AMELIORATION OF DEGRADED MINE SOIL FOR RECLAMATION PURPOSES USING AN INDUSTRIAL BYPRODUCT AND AN ORGANIC WASTE[1].

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Abstract. The South African mining industry has been the backbone of the country's economy for much of the past century. Mining has, however, often caused the degradation of productive soils. The amendment of these soils is often very expensive and often not sustainable. The University of Pretoria in co-operation with Eskom TSI, has over the past seven years conducted a series of trials. These trials have demonstrated the feasibility of using alkaline class F fly ash (from the coal-based Lethabo power generating facility) and organic materials to ameliorate acidic and infertile soils. Various pot and on-site field trials were established to measure and monitor the dry matter production, basal cover, botanical composition and the effect of amendments on the soil chemical properties. Based on the results obtained in the pot trials, it was concluded that fly ash and fly ash/organic material mixtures improved dry matter production as well as the soil pH, extractable K, Ca, Mg and P levels. This led to the expansion of the research programme. A field trial at a surface mine in the Mpumalanga Province was established. The results from this field trial confirmed pot trial findings. All parameters measured had been influenced by the fly ash and fly ash / organic material mixtures. Fly ash and fly ash / organic mixtures had 600% and 200% higher basal cover respectively, relative to the control. With respect to soil chemical properties, soil pH of AMD impacted soils were dramatically improved by 200% by the fly ash / organic mixture. An industrial byproduct such as fly ash, either by itself, or together with organic waste, can serve as a soil ameliorant for the reclamation of surface mined land.

Key Words: acidic soils, fly ash, infertile soils, organic materials, soil amendments

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Introduction

South Africa is a country with a shortage of land with high agricultural capability. A large percentage of this high capability class land is situated in the coal mining areas of the Mpumalanga Province. These soils tend to be acidic. Nevertheless, the land that is reclaimed on opencast coal mines is even more acidic. Current reclamation technologies for lands disturbed during the extraction of coal by surface mining have evolved during a period of more than 30 years. The importance of ongoing liming and fertilization to maintain a reclaimed area cannot be stressed enough. With respect to sustainability of pastures, production and cover on more marginal sites often decline after the withdrawal of fertilization. It is possible that an alternative to the conventional methods used to rehabilitate such areas will compensate for this.

In the future, conventional landfill and lagoon disposal of rapidly accumulating coal combustion byproducts, especially fly ash, and also organic biosolid wastes such as sewage sludge and animal manures, is unlikely to comply with increasingly stringent environmental regulations (Sopper, 1992; Walker et al., 1997). Land application of coal combustion residue wastes and biosolids, particularly fly ash either by itself or in a mixture with sewage sludge, may offer a sensible waste recycling alternative to current landfill or dump disposal and thereby serve as a source of micro and macro nutrients essential for plant growth. One major benefit is that these nutrients are made available over time (Truter, 2002; Norton et al., 1998). This can possibly be a method to establish a sustainable system. The University of Pretoria in cooperation with Eskom TSI has over the past seven years conducted a series of trials which have demonstrated the feasibility of using alkaline class F fly ash from the Lethabo coal fired power station to make sewage sludge safe for agricultural and land reclamation purposes. This mixture, known as SLASH, is characterized by the elimination of odor problems, the immobilization of possible metal contaminants, and the pasteurization of disease organisms in the sewage sludge. It has been used successfully to improve soil acidity and fertility (Rethman et al., 2000 a,b; Rethman and Truter, 2001; Truter et al., 2001).

<u>**Material and Methods**</u>

In the initial phase of this work, the response of *Cenchrus ciliaris* (a grass susceptible to acid soil conditions) to three different levels of fly ash, fly ash / sewage sludge mixture and dolomitic lime was investigated in pots. The other aim of the initial study was to determine how these treatments would influence the chemical properties of the soil. These treatments were compared to a control, which received no treatment. This set of 10 treatments was replicated six times on three different substrates. The three substrates used were; a mine cover soil, a soil impacted by acid mine drainage, and gold mine tailings.

The three treatment levels of fly ash, sewage sludge/ fly ash mixture and dolomitic lime were- **1)** calculated optimum (calculated according to the fly ash's neutralizing potential relative to that of lime, and based on the buffering capacity of the soil used in the trial), **2)** 33% above optimum, **3)** 33% below optimum. A control (no treatment) and a standard mine treatment (SMT) (the treatment used by the mine in the rehabilitation program), was included and served as a yardstick for the experiment.

The pot trial commenced in January 2000, and a period of 9 months was allowed for the treatments to stabilize (with frequent watering) before *Cenchrus ciliaris* seedlings were planted into the different substrates in September 2000. During the growing season of this species, four harvests were taken and the dry matter production determined. An initial soil analysis (pH_{H20}, P (Bray 1), extractable K, Ca and Mg) was taken before planting of the grass, with a final analysis after the last harvest of the season. The P was extracted using the Bray 1 method (1:7.5 extraction), and the other extractable cations, K, Ca amd Mg were extracted using (1:10) ammonium acetate extraction.

As a result of the positive findings from the pot trials, the study was expanded to a field trial on a surface mine in the Mpumulanga Province. The field trial consisted of the same treatments used in the pot trial with five replications. The calculated optimum level of fly ash, sewage sludge/ fly ash and CaO mixture (6:3:1 ratio on a wet basis) and lime for the field trial was 50 tons ha^{-1}, 166 tons ha^{-1} and 10 tons ha^{-1} respectively. The fertilizer and lime quantities used in the standard mine treatment in the establishment year were, 65 kg N ha^{-1}, 203 kg P ha^{-1}, 134 kg K ha^{-1} and four tons of dolomitic lime ha^{-1}. In the 2nd season, the standard mine treatment only received 100 kg N ha^{-1}. These treatments were applied to and incorporated into the mine cover soil which was placed over the spoil material. Once the soil had been treated, it was planted to a mixture consisting of the annual nurse crop *Eragrostis teff*, perennial grasses such as *Chloris gayana* (Rhodegrass), *Cynodon dactylon* (Bermuda grass) and *Digitaria erianthra* (Smutsfinger grass) and the perennial legume *Medicago sativa* (Alfalfa). In the first growing season, basal cover (Point-bridge method) and dry matter production was determined. In the second growing season basal cover was re-assessed before the execution of a botanical composition survey and the subsequent determination of dry matter production. Soil analyses were conducted for the field trials at 12 months and 18 months after treatment of soils. These analyses included soil pH_{H20} and extractable cations P, K, Mg, and Ca. The method of extraction was the same as for the pot trials.

Statistical analyses

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

Results and discussion

POT TRIAL

Dry Matter Production

It can be seen from Table 1 that the more degraded the substrate, the better the response is to amendment with SLASH. This may be partially be ascribed to the organic content of this amendment and partially due to macro- and micronutrients supplied by the fly ash and sewage sludge.

It is notable that the fly ash and lime gave very similar results for the cover soil and AMD impacted soil. This can possibly be because these amendments have similar effects on the soil environment, which enhances the plant growth.

Table 1. The influence of different soil amendments applied to three different substrates on the mean dry matter production for four harvests of *Cenchrus ciliaris.*

Treatment	Mine cover soil	AMD impacted soil	Gold tailings
	g/plant	g/plant	g/plant
Fly ash (Opt - 33%)	9.07 ^{a}	7.06 ^{a}	0.00 ^{a}
Fly ash	9.21 ^{a}	6.74 ^{a}	0.23 ^{b}
Fly ash (Opt +33%)	9.84 ^{a}	7.19 ^{a}	4.84 ^{c}
SLASH (Opt –33%)	9.78 ^{a}	11.45 ^{b}	7.46 ^{d}
SLASH	11.05 ^{b}	13.06 ^{b}	7.77 ^{d}
SLASH (Opt +33%)	11.79 ^{b}	14.93 ^{b}	8.61 ^{d}
Lime (Opt –33%)	7.99 ^{c}	6.07 ^{c}	0.00 ^{a}
Lime	7.88 ^{c}	6.13 ^{a}	0.58 ^{b}
Lime (Opt +33%)	8.11 ^{c}	6.57 ^{a}	1.80 ^{b}
Control	7.52 ^{c}	5.60 ^{c}	0.00 ^{a}

*abcd Column means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Tukey's Studentized Range Test)

SOIL ANALYSES

A) Mine cover soil The amendment of the soils used in the rehabilitation process is normally very costly and often not sustainable after 5 years. The results shown in Table 2 indicate that there may be other alternative amendments that can be used, depending on their economic viability. Whether these amendments will be sustainable must, however, still be determined.

The SLASH treatments all contributed to the improvement of P in the mine cover soil. From Table 2 it is also notable that the amendments used in this trial had little or no K, and this element may need to be supplemented by an inorganic fertilizer or some other source of K such as animal manures. It is also clear that the SLASH amendment also supplied a large amount of Ca, which can be ascribed to high Ca levels of the sewage sludge used. It can be seen from Table2 that both the fly ash and the lime had similar effects on the soil pH.

Table 2. The influence of different soil amendments on the soil chemical properties of a mine cover soil.

Treatment	pH (H_2O)	P	Ca	K	Mg
		$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
Fly ash (Opt - 33%)	6.5^{a}	7.1^{a}	211.7^{a}	14.7^{a}	28.2^{a}
Fly ash	7.1^{b}	10.1^{a}	293.7^{a}	17.3^{a}	35.3^{a}
Fly ash (Opt +33%)	6.5^{a}	13.0^{a}	304.7^{a}	15.7^{a}	34.8^{a}
SLASH (Opt –33%)	7.8^{b}	13.1^{a}	1957.8^{b}	17.2^{a}	26.3^{a}
SLASH	7.9^{b}	35.8^{b}	2395.3^{b}	18.8^{a}	32.0^{a}
SLASH (Opt +33%)	8.2^{b}	15.0^{a}	3046.3^{b}	18.8^{a}	31.5^{a}
Lime (Opt –33%)	6.4^{a}	2.4^{c}	293.5^{a}	16.0^{a}	79.8^{b}
Lime	6.3^{a}	6.5^{a}	274.5^{a}	27.5^{b}	96.2^{b}
Lime (Opt +33%)	6.9^{a}	1.3^{c}	272.7^{a}	16.7^{a}	122.3^{b}
Control	5.6^{c}	2.0^{c}	149.7^{c}	18.2^{a}	20.8^{a}

* abc Column means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Tukey's Studentized Range Test)

<u>B) AMD impacted soils</u> The effects of SLASH can be seen more clearly on the more degraded AMD impacted soil. These soils are very acidic and infertile. Table 3 indicates that both the fly ash and the SLASH contributed to the higher P status of the soil relative to the control. The K level of this soil was, however, only marginally improved by the different SLASH treatments. When compared to the mine cover soil, it can be seen that this soil interacted differently with amendments, making the K (available in the ameliorant) more available.

From Table 3 it is evident that both fly ash and SLASH improved the Mg levels of the soil by approximately 100%, whereas the dolomitic lime improved the Mg levels by 400%, relative to the control.

Table 3 also shows clearly how the SLASH dramatically improved the soil pH. This could, however, be a problem because the soil pH is being changed from an acidic to slightly alkaline situation, which could effect the germination of certain seeds planted in these amended soils. This dramatic pH effect can possibly be the result of too high applications of SLASH to the soil.

Table 3. The influence of different soil amendments on the soil chemical properties of AMD impacted soils.

Treatment	pH (H_2O)	P	Ca	K	Mg
		$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
Fly ash (Opt - 33%)	4.3 ^{a}	12.6 ^{a}	419.7 ^{a}	15.0 ^{a}	48.2 ^{a}
Fly ash	4.1 ^{a}	17.1 ^{a}	532.2 ^{a}	14.8 ^{a}	68.2 ^{a}
Fly ash (Opt +33%)	5.1 ^{a}	28.5 ^{b}	746.5 ^{b}	15.7 ^{a}	70.0 ^{a}
SLASH (Opt –33%)	8.0 ^{b}	13.7 ^{a}	3958.7 ^{c}	24.2 ^{b}	43.8 ^{a}
SLASH	8.2 ^{b}	10.6 ^{a}	4471.7 ^{c}	26.8 ^{b}	52.0 ^{a}
SLASH (Opt +33%)	8.3 ^{b}	4.0 ^{c}	4440.2 ^{c}	27.7 ^{b}	50.0 ^{a}
Lime (Opt –33%)	5.4 ^{a}	1.1 ^{c}	585.7 ^{a}	15.8 ^{a}	170.8 ^{b}
Lime	5.0 ^{a}	1.0 ^{c}	495.2 ^{a}	15.7 ^{a}	188.3 ^{b}
Lime (Opt +33%)	6.1 ^{b}	1.1 ^{c}	729.0 ^{b}	15.3 ^{a}	289.2 ^{b}
Control	4.0 ^{a}	5.3 ^{c}	259.8 ^{a}	14.8 ^{a}	25.3 ^{c}

*abc Column means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Tukey's Studentized Range Test)

The neutralizing ability of the soil ameliorant SLASH has proven itself over the past couple of years (Truter, 2002). It was believed that the fly ash component of the SLASH is the essential component in improving the soil pH. Fly ash used in this experimental trial has a neutralizing value of 20% that of lime, but when combined with the CaO and sludge, it was approximately 30-40% that of lime.

C) Gold tailings The data presented in Table 4 demonstrate very similar responses to the soil amendments as obtained on the AMD impacted soil. It can be clearly seen that both the SLASH and fly ash improved the soil extractable P by 100% or more. These levels are below the optimum required for plant production and will however, not support plant growth. With respect to the K levels, both fly ash and lime improved the K status, but not to the extent which SLASH did. The Ca levels of the tailings were initially high and the improvements in the SLASH amended tailings material indicated that the source of sludge used, had a high Ca content. This contributed to the high Ca levels seen for SLASH treatments in Table 4, whereas the fly ash treatments weren't necessarily different from the control.

The pH of gold tailings is normally very low, and could not sustain stable vegetation. It is noted from Table 4 that the SLASH undoubtedly improved the pH levels. This improvement in pH is also reflected in the growth enhancement by the SLASH treatments on these tailings. This pH stimulated plant roots to develop, which theoretically should improve the nutrient and water use efficiency.

Table 4. The influence of different soil amendments on the soil chemical properties of gold tailings.

Treatment	pH (H_2O)	P	Ca	K	Mg
		$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
Fly ash (Opt - 33%)	3.9 [a]	3.5 [a]	2574.0 [a]	2.0 [a]	368.7 [a]
Fly ash	4.4 [a]	2.9 [a]	2969.8 [a]	4.8 [a]	308.3 [a]
Fly ash (Opt +33%)	4.8 [a]	3.6 [a]	2313.7 [a]	3.2 [a]	292.2 [a]
SLASH (Opt –33%)	7.5 [b]	3.8 [a]	5368.2 [b]	61.2 [b]	196.8 [a]
SLASH	7.4 [b]	2.4 [a]	5157.7 [b]	100.2 [b]	153.8 [b]
SLASH (Opt +33%)	8.3 [b]	1.2 [b]	6155.5 [b]	151.8 [b]	110.5 [b]
Lime (Opt –33%)	5.0 [b]	0.5 [b]	1993.3 [a]	9.3 [c]	290.5 [a]
Lime	4.5 [a]	0.4 [b]	2297.0 [a]	7.2 [c]	326.5 [a]
Lime (Opt +33%)	5.4 [a]	0.5 [b]	2445.0 [a]	17.5 [c]	309.7 [a]
Control	3.9 [a]	0.7 [b]	2189.6 [a]	2.2 [a]	469.3 [c]

*abc Column means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Tukey's Studentized Range Test)

FIELD TRIAL

Plant measurements The field trial was an extension of the pot trial to determine whether the excellent results obtained in the pot trial would apply in the more practical situation. It was decided to use only the cover soil, which is used most often in the reclamation process. If good results were obtained, this would support the expansion of the investigation into more serious situations, which the mines encounter.

These mine soils are generally infertile and acidic, as it is seen for the control soil in Table 2 and 3. This could stunt the establishment of plants because the roots cannot develop properly to support aboveground plant material. From the results shown in Fig. 1, it can be seen from the basal cover measurement of the 1st growing season, which was dominated by the nurse crop *Eragrostis teff,* that the ash treated soils had a 6x higher cover than the control. The SLASH treated soil had a 2x higher basal cover than the control. The standard mine treatment also had a much lower basal cover that the SLASH and fly ash treated soils.

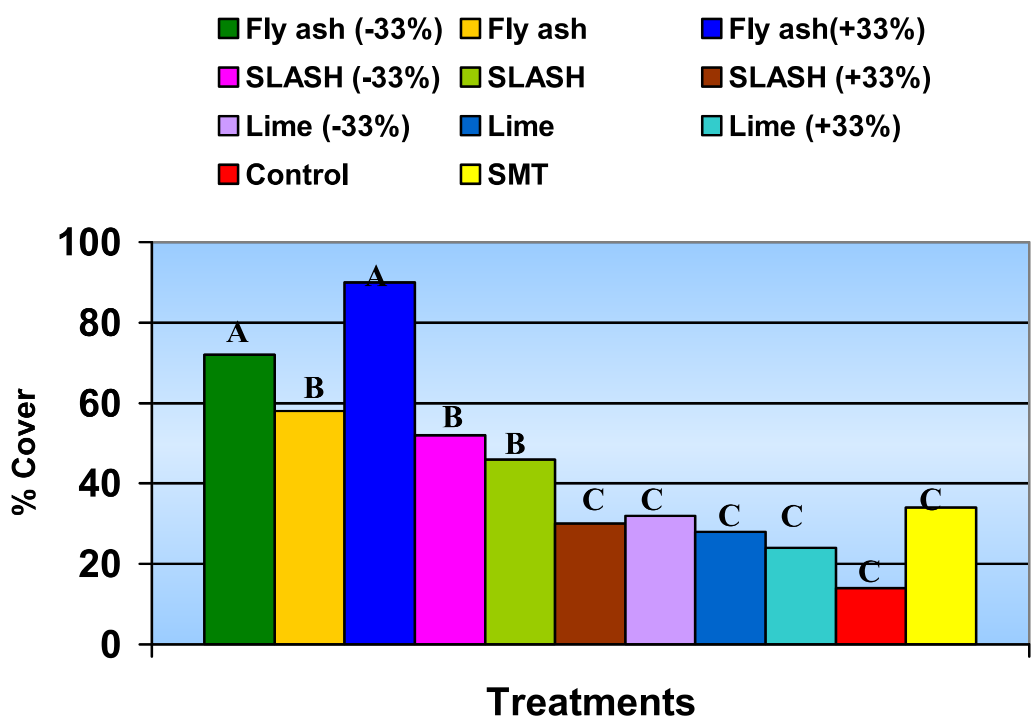

Figure 1. Basal cover measurement of *Eragrostis teff* in the 1st growing season after treatment application. (* Means with the same letter are not significantly different (P>0.05) (Tukey's Studentized Test)

By the second growing season cover had improved (Fig 2). Although the ash treated soils still had the best cover, the SLASH and lime treatments had improved as time progressed.

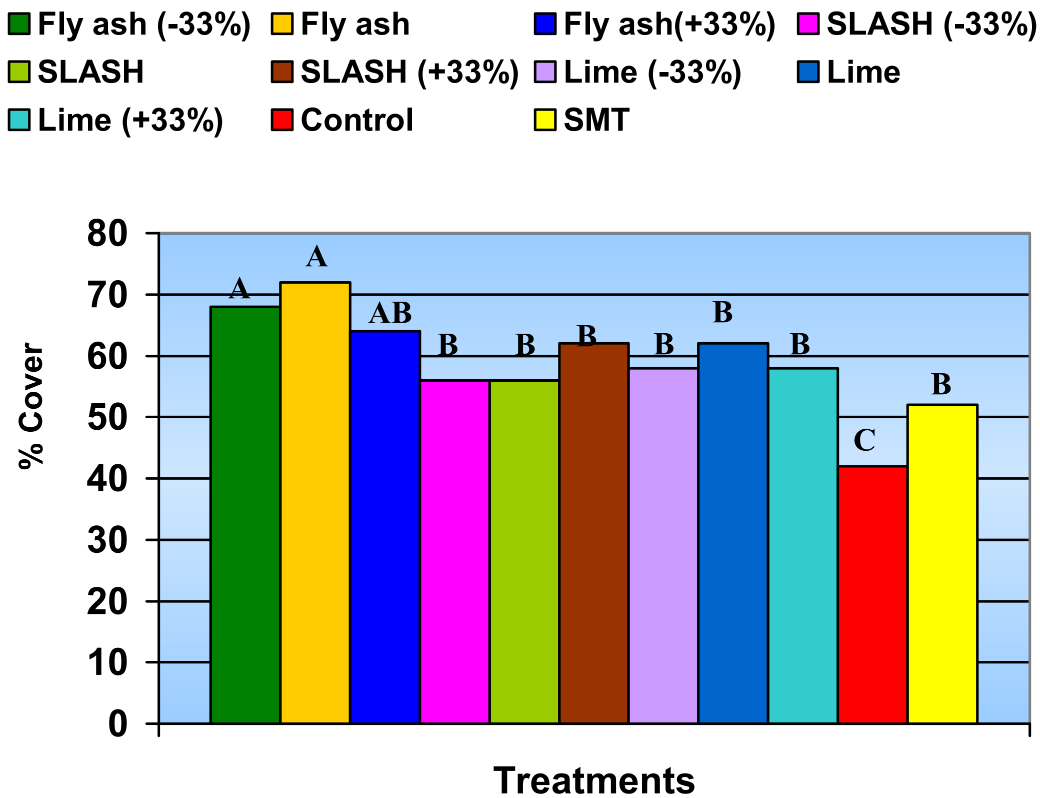

Figure 2: Basal cover measurement in the 2nd growing season. (* Means with the same letter are not significantly different (P>0.05) (Tukey's Studentized Test)

With respect to the dry matter production in the first growing season, it is evident in Table 5 that the fly ash treated soils produced slightly more than some of the SLASH treated soils and lime treated soils and considerably more than the control and the standard mine treatment. In the second growing season more or less the same trend was evident. However, the fly ash treated soils still maintained a much better yield than the lime, control and standard mine treatments. The higher SLASH treatment gave an indication that the application rate could possibly be too high, as it had a depressing effect on plant production when it was compared to the other SLASH treatments.

Table 5: The influence of different soil amendments on the dry matter production of grasses on the mine cover soil.

Treatment	1st Harvest	2nd Harvest
	Eragrostis teff	*Chloris gayana*
	tons ha^{-1}	tons ha^{-1}
Fly ash (Opt - 33%)	3.90 [a]	13.6 [a]
Fly ash	4.98 [b]	12.6 [a]
Fly ash (Opt +33%)	4.11 [a]	12.9 [a]
SLASH (Opt –33%)	4.24 [b]	12.3 [a]
SLASH	3.80 [a]	16.0 [b]
SLASH (Opt +33%)	3.19 [a]	10.6 [a]
Lime (Opt –33%)	3.31 [a]	8.5 [c]
Lime	4.02 [a]	8.4 [c]
Lime (Opt +33%)	3.65 [a]	8.4 [c]
Control	2.33 [c]	6.8 [c]
Standard mine treatment	2.48 [c]	8.7 [c]

* abc Column means with common alphabetical superscripts do not differ significantly (P> 0.05) (Tukey's Studentized Range Test)

Soil Analyses With respect to the analyses of the soil at the end of each growing season (Table 6), it is evident that both the SLASH and fly ash treatments improved the P and K status of the soils 12 months after the application of treatments.

The P levels were close to the required amounts necessary for plant growth whereas the K levels were well below the optimum amount needed in arable soils (FSSA, 2001). In Fig. 3 it is seen that the soil pH was also improved by the SLASH treatments with respect to the control, whereas the fly ash, lime and SMT treatments also improved the soil pH by approximately 1 pH unit.

Table 6. The influence of different soil amendments on the soil chemical properties of mine cover soil 12 months after treatment.

Treatment	P	K	Ca	Mg
	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
Fly ash (Opt - 33%)	22.68^{a}	25.2^{a}	370.8^{a}	35.0^{a}
Fly ash	29.76^{a}	27.6^{a}	454.8^{a}	39.6^{a}
Fly ash (Opt +33%)	38.10^{b}	21.0^{b}	514.4^{a}	49.0^{a}
SLASH (Opt –33%)	31.44^{a}	35.0^{a}	3388.6^{b}	43.2^{a}
SLASH	24.60^{a}	32.0^{a}	4146.2^{b}	56.4^{a}
SLASH (Opt +33%)	25.58^{a}	33.6^{a}	4344.6^{b}	53.4^{a}
Lime (Opt –33%)	4.32^{c}	25.0^{a}	287.8^{a}	102.8^{b}
Lime	2.54^{c}	18.6^{b}	408.4^{a}	139.0^{b}
Lime (Opt +33%)	3.12^{c}	18.4^{b}	370.6^{a}	129.2^{b}
Control	3.64^{c}	20.2^{c}	123.6^{c}	12.2^{c}
SMT	2.45^{c}	45.6^{d}	131.5^{c}	11.9^{c}

*abcd Column means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Tukey's Studentized Range Test)

This pH improvement is a confirmation of results obtained in the pot trials. The increased pH of the SLASH treated soils once again supports the hypothesis that the application rate of SLASH needn't be so high because it has a much higher neutralization value than 20-30% originally expected. Similar results were obtained 18 months after the initial treatment. It can be seen from Table 7 that both the P and K status improved slightly, indicating that both the fly ash and SLASH treatments have the ability to release nutrients slowly.

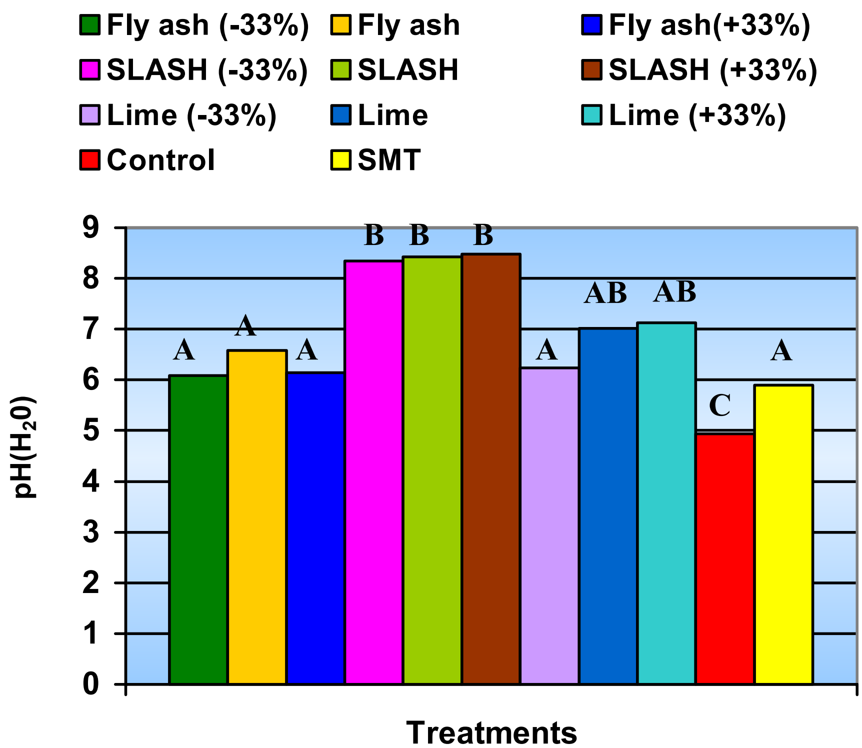

Figure 3: The effect of different treatments on the soil pH of mine cover soil in the field trial 12 months after treatment application. (* Means with the same letter are not significantly different (P>0.05) (Tukey's Studentized Test))

Although the K levels have marginally been improved, the challenge remains to investigate the addition of an animal waste, which is normally high in K (under South African conditions), into the mixture. It can also be seen that the fly ash and SLASH treatments provide a small amount of Mg as well, but little compared to the dolomitic lime.

Figure 4 shows that the pH of the mine soil had been improved by all treatments (except the SMT) by at least 1 pH unit relative to the control. The pH of SLASH treated soils had, however, declined to a more favorable level, which can be beneficial to plant growth. Both the fly ash and lime treatments had maintained a good pH, therefore creating a suitable soil environment for plants to utilize the elements present in the soil.

Table 7: The influence of different soil amendments on the soil chemical properties of an mine cover soil 18 months after soils had been treated.

Treatment	P	K	Ca	Mg
	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
Fly ash (Opt - 33%)	22.46^{a}	32.6^{a}	367.2^{a}	34.0^{a}
Fly ash	30.18^{a}	36.6^{b}	427.4^{a}	36.8^{a}
Fly ash (Opt +33%)	34.12^{a}	44.0^{b}	485.0^{a}	42.2^{a}
SLASH (Opt –33%)	37.54^{b}	48.0^{b}	3064.0^{b}	45.8^{a}
SLASH	38.22^{b}	43.2^{b}	3649.2^{b}	53.0^{b}
SLASH (Opt +33%)	37.94^{b}	47.0^{b}	4087.8^{b}	70.6^{b}
Lime (Opt –33%)	2.68^{c}	29.6^{a}	263.8^{c}	98.4^{c}
Lime	2.50^{c}	25.8^{a}	351.8^{a}	106.4^{c}
Lime (Opt +33%)	1.86^{c}	25.0^{a}	375.0^{a}	124.4^{c}
Control	2.42^{c}	31.8^{a}	125.0^{d}	14.8^{d}
SMT	1.02^{c}	73.4^{c}	128.6^{d}	11.0^{d}

* abcd Column means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Tukey's Studentized Range Test)

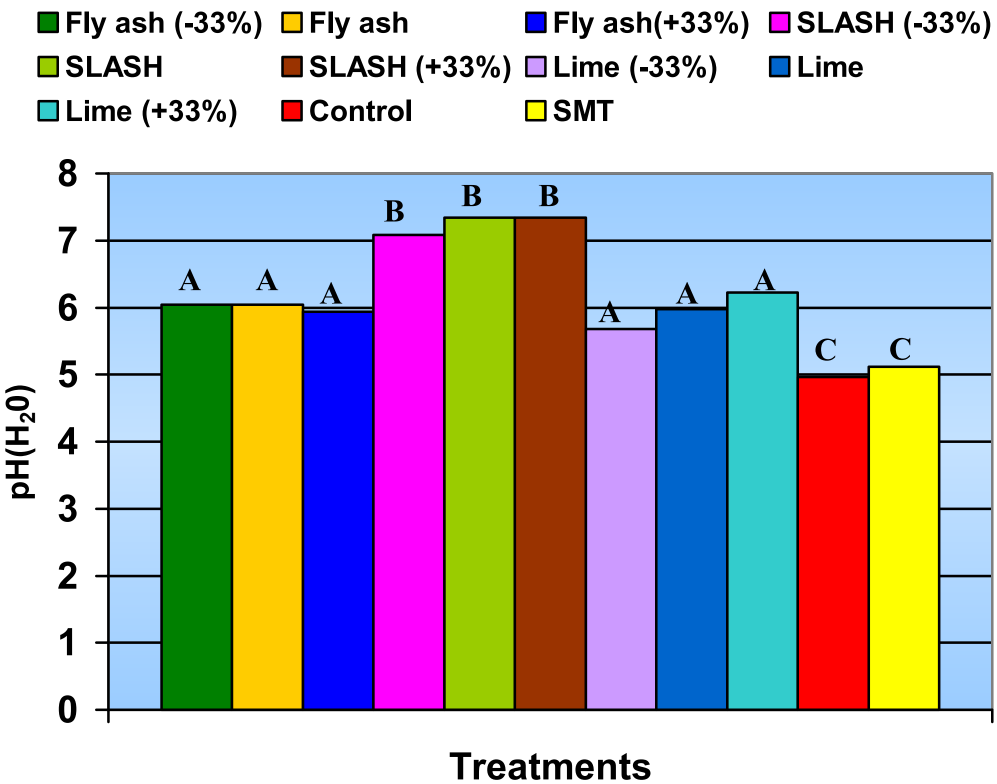

Figure 4. The effect of different treatments on the soil pH of mine cover soil in the field trial 18 months after treatment application. (* Means with the same letter are not significantly different (P>0.05) (Tukey's Studentized Test)

Conclusion

To reclaim a degraded soil is a major challenge. It is a costly process and it is often very difficult to establish a sustainable system. The problems that South Africa and many other countries face in terms of waste disposal could possibly become solutions for many of the problems experienced in reclaiming mined soils. The pot and field trials discussed in this paper indicate that the previous statement could become a reality. SLASH and similar waste mixtures have definite agricultural potential, and can be used effectively to reclaim disturbed soils. How sustainable will this system be? This is a question that remains to be answered over time. From previous work done on acidic agricultural soils, the residual effect of SLASH has been measured for three years (Truter, 2002). It is expected that SLASH will have the same residual effect on the more acidic mine soils.

Despite the good results obtained on the SLASH and ash treated soils, the importance of supplementing K is critical. This conclusion leads to the investigation of the incorporation of an animal waste component into a new mixture, which can address the K deficiency in SLASH. The fly ash treated soils have also given excellent results in terms of improving the soil pH, indirectly stimulating the growth of plants. When considering the establishment of different land capability classes in mine rehabilitation projects, for example, the class natural rangeland, with a good biodiversity, then the fly ash treatment could possibly be considered as a soil ameliorant with a low organic material content, creating soil conditions common for supporting good biodiversity. Whereas, highly productive pastures, require all the necessary macro-nutrients for growth enhancement from the organic materials such as in sludge. Therefore, a good combination of both fly ash and an organic material, can provide a alternative soil ameliorant such as SLASH.

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