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The Use of a Soil Ameliorant based on Fly ash and Sewage Sludge

Wayne F. Truter [1], Norman F.G. Rethman [1], Kelley A. Reynolds [2] and Richard A. Kruger [3]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria , 0002, South Africa
[2] Eskom Technology, Private Bag 40175, Cleveland, 2022, South Africa
[3] Ash Resources, PO Box 3017, Randburg, 2125, South Africa

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ABSTRACT

Due to limited prime agricultural land, South Africa is heavily reliant on the use of acidic and nutrient deficient soils to meet the needs for increased food production.

Environmental legislation has, however, placed restrictions on the application of sewage sludge to agricultural land. The prime concern being the accumulation of heavy metals and risk of disease. Previous research has, however, indicated that sewage sludge can be pasteurized and the toxic metals present in the sewage sludge immobilized, when it is treated with a mixture of Class F fly ash and lime. This product (SLASH) has been shown to have significant amelioration properties when applied to acidic soils, resulting in enhanced crop productivity.

This work describes the beneficial effects of SLASH incorporation into soils, in comparison to the individual ingredient treatments (sludge, fly ash and lime). It is shown that SLASH incorporation at 2.5%, 5%, 7.5% and 10% of the soil volume, provides prolonged growth enhancement and yield increases over several cropping cycles. Positive effects on pH, Ca, Mg, and P were recorded, and two possible translocated heavy metals (Ni, Cd) and the important micro-nutrient (B), which is toxic at high levels, are not translocated in significant amounts. SLASH definitely has beneficial effects on both soils and crops!

INTRODUCTION

Previous work by Reynolds *et al* (1999) to determine the feasibility of converting waste disposal problems into a soil benefication strategy has proven true. The co-utilization of fly ash and sewage sludge with added lime has delivered a product termed SLASH (that contains 60 % fly ash, 30 % sewage sludge and 10 % lime on a dry matter basis) which has beneficial soil ameliorant effects. Two problems experienced in the past were that, sewage sludge contains heavy metals and pathogens. As a result it's use is restricted for agricultural land application. Secondly, fly ash production in countries which rely on coal for energy, presents a major problem to those responsible for the consequences and implications of disposing of such "waste" products. These problems emphasize the need for co-utilization of wastes and thereby find other possible strategies for the safe disposal of such waste products. Nutrient poor and acidic soils in South Africa are becoming more prevalent as time goes by. Many farmers require alternatives to the high priced conventional methods in use.

Rethman *et al* (1999) conducted pot trials with corn , potatoes and beans to determine how SLASH could be used and how biomass and soil chemical properties could be influenced by SLASH. Other matters of concern were the possibility of translocation of heavy metals to the different plant components. Soil type , rate of SLASH application and plant species were identified as being important in this regard. It was concluded that wherever fertility was limiting , SLASH had a beneficial effect.[3] At the low application rates used in these pot trials , it was found that no heavy metals had been translocated. The need for trials arose to determine if any potentially toxic elements would be translocated at higher SLASH application rates. The question of how higher application rates would effect soil chemical properties and influence biomass production was also to be considered .

Subsequent trials with higher application rates (up to 30 % of soil volume) were conducted, and it was concluded that rates at 30% were too high, compared to the 5-10% treatments[4]. Once this was established, a comparison of SLASH applications at different levels with the individual components making up SLASH needed to be made. Emphasis would be on long term residual effects and heavy metal translocation in grain and cereal crops.

SLASH has also had marked beneficial effects on productivity and root development of forages for as long as two years after initial treatment.[7] While this study emphasized the potential of such soil amelioration for improved forage productivity and root development. It also resulted in considerable interest in the potential use of such waste products to re-vegetate and restore productivity of disturbed soils.[5]

MATERIALS AND METHODS

Simple raised beds, each with a surface area of $0.6m^2$ and an effective soil depth of 30 cm, were used in a randomized blocks design with eight treatments and five replications, to evaluate the effect over several cropping cycles. The eight treatments were applied to virgin soil in March 1999. Treatments were SLASH at, 0, 2.5, 5, 7.5, 10, % of the soil volume, fly ash at 3 % - , sewage sludge at 1.5 %- and lime at 0.5 % of the soil volume. Raised beds were watered regularly to eliminate moisture as a limiting factor. Crops in these raised beds did not receive any supplementary inorganic fertilizers, to enhance plant growth.

PLANT MEASUREMENTS

These raised beds were initially planted to cut flowers and vegetables in the autumn of 1999 to determine responses [6]. The positive results obtained led to a series of grain and cereal crops being planted in these beds over the following summer and winter growing seasons to assess heavy metal translocation, biomass production and the long term residual effect of the treatments .

Maize was to be the first grain test crop (second cropping) to be monitored in the summer of 1999/2000. Once the seeds had germinated , a seedling count was conducted, to determine if there was any effect on the germination of seeds. The beds were initially planted with twenty seeds which were thinned to ten once the seedling count had been completed. Of these ten, plants were harvested when the best treatment reached 20 cm and 40 cm to measure any difference in growth rate at those early stages . The plants harvested were weighed to measure wet mass and the material was then dried at 65^{o}C for 48 hours to determine total dry matter production.

Once the remaining plants reached the cob formation stage, the leaves adjacent to the cob were removed and washed with distilled water to remove any dust or particles which might hinder accurate analysis. These leaves were then analyzed for Ni, Cd and the B.

When the plants reached full maturity, the cobs were harvested to measure the amount of grain produced and the remaining plant harvested to determine biomass production at maturity. The grain harvested , was also analyzed for Ni , Cd and B.

Once the maize had been harvested , these beds were planted to *Triticale* (third cropping) for the second winter growing season.. Biomass production of this crop was measured using three consecutive harvests when plants had reached a height of +/- 40 cm. The harvested material was weighed to determine wet mass, and was then dried at 65^{o}C for 48 hours to obtain the dry matter (DM) yield of the individual treatments.

Once this crop had completed it's growth cycle , these beds where then planted to *Sorghum* spp. (fourth cropping) in the second summer growing season. The same measurements were taken for *Sorghum* spp. as for *Triticale*. This multiple cropping was to determine the residual effect of SLASH.

SOIL MEASUREMENTS

Before the maize was planted (+/- 6 months after the initial application of treatments) the soil was analyzed for P, K, Mg, Ca, and pH to give background information of the soil. Once the crops had been harvested the soil was analyzed again to assess any changes in soil chemical properties.

RESULTS AND DISCUSSION

MAIZE GROWTH RESPONSE TO VARIOUS TREATMENTS

At 20 cm height, treatment effects could be clearly seen.(**Table 1).** The sewage sludge treatment was by far the best . However, untreated sewage sludge is not recommended for agricultural use, because of it's pathogenicity and heavy metal content. SLASH, fly ash and lime treatment were not significantly better than the control.

Table1: Influence of sludge, lime and ash (both separately and in combination – SLASH) on dry matter production (excluding grain) of maize at different growth stages. (Relative mass (grams))

Treatments	1st Harvest (20 cm)	2nd Harvest (40 cm)	3rd Harvest (Mature)
	(g)	(g)	(g)
Control (T1)	0.92	12.3	439.20
2.5% SLASH (T2)	1.36	14.94	741.80
5% SLASH (T3)	1.42	16.18	811.60
7.5% SLASH (T4)	1.62	14.74	878.45
10 % SLASH (T5)	1.14	14.06	881.75
Sewage Sludge (T6)	15.34	20.00	1049.85
Fly ash (T7)	1.26	13.00	533.85
Lime (T8)	1.02	12.54	492.75

At the 40 cm stage the SLASH treatments were performing slightly better than the control, fly ash and lime treatments, but not significantly. The differences between these treatments and the sewage sludge was, however, smaller.

Plants harvested at maturity (**Table 1)** illustrates how the SLASH treatments have benefited plant growth by as much as 200 %. The sludge treatment yielded 239 % more than the control.

Grain yields **(Table 2**) indicate similar trends as for the plant material. SLASH treatments gave up to 333 % better yields than the control while the sludge treatment gave 565 % better yields. The risk of heavy metal translocation from sludge will depend on the source of sludge. In contrast, the SLASH product has delivered results which ensure the immobilization of heavy metals and a safer product to handle and apply in terms of possible disease organisms.

Table 2: Maize grain yields of treated soils (Relative mass – (g)).

Treatment	Grain Yield (Relative Mass (g))
Control	309.45
2.5 % SLASH	713.52
5.0 % SLASH	707.50
7.5 % SLASH	844.37
10.0 % SLASH	1025.98
Sewage Sludge	1718.33
Fly ash	348.10
Lime	451.83

With respect to heavy metals analyses of leaves the results obtained were compared to the limits set by law. [1] **(Table 3)**

Table 3: The mean elemental concentration of leaves of mature maize plants (mg kg^{-1})

Treatments	Ni (mg kg^{-1})	Cd(mg kg^{-1})	B(mg kg^{-1})
Control	2.908	2.59	27.96
5% SLASH	4.77	3.504	45.71
10% SLASH	3.926	3.192	38.66
3% SLUDGE	3.302	3.318	25.05
Limits set by law*	***400***	***15.7***	***80***

* **Kabata- Pendias A and Pendias H (1984)**

All heavy metal analyses were below the limits.[1] These analyses indicate that all treatments had insignificant levels of Ni an Cd which, were well below toxic levels. SLASH treatments, however, had a higher B concentration, and this can possibly be ascribed to the contribution of B from the fly ash.

The concern about heavy metal (Ni and Cd) translocation was not supported by the leaf analyses but the concern about possible heavy metal translocation(Ni and Cd) to the grain, which is the most important plant component still prevailed. Analysis of the grain indicated that there had been some translocation but this was evident in all treatments including the control.**(Table 4)**. The sludge's Ni and Cd content was similar to that of the SLASH treatments and control. Values were well below limits set by law. The B concentration differed from what was found in the leaf analysis, with considerably less B in the grain than in the leaves.

Table 4:The mean elemental concentration of maize grain (mg kg^{-1})

Treatments	Ni (mg kg^{-1})	Cd(mg kg^{-1})	B(mg kg^{-1})
Control	106.845	9.929	26.605
5% SLASH	102.797	9.361	27.269
10% SLASH	104.450	9.815	29.263
3% SLUDGE	104.135	9.819	25.613
Limits set by law	***400***	***15.7***	***80***

*** Kabata- Pendias A and Pendias H (1984)**

TRITICALE GROWTH RESPONSE

The total plant yields of three harvests of *Triticale* are presented in **Table 5.**

Table 5: Dry Matter (DM) g 0.6 m^{-2} production of *Triticale* over 120 days

Treatment	1st Harvest	2nd Harvest	3rd Harvest	Total DM
	(g)	(g)	(g)	(g)
Control (T1)	15.84	15.58	28.6	60.00
2.5% SLASH (T2)	25.06	22.28	35.00	82.34
5% SLASH (T3)	30.76	27.70	45.16	103.62
7.5% SLASH (T4)	32.54	31.08	46.46	110.08
10 % SLASH (T5)	45.76	44.92	53.10	143.78
Sewage Sludge (T6)	80.72	63.54	76.66	220.92
Fly ash (T7)	21.24	21.58	31.00	73.82
Lime (T8)	19.86	18.08	29.88	67.82

The sewage sludge still delivered a 370 % better DM yield than the control, while the highest SLASH treatment had 240 % better DM yield. The fly ash contributed only slightly to a better yield but this was not significant. This is understandable because of a low organic matter content and deficiency in essential macro-nutrient content in the fly ash.

An interesting result was **(Table 6)** the lower biomass production of the sludge relative to the SLASH treatments with Sorghum in the fourth crop cycle. This could possibly be attributed to an eventual start of depletion of fertility on the sewage sludge treatments. In this fourth cropping cycle, the highest SLASH treatment gave a 215 % better yield while the sludge only gave a 170 % better yield.

<u>Table 6: Dry Matter (DM) g 0.6 m^{-2} production of *Sorghum* spp. over 180 days</u>

Treatment	1st Harvest	2nd Harvest	3rd Harvest	Total DM
Control (T1)	48.72	45.26	46.80	140.78
2.5% SLASH (T2)	87.24	65.44	60.20	212.88
5% SLASH (T3)	90.42	69.78	65.72	225.92
7.5% SLASH (T4)	102.48	82.34	78.18	263.00
10 % SLASH (T5)	130.40	91.26	92.26	303.92
Sewage Sludge (T6)	71.24	81.82	89.32	242.28
Fly ash (T7)	73.08	56.40	52.56	182.04
Lime (T8)	47.46	45.64	46.74	139.84

SOIL ANALYSIS

The soil analysis illustrates the potential ameliorating characteristics of the SLASH in soils. The improvement of pH values are illustrated in **Table 7**.

<u>Table 7: Increase / Decrease of pH units relative to control</u>

Treatment	@ 12 months	@ 18 months
Control	0	0
5 % SLASH	**1.5**	**1.1**
10% SLASH	**1.7**	**1.2**
Sewage Sludge	-0.85	-0.95
Fly ash	0.9	0.75
Lime	0.7	0.55

SLASH treatments resulted in an improvement in pH values of the soils relative to the control. The sewage sludge in contrast had an acidifying effect, lowering the pH.

Sewage sludge and SLASH treatments are evidently good sources of Ca, P and Mg . This emphasizes the value of such organic material in such a product as SLASH to ultimately contribute to the plant growth enhancement ability. The fly ash too, has, a reasonable amount of P. The fly ash treatment has 0.3 % P in total , and when considering these figures in plant production you are referring to expensive plant nutrients.

The only disadvantage of both sewage sludge and SLASH is that they are almost devoid of K, an important macro- nutrient. **(Table 8)**

Table 8 : Increase or Decrease of P and K relative to the control (mg kg^{-1})

Treatment	Phosphorus	(P) (mg kg^{-1})	Potassium	(K) (mg kg^{-1})
	@ 12 months	*@ 18 months*	*@ 12 months*	*@ 18 months*
Control	0	0	0	0
5 % SLASH	76	64.9	-6	-7.5
10 % SLASH	57	65.3	-8	-9
3.0 % Sludge	227	275.9	-12	-6

Table 9 : Increase or Decrease of Ca and Mg relative to the control (mg kg^{-1})

Treatment	Calcium	(Ca) (mg kg^{-1})	Magnesium	(Mg) (mg kg^{-1})
	@ 12 months	*@ 18 months*	*@ 12 months*	*@ 18 months*
Control	0	0	0	0
5 % SLASH	4750	3183	64	7
10 % SLASH	6750	3633	85	17
3.0 % Sludge	375	860	27	18

The Ca and Mg levels remain higher than the control but are declining after every cropping.**(Table 9)**

CONCLUSION

With the exception of sewage sludge , SLASH offered greater benefits than any individual ingredients. Sewage sludge , although offering better growth, cannot, however be recommended due to the pathogenicity of the sludge and heavy metal content and the fact that the heavy metals are not immobilized in the sludge , as they are in the SLASH.

The use of a soil ameliorant based on sewage sludge and fly ash has definite agricultural potential. The ameliorant has promising liming qualities, improving the pH and maintaining it for a minimum of 18 months as recorded to date. For how long this effect will persist is still to be determined. It is also a promising plant yield enhancer. From the results of these raised bed trials it can be concluded that SLASH has a long term residual effect, and can be seen as a slow release source of elements required for plant growth.

Although SLASH is seen as good source of nutrients required for plant growth , it does not contain a full range of nutrients. It is devoid of K for example, and the need will exist for supplementary fertilization.

7.5 % - 10% Rate of SLASH application ultimately delivers the best results compared to the rest of the SLASH treatments. Under regulated experimental conditions there was no toxic elemental uptake. The two potential problem heavy metals , Ni and Cd , and the micro-nutrient B, which can be toxic at very high levels, are within the current safety specifications but may be open for review.

For economic reasons the use of SLASH at high levels is limited due to high transport costs, and the recommendation is that this ameliorant's use be restricted to sites in relative close proximity to the waste raw materials used in it's manufacture.

Another possible important quality SLASH might have is that at a neutral pH , the high Si quantity of fly ash can be beneficial in competing with P on the soil particle, thus making P more available for plant growth. This aspect, however, requires further detailed investigation.

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