CHAPTER 2

Prepared according to the guidelines of Bioresource Technology

The utilization of class F fly ash, and co-utilization thereof with sewage sludge, to ameliorate degraded agricultural soils and to improve plant production

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Abstract

Prime agricultural land is a limited resource in South Africa. It is, therefore, necessary to reclaim poor and disturbed soils to feed the burgeoning population. Using conventional methods is costly and not necessarily sustainable. The challenge is, therefore, to use potential alternative ameliorants in an economically, ecologically and socially sustainable manner. Previous research has shown that by mixing sewage sludge with class F fly ash and a suitable source of quicklime, the sewage sludge can be pasteurized. The **SL**udge**ASH** (SLASH) mixture has been extensively evaluated as a soil ameliorant and has proven to be viable for the reclamation of poor and marginal soils. Many pot and raised bed studies, focusing on the effect of SLASH on plant production of various plant species, have been conducted and reported on previously.

This paper reports on subsequent research conducted to determine the effect of both fly ash and SLASH on the production of maize *(Zea mays)*, wheat *(Triticum aestivum)* and lucerne (alfalfa) (*Medicago sativa*) in field applications. The effect of treatments on soil chemical properties was also monitored in this study. SLASH and fly ash treatments were compared with agricultural lime and an untreated control. The results obtained illustrate improvements in crop yields. Wheat yields on SLASH and fly ash treatments were 270% and 150% better than the control respectively, while yields of maize and alfalfa were improved by 130 % and 450% respectively. Soil chemical properties were also improved by the SLASH and fly ash treatments. The results presented are encouraging and justify further research on the use of fly ash and it's co-utilization with other by-products to restore productivity to poor agricultural lands in South Africa.

Keywords: class F fly ash, sewage sludge, soil ameliorant, plant production

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1. Introduction

South Africa is a country with very little prime farmland. A large percentage of this high agricultural capability land is generally acidic, but is situated in areas where large quantities of fly ash are available. To ensure healthy and productive vegetation, disturbed soils need to be ameliorated effectively. To date, conventional methods of liming and fertilization to improve productivity of impacted soils have been standard practices. This process can, however, be very expensive and is often not sustainable.

South Africa has plenty of waste products, which might be used as alternative ameliorants. Fly ash is characterized as a good source of certain micronutrients beneficial to plant growth in addition to it's liming qualities and other unique properties. This resource, together with other wastes such as sewage sludge or animal wastes (which are good sources of organic material and macronutrients essential for plant growth), can serve as a soil ameliorant in crop production systems (Norton *et al*., 1998; Truter, 2002). In future, conventional landfill and lagoon disposal of rapidly accumulating coal combustion byproducts, (especially fly ash), and 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).

The mixing of organic waste products such as sewage sludge or poultry litter with fly ash has been proposed to increase the macronutrient content of the resultant mixture while reducing odour and improving handling properties of the organic waste (Garau *et al*., 1991; Vincini *et al*., 1994; Schumann, 1997; Jackson and Miller, 2000). Field trials utilizing fly ash/ organic waste mixtures as fertilizers for maize (*Zea mays* L.) produced comparable yields to conventional fertilization techniques (Schuman, 1997). Soil acidity affects plant development by influencing the availability of certain elements required for growth (Tisdale and Nelson, 1975; Truter, 2002). Soil acidity is, therefore, of the greatest importance to plant producers and one that is easily corrected if dealt with immediately after detection. (Truter, 2002).

Soil acidification and, indirectly, nutrient depletion are ongoing natural processes. In natural ecosystems the rate of acidification is largely determined by the loss of base minerals (Ca, Mg, K) from the soil by leaching. The central problem of acid soil management lies in the constraints, which arise from the soil condition. The most serious of these is that at low pH's; acids (H^+) can release soluble aluminium (Al) and manganese (Mn) from soil minerals. Both Al and Mn have direct toxic effects on many plants (Beukes, 2000; Truter 2002). Al concentrations can be sufficiently high in acid soils, with pH values of 5.5 or below, to be toxic to plants (Ahlrichs *et al*, 1990; Truter 2002). Aluminium acts by restricting root extension growth, resulting in poor plant production and eventually a decline in food production. Soil acidification is thus a serious socio-economic concern. Very few countries can afford a decline in food production, which often accompanies the changes, which are taking place in our soils.

Previous work to determine the feasibility of converting waste disposal problems into a soil beneficiation strategy has proven true (Reynolds *et al*., 1999). The co-utilization of fly ash and sewage sludge with added lime in a ratio of 6:3:1 on a wet basis, has delivered the product termed SLASH. The aim of this study is to evaluate the effects of alternative ameliorants such as SLASH and class F fly ash on the chemical properties of nutrient poor and acidic soils and on the plant production.

2. Methods

A field study with randomized plots (nett plot: 3.75m x 8.65m = 32.44m^2) was conducted at the Hatfield Experimental Farm of the University of Pretoria, South Africa. Situated at 25°45'S 28°16'E, this site is 1327m above sea level. A uniform sandy loam soil was ameliorated with different levels of sewage sludge, fly ash and reactive lime (CaO) and in combination (SLASH), to determine how such treatments would influence the production of wheat (*Triticum aestivum)*, maize (*Zea mays*) and lucerne /alfalfa (*Medicago sativa)* over a 24-month period on soils of different levels of acidity. This field study was also to evaluate the practicality of using these ameliorants on a large scale in agricultural practice.

An agricultural land that had been acidified to three levels of basal soil acidity **[P1]** $pH_{(H2O)}$ = 4.5, **[P2]** $pH_{(H2O)}$ = 5.0 and **[P3]** $pH_{(H2O)}$ = 5.5 in the past, were treated with 2 levels of SLASH (**[S1]** 32 tons ha^{-1} and **[S2]** 64 tons ha^{-1}) and 2 levels of fly ash (**[FA1]** 9.5 tons ha^{-1} and **[FA2]** 19 tons ha^{-1}). These were compared to a dolomitic lime treatment **[L]** (4 tons ha^{-1}) and a control **[C]** (no treatment).

Figure 1: Class F Fly ash, SLASH and lime treated field trial at the Hatfield Experimental Farm, University of Pretoria.

Application rates were based on the buffering capacity of the soil. These treatments were replicated three times (R1-R3) and were only applied at the beginning of the trial, to determine their long-term residual effect with respect to sustainability. Two seasons of wheat production, one season of maize and three seasons of alfalfa were recorded. Grain yield and dry matter production (Five replicate samples R1-R5) of both wheat and maize were measured and multiple harvests of lucerne (alfalfa) were recorded during the trial period. Soil $pH_{(H2O)}$, P (Bray 1, 1:7.5 extraction) and K, Ca, Mg, (1:10 ammonium acetate extraction method) were also measured after each growing season to determine the plant available elements.

2.1 Statistical analyses

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

3. Results and discussion

3.1 Biomass production

3.1.1 Wheat

From the results presented in Tables 1 to 3, it is clear that a better grain yield can be achieved on soils treated with SLASH and fly ash, as opposed to the lime and control treatments. Wheat grain yields on average increased by 575% and 335% relative to the control.

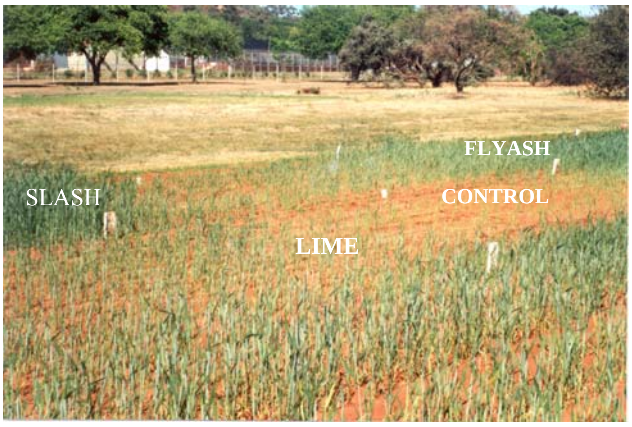

Figure 2: Wheat production as influenced by the various soil ameliorants

Table 1: Wheat grain yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 4.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H_20) =4.5**	
	1st season	**2nd season**
	kg ha^{-1}	**kg ha^{-1}**
S1	1276.84 $^{A}_{a}$ **(± 35.67)**	586.52 $^{B}_{a}$ **(±10.89)**
S2	1093.95 $^{A}_{a}$ **(±24.45)**	638.19 $^{B}_{a}$ **(±11.34)**
FA1	487.86 $^{A}_{c}$ **(±15.67)**	492.43 $^{B}_{b}$ **(±13.57)**
FA2	648.34 $^{A}_{b}$ **(±12.34)**	464.00 $^{B}_{b}$ **(± 12.34)**
L	246.67 $^{A}_{d}$ **(±9.87)**	318.38 $^{A}_{c}$ **(±9.23)**
C	67.15 $^{B}_{e}$ **(±5.46)**	260.86 $^{A}_{c}$ **(±7.98)**

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

Table 2: Wheat grain yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 5.0, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H_20) =5.0**	
	1st season	**2nd season**
	kg ha^{-1}	**kg ha^{-1}**
S1	2156.28 $^{A}_{b}$ **(±54.89)**	407.38 $^{B}_{c}$ **(± 11.93)**
S2	2593.66 $^{A}_{a}$ **(±51.23)**	624.52 $^{B}_{b}$ **(±10.87)**
FA1	1703.10 $^{A}_{c}$ **(±37.65)**	445.29 $^{B}_{c}$ **(±12.03)**
FA2	2080.72 $^{A}_{b}$ **(±47.89)**	812.05 $^{B}_{a}$ **(± 21.34)**
L	849.53 $^{A}_{d}$ **(±21.34)**	355.86 $^{B}_{d}$ **(±10.23)**
C	705.48 $^{A}_{d}$ **(± 16.78)**	406.95 $^{B}_{c}$ **(± 13.98)**

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

The increase in grain yield noted on soils ameliorated with SLASH and fly ash, relative to the untreated control for the different soil pH levels, was most significant for the soil with an initial pH of 4.5. This data indicates that ameliorants containing fly ash may be more effective in soils with a lower pH.

Table 3: Wheat grain yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 5.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H_20) =5.5**	
	1st season	**2nd season**
	kg ha^{-1}	**kg ha^{-1}**
S1	1805.60 $^{A}_{a}$ **(±29.89)**	597.90 $^{B}_{a}$ **(±13.24)**
S2	1611.09 $^{A}_{a}$ **(±35.67)**	463.71 $^{B}_{b}$ **(±14.01)**
FA1	877.13 $^{A}_{b}$ **(±23.45)**	597.33 $^{B}_{a}$ **(± 11.45)**
FA2	1077.55 $^{A}_{b}$ **(±23,56)**	498.19 $^{B}_{b}$ **(±10.89)**
L	648.93 $^{A}_{d}$ **(±11.23)**	366.19 $^{B}_{c}$ **(±16.78)**
C	769.71 $^{A}_{c}$ **(±14.34)**	343.86 $^{B}_{c}$ **(±14.56)**

***A** Row means with common alphabetical superscripts do not differ significantly ($P > 0.05$) (Bonferroni Test)

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

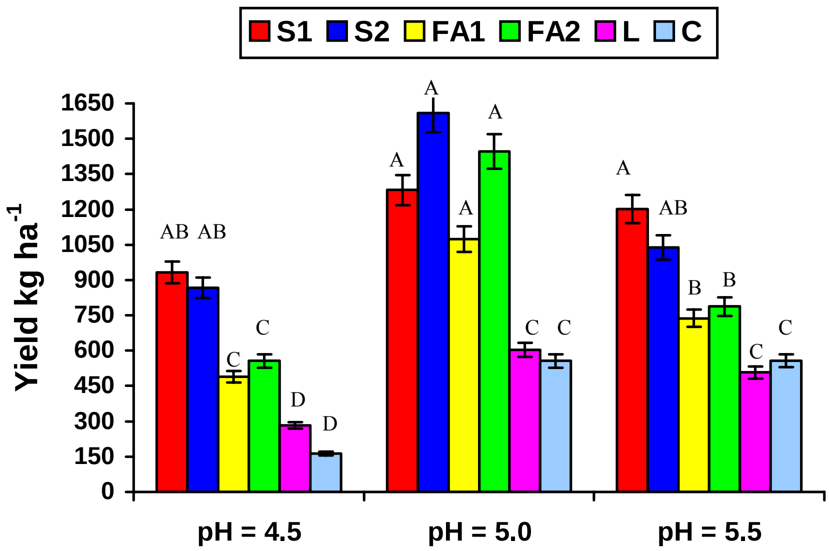

Figure 3: Mean wheat grain yield of two seasons on soils with three different pH levels.

 # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test)

With respect to the biomass production of the wheat, it is clear from Tables 4-6 and Figure 4 that the treatments containing sewage sludge, delivered 207% higher yields on average than that of the control. The trends of these results are similar to that of the grain yields, which illustrates that the higher macronutrient content of the SLASH treatments contributes significantly to the higher yields of wheat.

Table 4: Wheat DM yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 4.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH($H_2$0) =4.5**	
	1st season	**2nd season**
	kg ha^{-1}	**kg ha^{-1}**
S1	5210.5 $^{A}_{a}$ **(± 54.27)**	4403.5 $^{B}_{a}$ **(±13.81)**
S2	4564.78 $^{A}_{b}$ **(±34.45)**	3782.39 $^{B}_{b}$ **(±17.32)**
FA1	2634.79 $^{A}_{c}$ **(±21.37)**	2211.59 $^{A}_{c}$ **(±15.77)**
FA2	1253.57 $^{B}_{d}$ **(±18.64)**	1751.19 $^{A}_{c}$ **(± 23.64)**
L	116.26 $^{A}_{e}$ **(±7.57)**	172.08 $^{A}_{e}$ **(±8.33)**
C	1352.16 $^{A}_{d}$ **(±13.47)**	1250.72 $^{A}_{d}$ **(±14.78)**

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

Table 5: Wheat DM yield (kg ha^{-1}) and (±MSE) with a soil $pH_{(H2O)}$ of 5.0, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH($H_2$0) =5.0**	
	1st season	**2nd season**
	kg ha^{-1}	**kg ha^{-1}**
S1	6238.88 $^{A}_{b}$ **(±43.89)**	6079.63 $^{A}_{b}$ **(± 17.23)**
S2	8443.92 $^{A}_{a}$ **(±41.27)**	6814.64 $^{B}_{a}$ **(±14.37)**
FA1	4162.34 $^{A}_{d}$ **(±27.55)**	4054.11 $^{A}_{c}$ **(±22.13)**
FA2	5201.95 $^{A}_{c}$ **(±51.39)**	4400.65 $^{B}_{c}$ **(± 33.64)**
L	3659.83 $^{A}_{d}$ **(±32.64)**	2553.28 $^{B}_{d}$ **(±21.73)**
C	2351.24 $^{A}_{e}$ **(± 20.28)**	2117.12 $^{A}_{d}$ **(± 19.18)**

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

Similarly to the results obtained for wheat grain yield, wheat DM yield increases on SLASH and fly ash ameliorated low pH soils were more significant than the DM yield on the soil with a pH of 5.5.

Table 6: Wheat DM yield (kg ha^{-1}) and (±MSE) with a soil $pH_{(H2O)}$ of 5.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH($H_2$0) =5.5**	
	1st season	**2nd season**
	kg ha^{-1}	**kg ha^{-1}**
S1	7319.79 $^{A}{}_{b}$ **(±49.69)**	6439.93 $^{B}{}_{a}$ **(±17.24)**
S2	8705.61 $^{A}{}_{a}$ **(±29.37)**	6901.87 $^{B}{}_{a}$ **(±19.11)**
FA1	4951.34 $^{A}{}_{d}$ **(±43.75)**	2983.78 $^{B}{}_{d}$ **(± 18.25)**
FA2	5460.54 $^{A}{}_{c}$ **(±33.26)**	4486.85 $^{B}{}_{b}$ **(±23.79)**
L	3852.17 $^{A}{}_{e}$ **(±20.13)**	2617.39 $^{B}{}_{d}$ **(±26.28)**
C	3310.05 $^{B}{}_{e}$ **(±19.24)**	3770.02 $^{A}{}_{c}$ **(±30.76)**

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

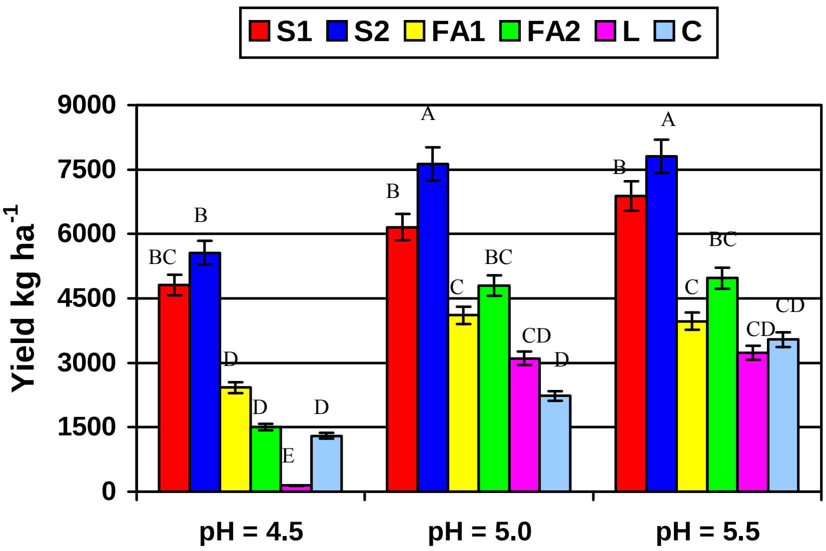

Figure 4: Mean DM production of wheat for two seasons on soils with three different pH levels.

 # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test)

3.1.2 Maize

The grain yield increases (Figure 7) obtained with maize on soils ameliorated with FA based ameliorants, can be ascribed to the improved soil pH, and a more effective uptake of macronutrients. As a result of the improved soil pH, increased yields noted for maize may also be attributed to nutrients in the soil and ameliorants being more available. Figure 8 demonstrates that maize biomass production, which is generally used for silage production, also benefited from the improved pH and certain macronutrient levels present in organic materials such as sewage sludge, especially on more acid soils.

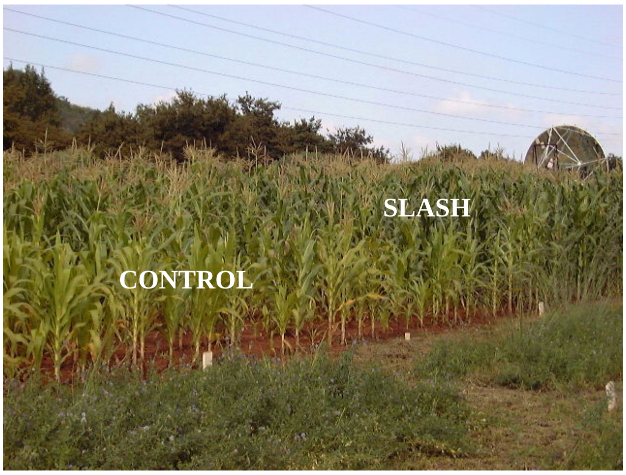

Figure 5: Maize production influenced by the different soil ameliorants.

Figure 6: Significant yields achieved for SLASH treatments.

Table 7: Maize grain yield (kg ha^{-1}) and (SE±) with a soil pH$_{(H2O)}$ of 4.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H$_2$0) =4.5**						
	kg ha^{-1}						
	R1	**R2**	**R3**	**R4**	**R5**	**Mean**	**SE**
S1	6758.91	7865.48	8282.01	7649.34	8735.11	7858.17$_b$	**±123.42**
S2	10087.23	8456.98	8588.92	7771.92	9123.45	8805.70$_a$	**±131.81**
FA1	7765.23	6784.9	7789.34	9232.65	7654.23	7845.27$_b$	**±109.89**
FA2	7652.89	8345.98	6675.43	7211.34	6310.36	7239.20$_c$	**±112.34**
L	7012.23	6709.54	8012.34	5987.34	5325.7	6609.43$_d$	**± 98.78**
C	7012.34	8876.34	7456.72	5467.89	5714.71	6905.60$_c$	**±93.24**

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

From the data presented in Tables 7-9 it can be noted that the SLASH treated soils provided significant increases in yield. These results obtained in the second growing season, without additional ameliorant inputs, emphasize the long-term residual benefits these fly ash based ameliorants can have on acidic agricultural soils.

Table 8: Maize grain yield (kg ha^{-1}) and (SE±) with a soil $pH_{(H2O)}$ of 5.0, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	pH(H_20) =5.0						
	kg ha^{-1}						
	R1	**R2**	**R3**	**R4**	**R5**	**Mean**	**SE**
S1	11456.78	10987.23	9878.77	12345.68	12377.88	11409.27_a	**±160.89**
S2	10876.43	11278.92	9834.56	10234.95	9339.49	10312.87_b	**±147.68**
FA1	9087.34	10235.67	11093.48	8234.58	8143.93	9359.00_c	**±140.80**
FA2	9245.68	8834.57	7999.89	9124.57	9867.64	9014.47_c	**±124.50**
L	8562.12	8576.23	9001.23	7896.56	7958.01	8398.83_d	**±113.45**
C	7913.90	8345.1	9001.23	7564.23	8345.69	8234.03_d	**±102.34**

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

Table 9: Maize grain yield (kg ha^{-1}) and (SE±) with a soil $pH_{(H2O)}$ of 5.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	pH(H_20) =5.5						
	kg ha^{-1}						
	R1	**R2**	**R3**	**R4**	**R5**	**Mean**	**SE**
S1	11234.57	8876.56	10786.34	10987.23	9070.30	10191.00_b	**±165.80**
S2	11758.00	9998.72	10034.45	12010.24	11098.23	10979.93_a	**±132.45**
FA1	8212.53	8657.45	10001.23	7976.45	9012.34	8772.00_c	**±123.45**
FA2	11225.50	9765.42	10923.34	9876.45	11234.78	10605.10_a	**±134.56**
L	7248.48	9001.23	6999.45	7986.54	8123.45	7871.83_d	**±99.78**
C	8308.28	7689.03	6897.34	9001.23	8342.12	8047.60_{cd}	**±107.45**

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

These significant grain yield increases, recorded for SLASH and fly ash ameliorated soils, as shown in Figure 7, can ultimately provide a higher economic return and, therefore, justify the use of such long-term soil amelioration strategies.

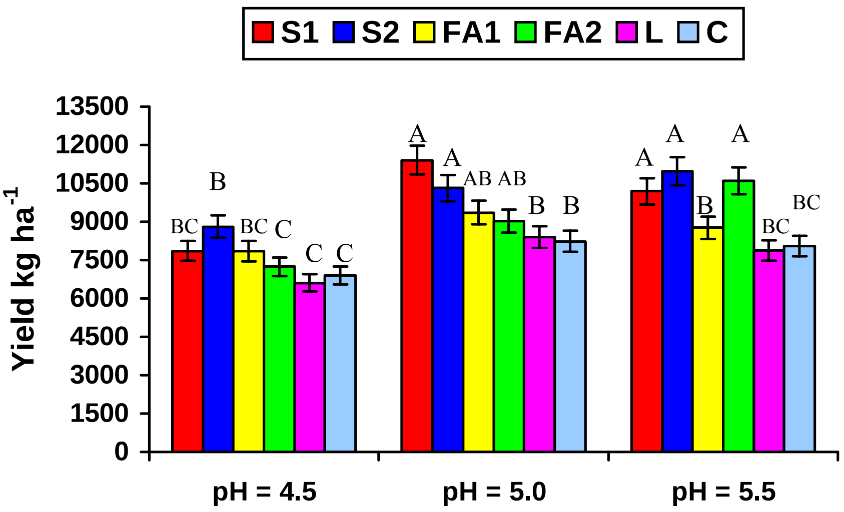

Figure 7: Mean grain production of maize on different pH level soils treated with SLASH, fly ash, lime relative to the control (no treatment) with supplemental irrigation.

. # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test

Tables 10-12 demonstrate the maize growth response s in terms of DM yields to different soil ameliorants. It is evident from these data, that SLASH treatments delivered significant increases in DM yields. These yield increases reflect the positive plant growth response, achieved on acidic soils ameliorated with fly ash based ameliorants. The yield increase differences noted between fly ash and SLASH treatments, highlights the additional benefit of the organic component of SLASH.

Table 10: Maize DM yield (kg ha^{-1}) and (SE±) with a soil $pH_{(H2O)}$ of 4.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH($H_2$0) =4.5**						
				kg ha^{-1}			
	R1	**R2**	**R3**	**R4**	**R5**	**Mean**	**SE**
S1	7685.93	8012.23	6789.32	7123.45	7889.07	7500.00$_a$	**±434.89**
S2	5567.98	4998.74	5001.98	5678.9	5314.92	5312.50$_b$	**±249.72**
FA1	4987.23	3998.56	4456.78	3786.56	3083.42	4062.51$_c$	**±327.57**
FA2	4394.57	3887.66	4908.75	3897.64	4786.43	4375.01$_c$	**±385.88**
L	5090.91	4234.5	5001.23	4213.45	4897.56	4687.53$_c$	**±358.84**
C	2816.11	2987.56	2567.98	2678.56	3012.34	2812.51$_d$	**±151.48**

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

Table 11: Maize DM yield (kg ha^{-1}) and (SE±) with a soil $pH_{(H2O)}$ of 5.0, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H$_2$0) =5.0**						
	kg ha^{-1}						
	R1	**R2**	**R3**	**R4**	**R5**	**Mean**	**SE**
S1	12023.45	11675.23	11023.48	12546.78	12106.11	11875.00 $_a$	**±431.95**
S2	12897.34	11876.23	12100.98	11899.78	12163.21	12187.51 $_a$	**±283.93**
FA1	6393.05	6987.23	7123.48	6657.89	7213.4	6875.01 $_b$	**±279.63**
FA2	13092.23	11098.87	12347.67	13098.23	14425.5	12812.51 $_a$	**±471.38**
L	3653.31	4897.61	5001.25	4432.12	5453.21	4687.51 $_c$	**±515.83**
C	6474.34	7324.56	6897.65	7895.43	7345.67	7187.53 $_b$	**±401.23**

***a** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

Table 12: Maize DM yield (kg ha^{-1}) and (SE±) with a soil $pH_{(H2O)}$ of 5.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H$_2$0) =5.5**						
	kg ha^{-1}						
	R1	**R2**	**R3**	**R4**	**R5**	**Mean**	**SE**
S1	10023.45	9987.65	8997.45	10123.01	10087.2	9843.75 $_a$	**±338.52**
S2	9001.34	8765.49	7997.34	9876.24	7328.34	8593.75 $_b$	**±744.73**
FA1	7012.57	6547.89	7123.87	6435.68	6473.79	6718.76 $_c$	**±279.57**
FA2	7862.87	9456.7	8001.23	7865.47	9001.23	8437.51 $_b$	**±633.17**
L	9654.24	9001.21	7865.46	8213.46	9015.68	8750.01 $_b$	**±568.44**
C	9101.04	9567.89	7865.43	10123.45	7098.34	8751.23 $_b$	**±401.48**

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

It is noted in Figure 8, that total DM yields were more sensitive to added fertility than grain yields, as in Figure 7.

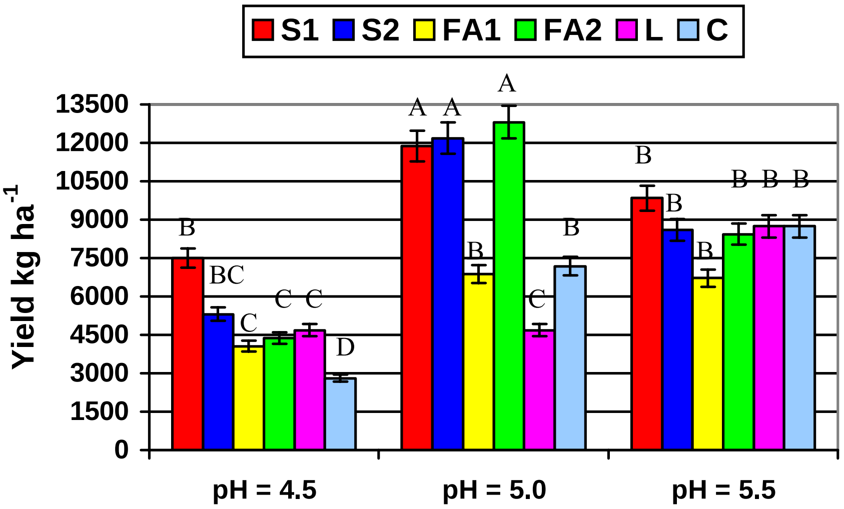

Figure 8: Mean DM production of maize on different pH level soils treated with SLASH, fly ash, lime relative to the control (no treatment) with supplemental irrigation.

. # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test

3.1.3 Lucerne

High quality forage, such as lucerne (alfalfa), is important in South Africa. This field trial simulated the use of a perennial crop with no annual soil cultivation. This study provided results that illustrated how soil ameliorants containing fly ash reacted in soils that remained physically intact for a 2-year period and how this affected crop yields.

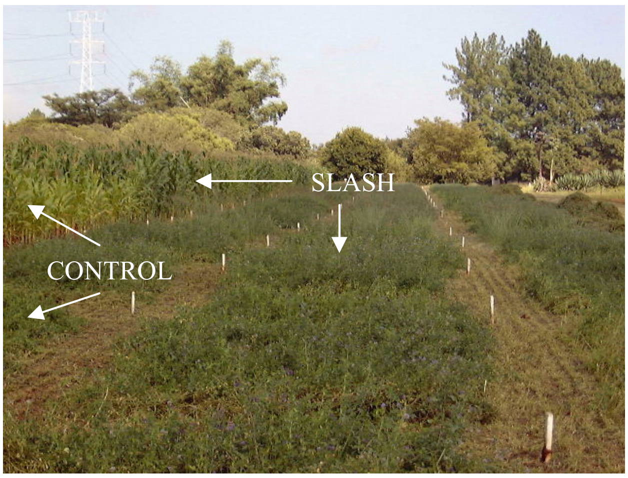

Figure 9: Lucerne (alfalfa) production as influenced by different soil ameliorants on acid soils

Table 13: Lucerne (alfalfa) DM yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 4.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	pH($H_2$0) =4.5							
	1st Harvest	2nd Harvest	3rd Harvest	Total DM 1st season	1st Harvest	2nd Harvest	3rd Harvest	Total DM 2nd season
	kg ha^{-1}							
S1	4098.78	5678.45	2701.67	12478.91^{A}_{a}	3987.67	5467.89	2132.24	11587.80^{A}_{a}
	(±102.34)	**(±89.34)**	**(± 54.78)**		**(± 86.43)**	**(± 57.98)**	**(±112.32)**	
S2	4235.68	5012.34	3739.43	12987.45^{A}_{a}	4087.45	4789.56	1324.99	10202.01^{B}_{a}
	(± 74.32)	**(± 91.23)**	**(± 43.67)**		**(± 37.89)**	**(± 99.10)**	**(± 41.29)**	
FA1	2213.34	3002.34	1771.66	6987.34^{A}_{b}	1987.67	2578.98	1239.77	5806.42^{B}_{b}
	(± 47.89)	**(± 56.98)**	**(± 32.48)**		**(± 38.94)**	**(± 58.92)**	**(± 21.39)**	
FA2	1987.67	2345.67	1431.00	5764.72^{A}_{c}	1235.67	1986.54	960.97	4183.18^{B}_{b}
	(± 59.91)	**(± 54.49)**	**(±28.93)**		**(± 41.92)**	**(± 76.32)**	**(± 29.39)**	
L	2145.61	2654.32	1764.79	6564.72^{A}_{b}	1765.98	2563.48	1351.58	5681.04^{B}_{c}
	(± 49.81)	**(± 51.29)**	**(± 39.82)**		**(± 49.87)**	**(± 55.92)**	**(± 51.01)**	
C	987.78	1234.11	564.59	2786.48^{A}_{d}	765.23	1134.58	677.07	2576.88^{A}_{c}
	(± 78.92)	**(± 68.92)**	**(± 45.92)**		**(± 76.23)**	**(± 59.82)**	**(± 61.29)**	

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

Lucerne (alfalfa), however, is very sensitive to low pH soils and production is severely reduced on acidic soils. Figure 10, clearly illustrates how the soil ameliorants containing fly ash improved the DM production. Although lucerne production was the best for the lime treatment at a pH of 5.0, the SLASH treated soils improved the yields overall, especially on the most acidic soils yielding 400% more DM ha^{-1} than the control treatment (Figure 10).

Table 14: Lucerne (alfalfa) DM yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 5.0, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	**pH(H_20) = 5.0**							
	1st Harvest	**2nd Harvest**	**3rd Harvest**	**Total DM 1st season**	**1st Harvest**	**2nd Harvest**	**3rd Harvest**	**Total DM 2nd season**
	kg ha^{-1}							
S1	4123.23 **(±123.21)**	4989.79 **(±142.23)**	3354.85 **(±165.23)**	12467.87^{A}_{a}	3876.46 **(±112.28)**	5673.49 **(±154.98)**	2366.35 **(±87.86)**	11916.30^{A}_{a}
S2	3876.46 **(±98.23)**	5786.34 **(±134.98)**	2696.12 **(±87.24)**	12358.92^{A}_{a}	3098.23 **(±79.34)**	5446.98 **(±131.87)**	2601.29 **(±79.98)**	11330.51^{B}_{a}
FA1	3786.34 **(±68.93)**	4568.93 **(±145.98)**	1521.24 **(±68.93)**	9876.51^{A}_{b}	2348.31 **(±91.29)**	3987.23 **(±139.82)**	1874.19 **(±65.23)**	8209.73^{B}_{c}
FA2	4013.23 **(±133.32)**	6012.37 **(±198.29)**	2957.65 **(±81.12)**	12983.25^{A}_{a}	3478.23 **(±82.34)**	4879.32 **(±166.23)**	2886.55 **(±85.92)**	11244.10^{B}_{a}
L	3421.87 **(±71.12)**	4011.23 **(±187.23)**	2356.13 **(±81.24)**	9789.23^{A}_{b}	2786.2 **(±90.29)**	3982.1 **(±103.49)**	2443.91 **(±71.29)**	9212.20^{A}_{b}
C	2345.63 **(±61.29)**	4234.13 **(±132.49)**	2396.25 **(±94.39)**	8976.01^{A}_{c}	2230.34 **(±88.29)**	3450.2 **(±93.29)**	2376.89 **(±80.12)**	8057.43^{B}_{c}

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

Table 15: Lucerne (alfalfa) DM yield (kg ha^{-1}) and (±SE) with a soil $pH_{(H2O)}$ of 5.5, treated with SLASH (S1 and S2), fly ash (FA1 and FA2), dolomitic lime (L) relative to the untreated control (C).

Treatments	$pH(H_20) = 5.5$							
	1st Harvest	2nd Harvest	3rd Harvest	Total DM 1st season	1st Harvest	2nd Harvest	3rd Harvest	Total DM 2nd season
	kg ha^{-1}							
S1	4598.23 (±117.89)	5239.41 (±201.28)	3285.83 (±98.29)	13123.47^{A}_{b}	3873.38 (±87.29)	4759.34 (±98.29)	3439.49 (±82.19)	12072.21^{B}_{b}
S2	5012.23 (±212.39)	4875.3 (±198.29)	4097.71 (±165.29)	13985.23^{A}_{a}	4125.98 (±132.98)	4467.98 (±172.39)	3706.15 (±101.29)	12300.11^{B}_{b}
FA1	3761.29 (±82.39)	4234.01 (±129.38)	3128.17 (±98.29)	11123.47^{A}_{c}	3319.34 (±81.10)	4002.29 (±113.29)	3312.17 (±92.39)	10633.81^{A}_{c}
FA2	4887.41 (±181.20)	5783.49 (±231.49)	3341.48 (±109.28)	14012.38^{A}_{a}	4786.35 (±178.29)	5139.24 (±211.38)	3369.12 (±103.29)	13294.71^{B}_{a}
L	3198.23 (±82.39)	3981.2 (±81.29)	3479.8 (±61.29)	10659.23^{A}_{c}	3129.46 (±72.19)	4127.83 (±83.29)	2887.32 (±62.92)	10144.61^{A}_{c}
C	2871.29 (±58.87)	3349.83 (± 77.22)	2749.9 (±52.28)	8971.02^{A}_{d}	2789.34 (±61.02)	3598.23 (±88.21)	1844.89 (±29.28)	8232.46^{A}_{d}

***A** Row means with common alphabetical superscripts do not differ significantly (P> 0.05) (Bonferroni Test)

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

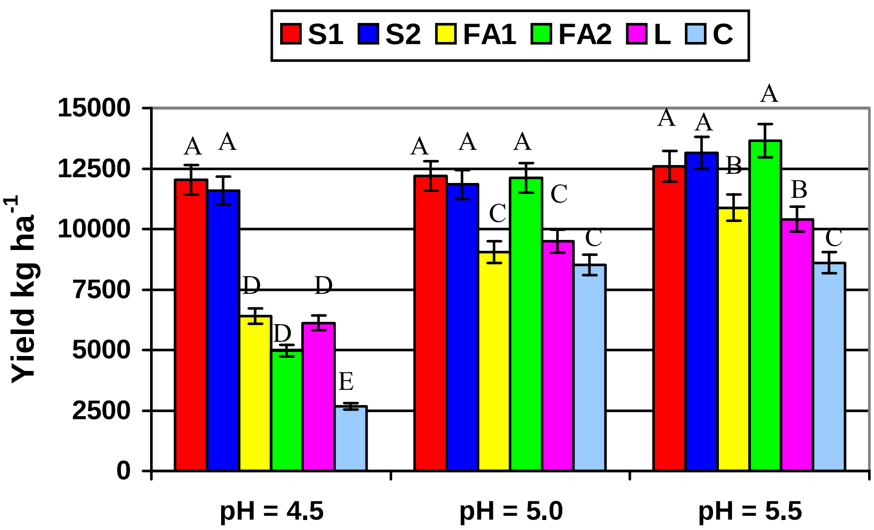

Figure 10: The influence of SLASH, fly ash and lime on the mean DM production of lucerne (alfalfa) on a soil with different pH's relative to the untreated control, with supplemental irrigation.

 # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test).

3.2 Soil chemical analyses

For optimal growth it is essential that macro- and micronutrients be supplied in desirable quantities. Inorganic fertilizers are usually the most effective and the quickest way of supplying nutrients for plant growth. These fertilizing practices are, however, not always sustainable, and new research is showing that organic materials and alkaline materials, other than lime, have beneficial soil ameliorating properties. The following data, presented in Tables 16-18, illustrates how the high-level fly ash treatment (FA2) increased the overall nutrient levels of the soil with a pH of 4.5. This trend was not, however, as prominent for the higher pH levels. The nutrient levels of the soils in Tables 16-18 clearly indicate that the treatments containing fly ash contributed significantly to these levels.

With respect to these data, it is evident that the Ca levels were significantly higher for the fly ash and fly ash containing treatments than the control and lime treatments. The Ca in the fly ash is generally supplied in the form of CaO and $CaSO_4$. It is thus important that the Mg levels of these soils are at satisfactory levels, to ensure that an acceptable Ca:Mg ratio of 4.5:1 is maintained, which is required for optimal plant production. High Ca:Mg ratios can result in either a chemical imbalance which effects other nutrients uptake, or possible phytotoxicity.

Table 16: The influence of SLASH and fly ash as alternative amendments on the mean soil chemical properties of a soil, with an initial pH of 4.5, compared to lime and control treatments, 24 months after treatment

Treatment	**P (mg kg^{-1})**	**K (mg kg $^{-1}$)**	**Ca (mg kg^{-1})**	**Mg (mg kg^{-1})**
S1	9.2_{c} **(± 0.78)**	59.7_{b} **(± 7.45)**	323.0_{c} **(±12.30)**	79.3_{b} **(±6.56)**
S2	11.3_{b} **(±0.98)**	43.3_{c} **(±5.34)**	589.7_{b} **(±15.67)**	61.7_{c} **(±4.56)**
FA1	7.2_{c} **(±0.65)**	61.7_{b} **(±5.45)**	904.3_{a} **(±21.34)**	83.0_{b} **(±6.78)**
FA2	21.7_{a} **(±1.23)**	70.0_{a} **(5.56±)**	850.0_{a} **(±18.79)**	73.0_{b} **(± 10.34)**
Lime	9.9_{c} **(±0.67)**	56.0_{b} **(±4.56)**	291.3_{c} **(±11.23)**	132.5_{a} **(±6.78)**
Control	1.3_{d} **(±0.23)**	34.7_{d} **(±5.67)**	245.7_{d} **(±8.90)**	75.7_{b} **(±6.78)**

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

The lime used in this study was dolomitic in nature, supplying high amounts of Mg to the soils. Tables 16-18, demonstrate how the initially high Mg levels of the lime treatment decreased quickly after a 24-month period in comparison to the S1 and FA1 treatments. It is noted that the fly ash and SLASH treated soils were often maintaining a better Mg content.

Table 17: The influence of SLASH and fly ash as alternative amendments on the mean soil chemical properties of a soil with an initial pH of 5.0, compared to lime and control treatments, 24 months after treatment

Treatment	P (mg kg^{-1})	K (mg kg $^{-1}$)	Ca (mg kg^{-1})	Mg (mg kg^{-1})
S1	6.1 $_b$ **(±0.65)**	74.3 $_a$ **(±6.87)**	491.0 $_c$ **(±10.98)**	118.0 $_a$ **(±9.76)**
S2	11.7 $_a$ **(±0.97)**	54.3 $_b$ **(±3.78)**	853.3 $_a$ **(± 19.06)**	75.0 $_b$ **(±5.89)**
FA1	6.4 $_b$ **(±0.52)**	63.7 $_b$ **(±5.67)**	678.3 $_b$ **(±14.56)**	102.7 $_a$ **(±8.87)**
FA2	11.4 $_a$ **(±1.40)**	53.3 $_b$ **(±5.02)**	503.7 $_c$ **(±11.68)**	86.0 $_b$ **(±7.05)**
Lime	10.8 $_a$ **(±1.80)**	53.0 $_b$ **(±6.78)**	322.8 $_d$ **(±8.98)**	99.0$_a$ **(±5.64)**
Control	7.1 $_b$ **(±0.68)**	62.7 $_b$ **(±7.88)**	342.1 $_d$ **(±6.89)**	60.7 $_c$ **(±9.87)**

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

Table 18: The influence of SLASH and fly ash as alternative amendments on soil chemical properties, of a soil with an initial pH of 5.5, compared to lime and control treatments, 24 months after treatment

Treatment	P (mg kg^{-1})	K (mg kg $^{-1}$)	Ca (mg kg^{-1})	Mg (mg kg^{-1})
S1	16.2 $_a$ (±1.45)	52.7 $_b$ (±3.89)	288.3 $_d$ (±10.76)	82.3 $_a$ (±5.78)
S2	11.2 $_b$ (±1.10)	35.7 $_c$ (±6.12)	714.0 $_a$ (±16.00)	61.3 $_b$ (±5.42)
FA1	13.0 $_b$ (±1.23)	53.7 $_b$ (± 3.21)	345.3 $_c$ (±12.45)	61.7 $_b$ (±6.08)
FA2	12.1 $_b$ (±0.92)	71.3 $_a$ (±6.01)	449.3 $_b$ (±9.89)	60.7 $_b$ (± 5.99)
Lime	9.3 $_c$ (±0.61)	49.7 $_b$ (±2.98)	274.8 $_d$ (±11.01)	79.0 $_a$ (±4.99)
Control	7.1 $_c$ (±0.67)	28.3 $_d$ (±1.78)	261.7 $_d$ (±10.54)	65.7 $_b$ (±5.13)

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

Figure 11 illustrates how the pH of soils was improved by the different treatments. The best amelioration after a 24 month period was registered by the highest fly ash application treatment, FA2, on the most acidic soil.

These results illustrate the long term effect which fly ash can have, over a period of 24 months, on acidic soils. This observation can be ascribed to the nature of the fly ash, in which the glass phase of the fly ash degrades slowly over time releasing the residual alkalinity it contains.

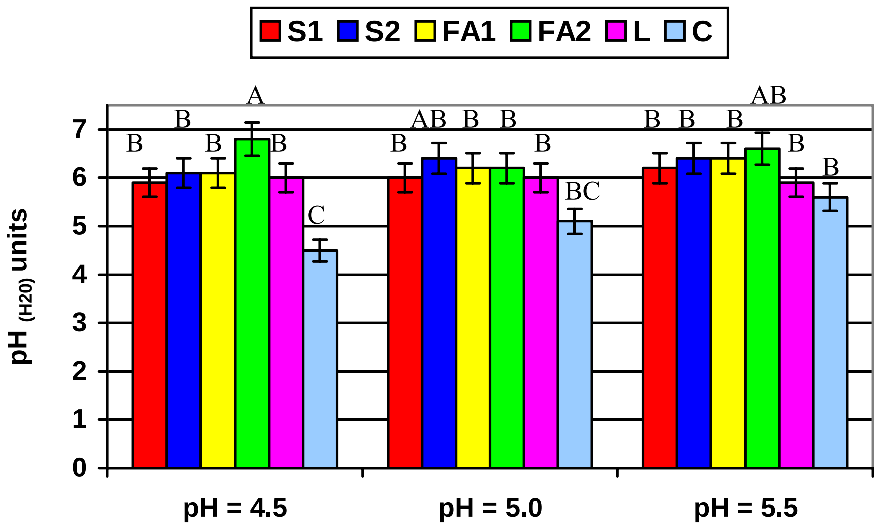

Figure 11: Influence of SLASH, fly ash and lime treatments on the pH of soil planted to two wheat crops and one maize crop, 24 months after treatment.

 # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test)

In Tables 19-21, it is evident that in the soil planted to lucerne (alfalfa), with no cultivation during the 24-month monitoring period, the nutrient status was often significantly better in amelioration treatments than in the control treatment. These results also highlight the benefits of combining alkaline materials with organic materials, to address the problem of acidic and infertile growth mediums, in a more sustainable way.

Table 19: The influence of SLASH, fly ash and lime on the nutrient levels of a soil with a $pH_{(H20)}$ of 4.5, 24 months after treatment, planted to lucerne (alfalfa).

Treatment	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
S1	9.3 $_b$ **(±0.53)**	39.0 $_c$ **(±6.98)**	629.7 $_a$ **(±12.34)**	64.7 $_b$ **(±6.03)**
S2	20.6 $_a$ **(±1.43)**	46.7 $_{bc}$ **(±2.54)**	819.7 $_a$ **(±17.98)**	61.3 $_b$ **(±5.23)**
FA1	6.2 $_c$ **(±0.61)**	59.3 $_a$ **(±5.11)**	216.3 $_b$ **(±9.54)**	53.7 $_c$ **(±5.69)**
FA2	9.3 $_b$ **(±0.67)**	50.7 $_b$ **(±3.23)**	211.7 $_b$ **(±8.89)**	58.7 $_b$ **(±5.01)**
Lime	6.8 $_c$ **(±0.71)**	63.7 $_a$ **(±5.88)**	207.3 $_b$ **(±9.01)**	77.0 $_a$ **(±6.01)**
Control	6.6 $_c$ **(±0.86)**	42.7 $_c$ **(±6.01)**	244.7 $_b$ **(±9.56)**	56.3 $_b$ **(±4.67)**

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

The overall P content of the different pH soils was significantly increased by the S2 treatment. The FA2 treatment also tended to improve the P levels of the soil (Tables 19-21). These increases can either be ascribed to the high amounts of silica in the fly ash causing the displacement of P from the soil particles at an improved soil pH, or in the case of SLASH treatments, P is added to the soil by the sewage sludge component.

Table 20: The influence of SLASH, fly ash and lime on the nutrient levels of a soil with a $pH_{(H20)}$ of 5.0, 24 months after treatment planted to lucerne (alfalfa).

Treatment	P (mg kg^{-1})	K (mg kg $^{-1}$)	Ca (mg kg^{-1})	Mg (mg kg^{-1})
S1	14.9 $_b$ **(±1.78)**	52.3 $_b$ **(± 4.55)**	591.0 $_a$ **(±11.56)**	82.3 $_b$ **(±6.01)**
S2	26.1 $_a$ **(±2.23)**	37.0 $_d$ **(±6.00)**	534.3 $_a$ **(±11.23)**	63.7 $_c$ **(±5.67)**
FA1	7.4 $_c$ **(±0.63)**	54.7 $_b$ **(±5.13)**	505.7 $_b$ **(±10.78)**	82.7 $_b$ **(±5.24)**
FA2	9.5 $_c$ **(±0.52)**	78.0 $_a$ **(± 6.75)**	330.0 $_c$ **(±12.01)**	99.3 $_b$ **(±10.23)**
Lime	5.6 $_d$ **(±0.54)**	69.0 $_a$ **(±5.98)**	475.7 $_b$ **(±10.45)**	129.7 $_a$ **(±11.01)**
Control	5.4 $_d$ **(±0.45)**	47.3 $_c$ **(±3.24)**	488.0 $_b$ **(±10.24)**	77.3 $_b$ **(±6.03)**

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

It is also evident from the results in Tables 19-21 that the Ca levels of the SLASH ameliorated soils are generally higher than some of the other soil treatments. These high Ca values can be attributed to the reactive CaO component of SLASH. The increase in Ca content of FA treated soils is as a result of the high amounts of Ca supplied by the calcium silicate compounds, a primary component of FA.

Table 21: The influence of SLASH, fly ash and lime on the nutrient levels of a soil with a $pH_{(H20)}$ of 5.5, 24 months after treatment planted to lucerne (alfalfa).

Treatment	P (mg kg^{-1})	K (mg kg $^{-1}$)	Ca (mg kg^{-1})	Mg (mg kg^{-1})
S1	16.4 $_b$ **(±1.54)**	40.3 $_d$ **(±6.56)**	591.3 $_b$ **(±12.32)**	75.3 $_b$ **(± 6.77)**
S2	20.3 $_a$ **(±1.98)**	51.0 $_c$ **(±5.99)**	713.7 $_a$ **(±15.45)**	69.3 $_c$ **(±7.12)**
FA1	7.8 $_c$ **(±0.78)**	61.3 $_b$ **(±5.43)**	596.7 $_b$ **(±13.24)**	85.7 $_b$ **(±5.46)**
FA2	9.9 $_c$ **(±0.65)**	45.3 $_c$ **(±3.01)**	555.3 $_b$ **(± 13.67)**	96.0 $_a$ **(± 8.78)**
Lime	6.7 $_d$ **(±0.93)**	71.3 $_a$ **(±6.33)**	324.0 $_c$ **(±11.34)**	117.3 $_a$ **(±9.67)**
Control	5.0 $_d$ **(±0.43)**	40.0 $_d$ **(±2.98)**	363.3 $_c$ **(±11.56)**	76.3 $_b$ **(±6.23)**

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

The available K content of soils generally increased with an increase in soil pH, with no significant amounts of K being supplied by the different ameliorants. The noted increase in K is rather as a result of increased availability due to the improved cation exchange, possibly caused by the addition of high amounts of Ca, in SLASH, fly ash and lime ameliorants. The increased K level of lime treatments, is attributed to the improved Ca:Mg ratio, caused by the addition of Mg through the application of dolomitic lime.

An optimal pH and adequate nutrient levels are essential for good crop production. Figure 12 illustrates how the different treatments affected the pH of soils, 24 months after treatment. Visual observations, as seen in Figure 2 and 5, are confirmed by the data presented in Figure 12, the lower the pH the lower the yield, therefore the soil pH plays a dominant role in efficient use of nutrients by lucerne (alfalfa).

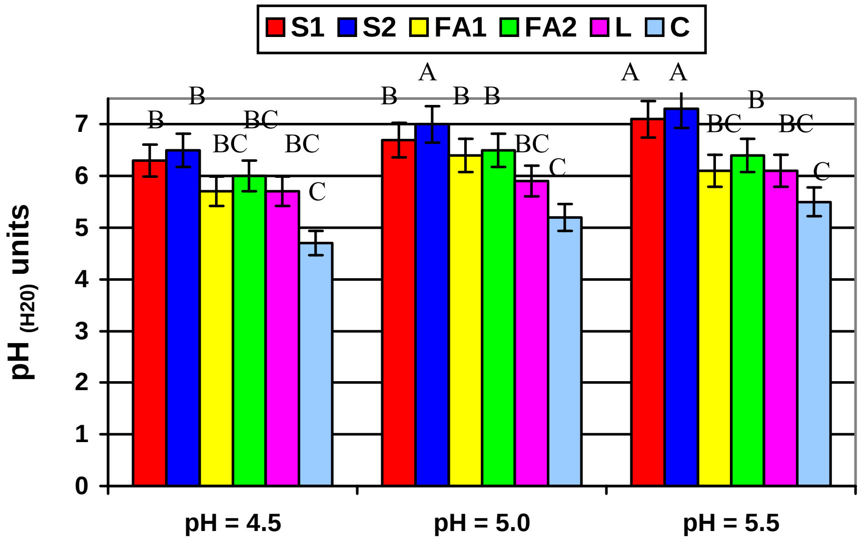

Figure 12: Influence of SLASH, fly ash and lime treatments on pH of soil planted to lucerne (alfalfa), 24 months after treatment.

 # Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test).

4. Conclusions

SLASH and fly ash definitely have agricultural potential for the amelioration of agricultural soils. For optimal crop production specific soil conditions are required for specific crops. Therefore, it is important that soil pH and other nutrient levels meet crop requirements. 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 of the three test crops, because, nutrients already present in these agricultural soils could now be used more effectively, because of unrestricted root development. Similar observations were made for wheat and maize 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.

Utilizing the micro-nutrient content and neutralizing qualities of fly ash, together with the macronutrients and organic content of sewage sludge, can provide an alternative soil ameliorant such as SLASH. Increased P values caused by the addition of SLASH to the soils, has illustrated that P can either be supplied by the organic component of SLASH and/or by the possible chemical interaction of silica in fly ash with soil P, making it available for plant uptake. It can also be concluded in this study that low levels of K recorded, highlight the need to provide K through an additional source, such as animal manures.

From previous work done on acidic agricultural soils, the residual effect of SLASH has been measured for up to three years. To date, conventional liming and fertilization had been the preferred method of ameliorating degraded soils, but this is not necessarily sustainable. Therefore, these preliminary results justify the expansion of the investigation of the use of SLASH to restore nutrient poor and acidic soils over the long term. The productive utilization of waste products is also important in ensuring a sustainable environment.

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