Crop Responses to SLASH (Mixture of Sewage Sludge, Lime and Fly Ash) as Influenced by Soil Texture, Acidity and Fertility

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ABSTRACT

The use of mixtures of sewage sludge and fly ash to pasteurise disease organisms and to provide a soil ameliorant has tremendous potential in South Africa, which has large quantities of such "waste" products. To investigate the feasibility of converting waste disposal problems into a soil beneficiation strategy, pot trials were conducted with corn, potatoes and beans to determine the effect of such a product (SLASH: sludge, quicklime and fly ash) under different soil conditions (acidic, neutral or alkaline; sandy or loam texture; optimal or sub-optimal fertilization) on crop yields and composition.

Although the corn, bean and potato crops differed in their response to soil texture, pH and fertility, some being more sensitive than others, it was a general finding that at the fertility levels used in these trials augmentation with SLASH either improved or had little or no effect on crop yields. At the rates of application employed (0-20 t/ha), SLASH had no significant negative effects. More importantly, however, no evidence was found of heavy metal translocation from the soil to the biomass. It was clear from these trials that potential soil amelioration properties, which might benefit crop, production should be studied under lower fertility conditions.

INTRODUCTION

Reynolds, Kruger and Rethman[1] found that a mixture of sewage sludge, quick lime and fly ash (SLASH), may hold considerable potential for both agricultural crops and re-vegetation projects. This product is, furthermore, "safe" with respect to potential disease organisms from the sewage. There has, however, been concern about the possible uptake of heavy metals by crops. It was, therefore, decided to conduct a series of pot trials to ascertain whether translocation of heavy metals occurred and if so to what extent does the type of soil, the rate of SLASH application and the plant species influence the results.

GROWTH OF CORN IN SLASH AMENDED SOILS

A randomized pot trial, with five replications, six levels of "SLASH" and three soil types, was conducted in a controlled environment (15°C for 12 hours and 25°C for 12 hours), using corn (*Zea mays*) as a test crop. "SLASH", consisting of a mixture of 60% sewage sludge, 10% quicklime and 30% fly ash was prepared as described[1]. The product was added to three types of soil; sandy (SS), sandy clay loam (SCL) and acidic (AS) at zero 0,125; 0,25; 0,5; 0,75 and 1% level.

The characteristics of the soils prior to a amendment are given in **Table 1**. The SCL and AS have a higher clay content than the SS. In particular the SS and AS can, due to the low P, K and Mg be regarded as nutrient deficient.

Table 1: Chemical and physical composition of experimental soils prior to the commencement of the trial

Parameter / Soil	Sandy Clay Loam (SCL)	Sandy Soil (SS)	Acidic Soil (AS)
P mg kg^{-1} (Bray I)	20	2	<2
Ca mg kg^{-1} (Amm. acetate extract)	100	102	80
K mg kg^{-1} (Amm. acetate extract)	80	28	25
Mg mg kg^{-1} (Amm. acetate extract)	78	58	50
pH	5.6	5.5	5.0
Sand fraction	75.1	85.3	77.1
Silt and clay fraction	22.6	15.0	22.4

To eliminate moisture and fertility as growth limiting factors all pots were watered on a daily basis and a complete nutrient solution was applied each week. Nutrient deficiency assessed as a function of chlorosis at the two leaf stage was evident and the level of nutrient supply was therefore increased midway through the trial. Nutrient deficiency was particularly evident in the SCL and AS at the lowest level of SLASH amendment but decreased rapidly as the level of SLASH addition increased. This was ascribed to the additional nutrients provided by the SLASH. Despite initial lower P, K and Mg, no nutrient deficiency was found in any of the SS series. In this regard the retention of these elements in clay fraction of the other soil types could be considered a factor.

Although the deficiency symptoms became less apparent as the plants grew the benefits of SLASH was still reflected in the heights of corn plants at two months of age (**Table 2**).

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Table 2: **Influence of SLASH applications on the height (cm) of corn plants growing in different soils, at two and three months of age**

SLASH (%) / Age (mths)	Sandy Soil		Sandy Clay Loam		Acidic Soil	
	2	**3**	**2**	**3**	**2**	**3**
0.000	18	49	18	40	17	52
0.125	19	58	20	42	16	43
0.250	18	57	20	45	18	35
0.500	18	64	22	47	20	52
0.750	18	61	20	52	20	64
1.000	19	67	22	64	25	81

At two months there was a positive response, in terms of plant height, to differential SLASH applications on only the SCL and AS types. At the age of three months (**Table 2**) there was a positive response to SLASH application on all three soils! This response was however evidently registered in the presence of nutrient deficiencies - as evidenced by dark red discolouration of many leaf sheaths.

It would therefore appear that in nutrient deficient soils the addition of SLASH enhances plant vitality in the initial stages of growth,

The decision to apply extra nutrients from 3 months onward might have had an influence on the response to SLASH in the final growth stages. Despite this increased level of fertilization, SLASH still had a positive influence on corn production, and the yield of corn plant components, at final harvest for the acidic soil and the sandy clay loam (**Table 3)**.

Corn plants grown on the sandy soil were taller, leafier, weighed more and produced more grain than plants growing on the other soils but did not respond significantly to amendment with SLASH. Plants on the sand clay loam exhibited a significant increase in leaf production only. Other plant components did not differ significantly. It was, however, on the acidic soil where the most significant results were registered. It was clear that, with respect to total yield, grain production and leafiness, significantly better performances were registered on 0,75 and 1,0% treatments, whilst the significantly poorer performances came from treatments where less SLASH was added. Irrespective of soil type or amendment the mass of the stems were not influenced. It would appear that the corn plant preferentially grew more leaves or yielded more grain as the fertility increased.

Table 3: Dry matter yields of corn plants (g/plant) and major yield components on three soil types as influenced by the level of SLASH applications

SLASH (%)	Total	Grain	Leaves	Stem
Biomass yield on Sandy Soil (SS)				
0.000	218 a	71 a	23 a	79 a
0.125	202 a	78 a	23 a	61 a
0.250	197 a	66 a	20 a	56 a
0.500	201 a	48 a	26 a	70 a
0.750	166 a	62 a	17 a	50 a
1.000	196 a	76 a	22 a	56 a
Biomass yield on Sandy Clay Loam Soil (SCL)				
0.000	123 a	53 a	12 a	26 a
0.125	101 a	43 a	13 ab	22 a
0.250	115 a	49 a	14 ab	26 a
0.500	138 a	56 a	15 ab	34 a
0.750	146 a	57 a	17 ab	38 a
1.000	139 a	52 a	18 b	38 a
Biomass yield on Acidic Soil (AS)				
0.000	112 ab	48 ab	12 b	23 a
0.125	147 ab	50 ab	17 ab	48 a
0.250	101 a	27 a	13 b	33 a
0.500	153 ab	63 ab	17 ab	36 a
0.750	170 ab	69 b	17 ab	43 a
1.000	185 b	84 b	19 a	42 a

Yields, within a column, with the same letter are ***not*** *significantly different*

With respect to the possible uptake of potentially toxic minerals, analyses were limited to leaf and grain samples from plants produced on acidic soil at zero and 1% amendment. These results were compared with the standard acceptable levels for such minerals[2] to determine whether there were any problem areas requiring more in-depth research (**Table 4**).

Table 4: Elemental concentration in corn components (μg/g) grown in an acidic soil at zero and 1% SLASH addition

Element	0% SLASH		1% SLASH		Typical Values
	Leaf	Grain	Leaf	Grain	
Cd	1.2	1.7	1.9	1.0	0.01 - 14.2
Co	5.4	nd	0.9	nd	0.1 - 100
Cr	nd	nd	nd	nd	0.02 - 0.2
Cu	11.7	8.3	11.7	5.3	5 - 1500
Mo	nd	nd	nd	nd	0.3 - 5.0
Ni	3.2	nd	0.6	2.4	0.1 - 3.7
Pb	1.6	nd	0.8	nd	0.1 - 10.0
Zn	25	24	21	24	22 - 73
Mn	252	19	156	13	15 - 500
Bi	1.3	0.7	0.9	0.3	0.02 - 11
Al	811	101	159	21	± 200
Fe	1531	144	230	138	18 - 1000
Sr	17.1	0.6	12.0	0.2	10 - 1500
As	20.8	20.1	16.3	6.3	0.1 - 1000

nd denotes not detected

These analyses indicate that only in the case of Cd in leaf material and Ni in the grain was the elemental concentration marginally higher in the corn plants grown in the 1% amended acidic soil than in unheated soil. In both instances levels are within the range encountered in corn plants[2]. The concentration of all the other elements analysed were either similar (Zn) or lower in the 1% SLASH amended soil than their counterparts grown in the untreated acidic soil. Chromium and Mo were not detected in the leaves or grain.

The decrease in Al concentration was ascribed primarily to the increase in pH from 6.2 to 6.9 upon the addition of SLASH.

Analysis of the soils after harvesting showed that the Ca and Mg level available to the plants had increased from 43 to 84 and 7 to 14 μg/g respectively. Potassium decreased from 38 to 34 μg/g.

GROWTH OF BEANS AND POTATOES IN SLASH AMENDED SOILS

Beans and potatoes were used as test crops in pot trials with only two soil types (SS and SCL). A range of pH conditions was created by adding lime at two different levels to these soils. On the SS this resulted in pH(H_2O) values of 7.1, 7.7 and 8.3 respectively, while on the SCL the pH(H_2O) values were 5.3, 6.1 and 7.3 respectively. Two levels of fertility were also applied prior to planting. These amounted to 250mg N, 15mg P and 35mg K/kg soil on the SCL and 250mg N, 25mg P and 40mg K/kg soil on the SS at the f_1 level. At the f_2 level these dressings were doubled. Superimposed on these factors were four levels of "SLASH", 0, 5, 10 and 20 t dry material/ha.

The beans (cultivar MKUZI) and potatoes (cultivar BP1) were planted in the treated substrates and raised in a hothouse at temperatures of 17°C and 25°C and 12°C and 20°C respectively to stimulate typical night and day temperatures in their growing season. Irrigation was applied twice daily to minimize any possible effect of moisture stress. Nine weeks after planting half of the bean plants were harvested. The green beans were separated into stem, leaf and pod components and dried to determine yields. This dried material was then milled and analysed to determine the concentration of different elements. At maturity (13 weeks after planting) the remaining bean plants were harvested, separated into components, and dry material yield determined.

Green beans: The total plant yield at the green bean harvest stage, are presented in **Table 5.** Total average yields were markedly better on the SS (46%) than on the SCL. As this was unlikely to be as a result of fertility (even the low fertility treatment (f_1) received a relatively heavy fertilization), or moisture, soil pH was examined, as beans are generally sensitive to this factor. On the SS average pH values were high (from 7.5 - 8.3) whilst on the SCL it ranged from 5.4 - 7.1. It would appear that beans respond positively up to a pH of 7.1 - 7.5 but that, in more alkaline soils, a slight depression in yields might be expected.

Table 5: Total dry matter yield of bean plants harvested at the green bean stage (g/plant)

		Sandy Soil (SS)				Sandy Clay Loam (SCL)			
Lime Level	**SLASH t/ha**	**pH**	**f_1**	**f_2**	**Mean**	**pH**	**f_1**	**f_2**	**Mean**
P_1	0	7.1	10.6	16.3	13.45	5.3	3.4	3.3	3.35
	5	7.3	8.4	11.5	9.95	5.3	4.1	6.5	5.30
	10	7.8	11.6	12.6	12.10	5.3	4.6	7.7	6.15
	20	7.8	11.2	8.9	10.05	5.8	8.2	11.2	9.70
Mean		7.5	10.45	12.33	(11.39)	5.4	5.08	7.18	(6.13)
P_2	0	7.7	11.6	9.1	10.35	6.1	5.0	6.4	5.70
	5	8.2	10.5	11.3	10.90	6.3	9.7	7.2	8.50
	10	8.0	10.0	10.5	10.25	6.2	9.3	4.3	6.80
	20	8.2	10.8	8.1	9.45	6.2	7.2	11.3	9.25
Mean		8.0	10.73	9.75	(10.24)	6.2	7.80	7.33	(7.56)
P_3	0	8.3	9.4	9.2	9.30	7.3	7.2	7.9	7.55
	5	8.4	8.8	10.7	9.75	6.9	6.2	9.9	8.05
	10	8.4	8.9	9.0	8.95	7.1	4.7	10.9	7.80
	20	8.2	9.5	13.6	11.55	7.3	7.2	8.9	8.05
Mean		8.3	9.15	10.63	(9.89)	7.1	6.33	9.40	(7.86)

f_1 and f_2 are fertility treatments (see text)

The effect of liming and SLASH on soil pH is important since on both soils liming and SLASH addition increased pH. Depending therefore, on the initial status of the soil and the desired condition for specific crops, either, or both, of these soil ameliorants may be used to achieve a desired pH status.

On SS which had a high initial pH the addition of SLASH appeared to have little or no effect on the total biomass yielded. On the SCL soil however where the pH was acidic plant yield increased along with the addition of SLASH. Increasing the level of fertilisation from f_1 to f_2 seemed to improve the biomass yield at the P_1 and P_3 level of lime addition but not at P_2. This cannot be explained.

For the vegetable producer the critical factor would be the influence of treatment on the production of the green bean itself. These results are reflected in **Table 6.**

Table 6: Yield of green beans expressed as g dry matter/plant

		Sandy Soil (SS)			Sandy Clay Loam (SCL)		
Lime Level	**SLASH t/ha**	**f_1**	**f_2**	**Mean**	**f_1**	**f_2**	**Mean**
P_1	0	3.9	8.6	6.3	0.5	1.2	0.9
	5	4.6	2.9	3.8	3.2	1.2	2.2
	10	7.2	5.3	6.3	2.1	0.7	1.4
	20	6.3	4.5	5.4	2.9	2.5	2.7
Mean		5.5	5.3	5.5	2.2	1.4	1.8
P_2	0	5.4	4.3	4.9	2.0	1.1	1.6
	5	5.6	6.7	6.2	4.9	2.9	3.9
	10	7.1	5.2	6.2	3.3	0.5	1.9
	20	5.2	3.6	4.4	3.0	6.0	4.5
Mean		5.8	5.0	5.4	3.3	2.6	3.0
P_3	0	4.8	4.0	4.4	3.8	4.7	4.3
	5	5.1	6.0	5.6	3.1	4.2	3.7
	10	5.2	4.2	4.7	2.9	4.7	3.8
	20	5.6	7.7	6.7	4.3	3.3	3.8
Mean		5.2	5.5	5.3	3.5	4.2	3.9

As with total plant yields, the yield of green beans was markedly higher on the SS (5.4 g dried green bean/plant) than on the SCL (2.9 g). The effect of liming was, once again, particularly evident on the more acidic SCL where an increase in the pH from 5.4 to 7.1 resulted in a yield increase of 117%, from 1.8 to 3.9 g dried green beans per plant. On the SS, where high pH's were predominant, liming had no beneficial effect on pod yields. The effect of SLASH was non-significant and no clear trends, on either of the soils, were observed.

Dry beans: The alternative to green bean production is to allow the plant to grow a full cycle and harvest the dry beans. The yield of dry bean pods are presented in **Table 7.** As in **Tables 5 and 6,** the major effects were the differences between soils and pH levels. The high pH's on the SS consistently gave higher yields, the low pH's on the SCL registered very poor yields (only 2.9 g dry matter/plant at pH of 5.4). While liming definitely improved yields (2.9; 4.6; 4.9) on the latter soil the best treatments on this soil were still considerably poorer than those on the SS.

Table 7: Pod yields (g dry matter/plant) at the dry bean harvest stage

		Sandy Soil (SS)			Sandy Clay Loam (SCL)		
Lime Level	**SLASH t/ha**	**f_1**	**f_2**	**Mean**	**f_1**	**f_2**	**Mean**
P_1	0	6.8	8.1	7.5	0.1	2.5	1.3
	5	11.4	9.4	10.4	1.2	3.5	2.4
	10	6.5	8.0	7.3	3.6	1.8	2.7
	20	7.0	6.3	6.7	6.7	3.7	5.2
Mean		7.9	8.0	8.0	2.9	2.9	2.9
P_2	0	7.9	8.3	8.1	6.8	1.5	4.1
	5	7.5	10.1	8.8	4.6	5.9	5.3
	10	7.9	11.9	9.9	4.1	1.8	2.9
	20	7.7	11.9	9.8	5.0	7.6	6.3
Mean		7.8	10.5	9.1	5.1	4.2	4.6
P_3	0	6.8	9.3	8.1	5.6	3.8	4.7
	5	4.7	8.2	6.4	4.7	6.4	5.6
	10	6.4	9.1	7.7	3.1	4.9	4.0
	20	8.7	11.9	10.3	3.5	6.9	5.2
Mean		6.6	9.6	8.1	4.2	5.5	4.9

Mineral concentrations in beans: A major consideration, when assessing the use of SLASH, is the possible uptake of toxic elements by plants.

An in-depth evaluation of the translocation of trace elements from the soil to the plant biomass is beyond the scope of this paper. By way of illustration however the effect of SLASH addition to the original soil without any lime amendment (P_1) can be considered as typical. In **Table 8** the data is presented for the two types of soil.

Table 8: The concentration of selected trace elements (μg/g) in leaves and pods of green beans grown in sandy soil and sandy clay loam with different levels of SLASH

SLASH t/ha / Element	Leaves					Pods				
	B	**Cd**	**Ni**	**Zn**	**Mn**	**B**	**Cd**	**Ni**	**Zn**	**Mn**
Sandy Soil (SS)										
0	120	1.2	33	63	220	26	1.3	13.5	36	25
5	113	0.5	22	58	95	26	1.5	3.7	18	14
10	128	2.7	22	60	110	25	1.8	1.8	10	12
20	144	1.6	23	37	75	22	1.1	0.4	10	10
Mean	127	1.5	25	55	125	24	1.4	4.8	19	15
Sandy Clay Loam (SCL)										
0	9.2	0.4	2.3	4.0	53	72	nd	nd	4.6	51
5	7.9	0.1	1.8	0.4	164	47	nd	nd	1.8	25
10	8.0	0.3	2.5	1.7	60	52	nd	nd	11.4	70
20	8.8	0.5	2.3	2.1	28	67	nd	nd	4.3	55
Mean	8.5	0.3	2.2	2.0	76	60	nd	nd	5.5	52

These figures indicate that increased loadings of SLASH do not necessarily lead to higher elemental concentration in the biomass. More interesting is the partition of the elements between the different parts of the plant which, in some instances, is also soil specific. For example in this test B accumulated in the leaves when the beans were grown in SS but in the pods when grown in SCL.

It is known that pH is one of the major factors influencing the uptake of elements from the soil to the plant. For SS the addition of SLASH increased the pH from 7.1 to 7.8 and in the case of SCL it increased from 5.3 to 5.8 (see **Table 5**). This difference in pH did not seem to influence the translocation of elements except perhaps for Zn and Mn in the pods.

The concomitant effect of the addition of both lime and SLASH on the pH and hence the translocation of elements is shown in **Table 9**. From these results it is clear that no generalisations can be made as there is considerable variability in the results. It must also be noted that the elemental concentration in plants grown on the SS, which had a much higher pH than the SCL, were much higher. Explanations for concentrations in plant material must, therefore, not be limited to pH and soil ameliorants only, but should also take factors such as soil texture, inherent soil analyses (especially the clay content) and even crop components, into consideration.

Table 9: Elemental concentrations in the leaves and pods of beans harvested at the green bean stage, as influenced by pH on different soils, all elemental concentration (μg/g)

Element / pH	Sandy Soil						Sandy Clay Loam					
	Leaves			Pods			Leaves			Pods		
	7.5	8.0	8.3	7.5	8.0	8.3	5.4	6.2	7.1	5.4	6.2	7.1
B	127	58	89	25	36	24	9	10	6	60	49	39
Cd	1.5	0.5	0.2	1.4	1.1	0.1	0.3	0.1	0.2	nd	nd	nd
Cr	nd	nd	nd	1.1	nd	nd	0.1	nd	0.1	nd	nd	nd
Ni	25	7	nd	5	41	34	2.2	1.7	1.5	nd	nd	nd
Pb	nd	nd	nd	22	1	12	0.8	1.7	0.8	nd	nd	nd
Zn	55	26	nd	19	36	14	2	23	2	6	12	19
Mn	125	58	44	15	41	9	76	45	10	52	51	30

Potatoes: The dry matter yields of potato tubers are presented in **Table 10.** Unlike beans, which were very sensitive to soil type, potatoes yielded only marginally better on the SS than on the SCL. Potatoes also responded to higher levels of fertility, with the differences between fertility levels being much greater than the differences between soil types. Potatoes were not as sensitive to pH. On the SCL-soil response to liming was limited. On the neutral SS additional liming even depressed yields. On the basis of these results it can be concluded that under these conditions SLASH had no effect on tuber yields.

Table 10: Influence of soil type, pH, fertility level and SLASH on tuber yields (g/pot)

		Sandy Soil (SS)				Sandy Clay Loam (SCL)			
Lime Level	SLASH t/ha	pH	f_1	f_2	Mean	pH	f_1	f_2	Mean
P_1	0	7.1	45	58	51	5.3	35	33	34
	5	7.3	45	48	47	5.3	40	44	42
	10	7.8	43	51	47	5.3	39	45	42
	20	7.8	46	56	51	5.8	37	50	43
Mean		7.5	45	53	49	5.4	38	43	40
P_2	0	7.7	45	57	51	6.1	37	45	41
	5	8.2	43	47	46	6.3	38	46	42
	10	8.0	40	48	44	6.2	37	43	40
	20	8.2	44	55	50	6.2	36	51	43
Mean		8.0	43	52	47	6.2	37	46	42
P_3	0	8.3	36	51	44	7.3	38	52	44
	5	8.4	37	52	45	6.9	46	48	47
	10	8.3	44	52	48	7.1	38	43	41
	20	8.2	32	49	40	7.3	40	48	44
Mean		8.3	37	51	44	7.1	41	48	44

f_1 and f_2 are fertility treatments (see text)

Elemental analysis of the tubers showed high variability which mitigated against in-depth interpretation. Discussion is, therefore, limited to some main effects. The most notable finding was that although cadmium, chromium, nickel and lead were present in bean plants there were no traces of these elements in potato tubers. Boron, zinc and manganese were all found in lower concentrations where SLASH was used, indicating that factors such as soil texture, soil pH and fertilization all had a stronger (but not always consequential) influence on uptake of elements than the use of SLASH.

CONCLUSIONS

In the case of corn where lower fertility prevailed, the addition of SLASH enhanced early growth. In acidic soils the yield increased along with the addition of SLASH. The use of a soil ameliorant based on sewage sludge and ash has agricultural potential. Where beans and potatoes were used as test crops, it was abundantly clear that soil type, liming and - in the case of potatoes - level of fertilization were all more important than the level of SLASH application. Where fertility was limiting SLASH did have a beneficial effect, although it is unclear whether this should be ascribed to a fertility effect or to the effect that it has on pH.

Under experimental conditions employed it is evident that SLASH has no negative effect on the uptake of potentially toxic elements. This was a particular concern when the work was initiated. Future trials with such a product should probably place greater emphasis on the positive aspects of using it as a partial replacement for lime and/or fertilizer, especially where acid and infertile soil conditions prevail. Recommendations in this respect should also have taken cognisance of specific requirements and sensitivities of different crops and the chemical status of soils, sludge and fly ash.

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