the dry matter production of the test crops. The crops planted on a relatively nutrient poor and acidic Hutton soil, were two annual crops, maize (*Zea mays*) and wheat (*Triticum aestivum*) and the perennial pasture legume (*Medicago sativa)*. Crop performance overall was much better on the class F fly ash and SLASH ameliorated soils. High grain yields, of up to 575 % more than the controls were registered for prolonged periods on the SLASH treatment, without annual inputs of fertilizers and conventional soil amelioration practices, even under intensive cultivation practices. Three different soil pH levels were monitored, and similar trends were noted for all three levels. These data, have demonstrated, that even though the SLASH ameliorant had the assumed advantage of an organic component, with a higher proportion of macronutrients, the class F fly ash treatment produced relatively high wheat grain yields of up to 335 % more than the control treatments. These results can possibly be ascribed to the fact that the correction in soil pH alone had a significant affect on crop production, because, baseline nutrients present in these agricultural soils could now be used more effectively, because of improved conditions for better root development. Similar observations were made for wheat dry matter production. It was, however, noted that only very small differences between treatment effects for the soil pH's 5.0 and 5.5 were evident. The more acidic soil (pH of 4.5) illustrates the significant differences between the SLASH and class F fly ash treatments. The acid sensitive perennial *M. sativa* (lucerne) was also favored by treatments with class F fly ash and SLASH producing up to 370 % higher DM yields over an extended period, with no cultivation after establishment.

From previous work, conducted on acidic agricultural soils, the residual effect of SLASH persisted for up to three years. To date, conventional liming and fertilization has been the preferred method of ameliorating such acidic and nutrient poor soils, on which these legumes are grown, but this is not necessarily sustainable. With the initial focus of this study being on the affect of class F fly ash and SLASH on the chemical properties of degraded soils / substrates, it has been concluded that SLASH is a good source of a variety of essential micro- and macro-nutrients, while also having the potential to improve pH. The significant role of coal combustion by-products (CCB's) in neutralizing acidity is due in part to the residual alkalinity, and hence it's ability to modify the soil chemical balance over extended periods so that nutrients become more available for plants.

It is also concluded that both SLASH and class F fly ash have contributed to higher nutrient levels. No significant differences in nutrient levels, were noted between the different soil pH levels. It is, however, evident that the ameliorants reacted differently in soils with the different soil pH's. These phenomena can possibly be ascribed to variability of ameliorant reactivity, composition, application and different frequency of soil cultivation. It was noted that SLASH, at the lowest soil pH, had the most significant effect on the Ca levels of the ameliorated soil, which, was planted to the lucerne and only cultivated at establishment. Thereafter, the FA ameliorants had the most significant effect on the soil Ca levels. The opposite is true in soils that were cropped with annual species. Under more frequent cultivation, FA was more reactive in the lower pH soil, while the effect of SLASH on Ca content was more prominent in the higher pH soils. This difference in reactivity of ameliorants is possibly as a result of the CaO component of SLASH being more reactive in soils with a lower pH. The Ca availability of FA treatments, however, is more evident at slightly higher pH levels, or when soils are more actively mixed during annual cultivation. From the results obtained it is clear that the SLASH and fly ash ameliorants significantly improved the P content of the soils. This can possibly be as a result of the silica in the calcium silicates, which are the major components of FA, competing with phosphorus on soil particles, making P more available for plant uptake. Similar results were noted at the higher levels of SLASH amelioration. It was consistently noted that the dolomitic lime treatments significantly improved the Mg levels of the soils, due to the lime's chemical makeup of $MgCO_3$. It is also evident that FA ameliorated soils illustrated a significantly higher K level, which is surprising because fly ash contains very little or no K. This increase in K, however, may be as a result of an improved soil pH, making K more available, and possibly as a result of the calcium and aluminum silicates displacing K from soil particles.

The chemically improved soil conditions resulting from the use of class F fly ash and SLASH were possibly as a result of relatively high application levels of these ameliorants. On the basis of these class F fly ash studies it is concluded that class F fly ash used has a higher $CaCO_3$ equivalent than the 20% referred to in international literature. It is estimated that the $CaCO_3$ equivalent was approximately 33% or more. It is, however, recommended that more detailed studies be conducted to scientifically substantiate this value, especially on fly ash from different sources, and to standardize a method to determine the true neutralizing capacity of fly ash based ameliorants.

7. 2 The utilization of soil ameliorants, containing class F fly ash, to improve the physical and microbiological properties of soils

SLASH and class F fly ash have not only the potential to improve the chemical properties of substrates but can also have a beneficial affect on soil physical and microbiological properties. One of the most important properties affecting other soil physical properties, and regulating many moisture related processes, is soil texture. With the addition of soil ameliorants based on class F fly ash, the silt fraction of the soil was increased by 143%. With an increased silt fraction, in soils and substrates ameliorated with SLASH and class F fly ash, the bulk density of the medium was improved by a 5 % and 14% reduction in density, respectively. These modified soils physical properties resulted in a change in moisture characteristics, such as water infiltration rate and soil hydraulic conductivity. The class F fly ash was, overall, the best ameliorant with respect to the significant affect on the rate of water infiltration into the experimental soil, increasing this by as much as 60%. This can possibly be ascribed to a 26% lower soil hydraulic conductivity. For optimal crop production good soil conditions are required to ensure a healthy and well-developed root system. Soil physical conditions, together with soil nutrient status, determine the extent and health of plant roots. A healthy and vigorous root system will ensure a productive growing plant. Root biomass is a good parameter to determine the effectivity of soil ameliorants, in creating more favourable soil rooting environments. Good correlations were observed between enhanced plant production, increased nutrient and soil pH levels, improved soil physical properties and well developed root systems. Root biomass data were correlated with improved soil physical parameters, with an improved root biomass (of up to 74 – 82 %) where the class F fly ash based soil ameliorants were used. This was also true of the SLASH ameliorant, which had the additional benefit of macronutrients in the organic component (sewage sludge).

By improving chemical and physical soil conditions, improvements in microbiological properties can also be ensured. The effect that SLASH had on biomass enhancement emphasizes the importance of including organic materials, to provide the essential nutrients required for plant growth. The added organic matter, provided in sewage sludge, and the improved pH, provided by class F fly ash, also create a more favorable soil environment for microbial activity. This was the conclusion in the preliminary study conducted on microbiological aspects. Humans and animals use many agricultural legume crops grown for protein production. The soil requirements for such crops have to be such that good root development occurs and that microbiological symbiotic relationships are promoted to ensure nitrogen fixation. This aspect was substantiated by data that illustrated how SLASH and fly ash ameliorants improved soil microbial activity by 200% and 172%, respectively. Similar trends were evident for *Rhizobium* nodulation, with increases of 35 % and 15 %, respectively for SLASH and fly ash ameliorants

By improving both chemical and physical soil conditions, an improvement in microbiological activity was also registered. The change in soil pH and soil texture, as a result of the addition of class F fly ash, can - together with the organic matter introduced by the sewage sludge - help create a better soil environment for microbial activity.

Due to intensive agricultural practices, such as chemical fertilization and mechanical cultivation, microbial communities are often stressed and eventually diminish. Soil amelioration, thus has an additional role in improving soil conditions, which promote the life of the soil through improved microbial and biological activity.

7.3 The utilization of soil ameliorants containing Class F fly ash to reclaim mine soils and mining substrates to facilitate sustainable re-vegetation

Soils disturbed for non-agricultural reasons, such as surface coal mining, are generally more degraded as a result of the exposure to more extreme mechanical / chemical processes. The stripping of topsoil in the surface coal mining process does not concentrate on the preservation of different soil horizons due to apparent economical and practical reasons. The A- horizon generally contains a viable indigenous seed bank, organic matter, microbial and biological organisms and the nutrients available for plant growth. These factors determine soil health and health of a living soil. The underlying horizons are, however, generally nutrient poor and often cannot sustain good plant growth. These soil horizons are unfortunately mixed during topsoil stripping and placement, and the properties of each horizon are lost due to the dilution effect. This is to the disadvantage of the vegetation established on such soils. It is as a result of this dilution effect, that soil amelioration of degraded mine soils is essential to establish or develop, a sustainable, healthy and living growing medium for plants.

Mine soils and waste disposal sites, such as gold tailings, ash dumps or coal discard dumps, are generally lower in fertility and are more acidic than natural topsoil and will benefit from the addition of organic materials together with an amendment with neutralizing potential. A variety of organic waste materials are available for this purpose. In particular, municipal biosolids are often freely available. Animal manures can also serve as a source of organic material and certain essential macronutrients, (such as K), which are often lacking in South African biosolids. Soils treated with FA have an improved pH, indirectly stimulating the growth of plants. These waste materials, unfortunately, vary greatly in nutrient trace metal content as well as liming potential. These factors can affect both re-vegetation success and the environmental impact of reclamation. It can be concluded, that the class F fly ash, used in this experimental work, does have a higher $CaCO_3$ equivalent than what is referenced in international literature. This conclusion is based on the significant increases in soil pH and soil root biomass, which have resulted in enhanced plant growth.

It is, therefore, imperative to combine careful analysis of the organic material, the fly ash and the mine soil or substrate to which it is to be applied. The pH of the soil or substrate must be controlled to limit the mobility of heavy metals and to ensure long-term plant vigour on rehabilitated sites. To reclaim a degraded soil or substrate is a major challenge, and can be a very expensive process if a sustainable ecosystem is to be established. The problems which many countries face, in terms of waste disposal, could possibly become solutions for many of the problems experienced in reclaiming mined soils or other substrates. The pot trials, discussed in this investigation, indicate that there is definitely a potential for using waste products, or mixtures thereof, such as SLASH and similar waste mixtures, to reclaim degraded soils or substrates. It was evident from the results that the addition of SLASH and fly ash enhanced the mean DM production of *Cenchrus ciliaris* by 72 % and 24 %, respectively on degraded mine cover soil. Similar results were obtained where SLASH and fly ash, enhanced the mean DM production on AMD impacted soils and gold mine tailings, by 144% and 48 %, and 697 % and 257 %, respectively. The most significant effect of fly ash based ameliorants on root biomass can be seen in the results obtained in the amelioration study of gold mine tailings. Root biomass of *C. ciliaris*, was improved by 4633% by SLASH and 566 % by fly ash amelioration. In comparison to current practice of amelioration, dolomitic lime and inorganic fertilization only improved root biomass by 122%.

With reference to the influence of fly ash based ameliorants on degraded soil and substrate chemical conditions, it evident that firstly SLASH, and secondly fly ash, have positive effects on soil or substrate pH relative to the lime and control treatments. It is clear from the data presented in this study that both SLASH and fly ash had a more pronounced effect in the most acidic medium (such as the AMD impacted soil), raising the soil pH from 3.4 to approximately 8.2 and 6.8, respectively. Similar trends were noted for mine cover soil and gold mine tailings. These significant increases in pH evidently occurred in the first 12 months of soil conditioning after treatment application, during which period crops were not produced. Only after the 12 month soil conditioning period, because of initial unsuccessful germination, were soils cropped, and no further reduction in pH was noted for the mine cover soil, for both SLASH and fly ash treatments, in comparison with the reduction in pH on the lime treatment. The AMD impacted soil, however, registered a slight reduction in pH of the SLASH treatment, but this was still 38% higher than the reduced pH of the lime ameliorated soil. Gold mine tailings, showed a similar reaction to the different ameliorants. After the cropping period of 12 months it was evident that the pH levels of soils ameliorated with SLASH and fly ash were above pH levels suitable for optimal crop production. These data, therefore, substantiate the conclusion that fly ash has a longer residual alkalinity, enabling it to maintain a good pH for longer periods.

These by-products are rich sources of nutrients or organic matter, which can be beneficially, utilized for crop production, to improve agricultural soils or the physical, chemical or microbiological properties of relatively inert substrates. Co-utilization of byproducts can often combine beneficial properties of the individual components to have a more significant effect on the degraded soil or substrate. They can provide a more complete/balanced nutrition, enhance soil condition and improve the economic, or environmental value of these individual by-products. The macro-nutrient levels of degraded soils and substrates in this study were positively influenced by the addition of SLASH and class F fly ash. Phosphorus levels were generally increased by SLASH, fly ash and lime ameliorants. More significant increases in P levels by the fly ash ameliorant were, however, noted for the more degraded AMD impacted soil and gold mine tailings. This observation was also true for Ca, although basal levels of Ca where initially high. All ameliorants caused an increase in Ca levels, but the most significant impacts were with SLASH and fly ash applied to AMD impacted soils and gold mine tailings. Potassium levels were significantly higher in lime treated mine cover soil, SLASH treated AMD impacted soil, fly ash treated gold mine tailings and most significantly SLASH treated gold tailings.

After approximately seven years of field scale research on a surface coal mine, it was concluded that both class F fly ash and SLASH have long-term residual affects on the soil condition of a mine cover soil. Consequently these effects, affect plant production, despite no fertilizer being applied since the 1st season to all treatments accept the standard mine treatment (SMT). The newly identified soil ameliorants used in the experimental work to date, have performed better than conventional ameliorants currently in use on surface coalmines. The effects of class F fly ash and SLASH ameliorants are highlighted when results are compared to the untreated controls used in the various studies. It would also appear that such ameliorants produced more sustainable vegetation than current practice. Due to their chemical nature and reactivity, long-term residual soil effects were noted. From these data it can be concluded, that this class F fly ash definitely has a much higher $CaCO_3$ equivalent than the 20%, which was originally assumed.

Subsequent to the pot trial study, a field scale study evaluating class F fly ash and SLASH amelioration of mine cover soils, provided results demonstrating significantly higher DM yields, in comparison to the lime and control treatments.

After 72 months, soils ameliorated with fly ash were still producing 236 % and 219% and SLASH ameliorated soils, 103% and 92% more DM than the control and SMT, respectively. Lower fertility treatments, such as the lime and the control, did, however, have a greater diversity of species in comparison to the higher fertility treatments, SLASH and class F fly ash, which were dominated by *Digitaria eriantha* and *Chloris gayana*. Excellent basal cover and yields can be obtained when planted pastures on reclaimed soils are fertilized with some kind of nutrient source, organic or inorganic, which is evident in the basal cover from SLASH and fly ash treatments. An acceptable basal cover percentage, used as a measure of grassland in good condition in South Africa, is between 30-40%. Mean basal cover percentages of 33% for SLASH and fly ash ameliorated soils were obtained 72 months after initial ameliorant application, relative to the 7.3% and 15.7 % basal cover percentage of the control and standard mine treatment (SMT).

Significant increases in the macronutrient (P, Ca, K, Mg) content of treated soils were also evident in this field study. The results obtained in the pot trials were confirmed in this field study. Optimum levels of fly ash, SLASH, lime and SMT improved P levels by 1577%, 2000%, 94% and 105%, respectively 72 months after initial treatment application. Potassium levels were increased by 65%, 74% and 32% by fly ash, SLASH and SMT respectively. The most significant increase in Ca levels was noted for the SLASH ameliorated soil, mainly as a result of the CaO component of SLASH, raising the Ca level by 3072%. This increase could raise concerns about possible phytotoxicity, but requires detailed investigation. Finally, the influence of alternative soil ameliorants on the soil pH, has presented similar trends noted in the earlier pot trial. SLASH, in the first 12 months had a significant influence on soil pH, raising the pH by approximately 4 pH units. This increased pH can possibly have a negative effect, on seed germination, which was observed after the establishment of test grass species. This pH, however, dropped over 72 months to just below 7.0, which remained approximately 2 and 3 pH units higher than the SMT and control, respectively. Fly ash alone, however, raised the soil pH by approximately 2 pH units and maintained it over the 72-month experimental period. These data substantiate the residual alkalinity of FA, to provide a more sustainable amelioration option. The significant rise in pH caused by SLASH, has led to the conclusion, that SLASH was possibly applied in too high a level. This incorrect calculation of SLASH application rate and results showing that soil pH is maintained by fly ash over the 72-months is partly due to an underestimation of the 20 % $CaCO_3$ equivalent of fly ash and partly due to CaO content of SLASH.

The challenge, therefore, is to establish a sustainable system, when inorganic fertilization is either reduced or stopped. Industrial and urban by-products have unique properties and release both micro- and macronutrients slowly over time, to sustain productivity, and to effectively reclaim degraded soils. On the basis of these results, investigations into the use of alternative materials as ameliorants to reclaim degraded mine soils should be expanded.

It is thus recommended that such soils/substrates be evaluated to determine the main requirements to make such media optimal for plant growth. It is also recommended that ameliorants available for use, be evaluated to establish their inherent characteristics, which will ultimately determine their suitability for the task envisaged and the volumes required. Economic and environmental considerations should not be neglected.

7.4 The utilization of class F fly ash to reclaim coal discard materials and discard cover soils

The use of an alternative ameliorant, such as class F fly ash, in reclaiming coal discards and their cover soils in a more sustainable manner, has tremendous potential. A preliminary study highlighted the positive chemical reactions caused by class F fly ash in these acidic mediums. The incorporation of class F fly ash into the coal discard and the potentially acidic cover soil, or the use of fly ash as a barrier (buffer zone) between the soils and discard material, has delivered positive results. 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 test crop *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. This study provides an unexpected performance of the two well known species used in mine land reclamation. Under well known reclamation conditions in South Africa, it was expected that *D. eriantha* would become the dominant species in re-vegetated mine land. However, *C. gayana* is proving to be the more adaptable species under even more harsh conditions, such as on coal discard.

With respect to the influence of class F fly ash on the chemical properties of discard cover soil, pH was the only soil property, which responded slightly to the different treatments. A slight reduction in pH was noted over the 24-month period for the untreated control and conventional lime treatment, whereas the treatments containing class F fly ash showed no major reduction in soil pH. In this study there were no obvious treatment effects on soil macronutrient levels. A dramatic reduction in soil nutrient levels, between 12 and 24 months, was, however, evident and can either be ascribed to the high nutrient uptake of plants and/or the possible immobilization of nutrients due to unexplained chemical reactions.

The research conducted in this study has raised many questions and theories, and provides the opportunity to develop scenarios which will explain the dynamics of utilizing, or co-utilizing, agricultural, domestic and industrial by-products to ameliorate degraded soils / substrates, which are to be re-vegetated with certain plants for specific purposes. Although promising results were obtained in this study, many questions remain on how class F fly ash reacts with acid generating coal discard; and how it can 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 using effective, economic and sustainable amelioration.

7.5 Recommendations

The recommendations, which can be made at this stage, are that once degraded soils and /or substrates are identified, and if an alkaline material or micronutrient sources are required for amelioration, class F fly ash should be seriously considered as an ameliorant. If there is an additional requirement for organic matter and macronutrients it is recommended that an organic material such as animal manures and/or sewage sludge (biosolids) be co-utilized to create a similar product to SLASH. It is also essential that plant species for the re-vegetation of degraded soils / substrates, should always be selected according to their adaptation to the environment and proposed post-mining land use.

The coal combustion by-product, class F fly ash, has many beneficial characteristics, and has the potential of being an effective soil / substrate ameliorant when used in relatively large volumes. Together with other agricultural and municipal by-products, such as animal manures and sewage sludge, these mixtures can be used as sources of nutrients and/or organic materials to enhance plant production and make it more sustainable.

Agricultural, municipal and industrial by-products are materials, which are rich sources of nutrients or organic material, and can be beneficially utilized for crop production, to improve the physical, chemical or microbiological properties of soils or inert substrates. These materials can be co-utilized, or combined, so that the materials are more easily applied to land, or to provide a more complete/balanced nutrition, or enhance soil conditioning and to improve the economic, or environmental value of these individual by-products.

Returning nutrients and organic matter to soil, or substrates, via industrial-, municipal-, domestic by-products, animal manures or other organic materials completes the natural cycle on which all life depends. The value of these materials in supplying nutrients for crops has been noted since the beginnings of agriculture when, for example, manured crops grew visibly better than those without. In recent years, numerous studies, conducted in various parts of the world, have examined the amelioration values of alternative soil amendments. Aside from the traditional value placed on animal manures (for example, as fertilizers supplying N-P-K) supplementary traits that encourage plant growth have often been attributed to manures. These additional benefits have been ascribed to plant nutrients such as Ca, Mg, or micronutrients, or to physical changes in soil structure. Difficulties in separating individual physical and chemical effects of alternative soil amendments, usually results in less than satisfactory identification of growth promoting factors, either quantitatively or qualitatively. Chemical fertilizers have mostly supplied the nutrient demand formerly supplied by animal manures and organic materials, but the extensive use of chemicals and mechanization is increasing the awareness of the potential value of industrial, municipal and domestic by-products, animal manures and organic wastes as soil conditioners, thereby contributing to a more holistic approach to sustainable amelioration scenarios.

"Create opportunity by using one environmental challenge to solve another environmental challenge"