REFEREED PAPER

EVALUATION OF THE IMPACT OF A RANGE OF SOIL AMELIORANTS ON SOIL CHEMICAL AND BIOLOGICAL PROPERTIES

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Abstract

Crop yields in southern African sugar industries are frequently limited by unfavourable chemical and biological conditions in soils. In addressing these problems, growers make use of various organic and inorganic products, depending on the nature of the limitation. However, the efficacies of numerous products currently in use remain untested. This investigation involved the evaluation of 12 products in a short-term (8 weeks) pot incubation study using a sandy, acid Cartref topsoil. The organic products included were chicken litter (CL), mushroom compost substrate (SMS), flyash, filterpress, vermicast, liquid CMS (CMS_L), and granular CMS (CMS_G). Inorganic products were the liming agents, dolomitic lime and Calmasil, and gypsum, Langfos, and quarry dust. Short term (3-day) CO_2 release, a sensitive indicator of biological activity, increased significantly with the application of the liming agents, filterpress, CL and flyash. Mineral N levels were increased significantly by liming agents, CL and CMS_G. Potassium levels were unaffected by inorganic products but increased with the application of CL and CMS_L. Resin-extractable P levels increased with CL, filterpress and CMS_G; Calmasil, too, increased resin P levels, with this being probably due to the Si in the product promoting P release from soil colloids. Of all the products tested, only lime and Calmasil increased pH significantly. Acid saturation was decreased by liming agents, gypsum and quarry dust, while CMS_G increased acid saturation, probably due to nitrification of the ammoniacal N in the product. It is concluded that short-term incubation studies of this kind provide a useful alternative to more costly field trials for characterising the efficacies and modes of action of various soil ameliorants.

Keywords: soil ameliorants, soil testing, CO_2 release, mineral N, pH

Introduction

Crop yields in southern African sugar industries are frequently limited by unfavourable chemical and biological conditions in soils. In addressing these problems, growers make use of various organic and inorganic products, depending on the nature of the limitation. Inasmuch as the impact of some of the products on soil properties has been researched (Dee *et al.*, 2002; Nixon *et al.*, 2003; van Antwerpen *et al.*, 2003), the efficacies of numerous products currently in use remain untested. Understandably, there is demand from growers for reliable information on the impact of products on soil properties as well as the economic implications of their use in the crop production cycle.

Field trials used to study the impacts of different products on soil properties are generally costly, time-consuming and laborious. There is thus a need for a short term test that assesses how different products impact chemical and biological properties of the soil. Short term pot incubation studies have the potential of addressing this need.

The objective of this study was to evaluate the impact of twelve different products on the properties of an acid topsoil in a short term (8 weeks) incubation.

Materials and Methods

Materials

The pot incubations were carried out on a sandy Cartref topsoil (0-200 mm) which was collected from a farm in the Stanger area. The soil was air-dried, milled to pass through a 1 mm sieve and analysed at the Fertiliser Advisory Service (FAS) laboratory at the South African Sugarcane Research Institute (SASRI). Selected properties of the soil are presented in Table 1.

Table 1. Selected properties of the soil used in the pot trial.

pH ($CaCl_2$)	Truog P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Total cations (cmol/L)	Acid saturation (%)	Si (mg/L)	Clay (%)	Total C (%)
4.51	27	132	240	56	19	2.24	6.25	9.3	12.5	1.22

Twelve products were used in this investigation. Organic products were chicken litter (CL), spent mushroom compost substrate (SMS), flyash, filterpress, vermicast, liquid condensed molasses solids (CMS_L), and granular CMS (CMS_G). Inorganic products were dolomitic lime, Calmasil[R], phosphogypsum, Langfos[R], and quarry dust (dwyka tillite). Samples of the products were sourced from grower operations in which the products were in the process of being applied commercially. Calmasil is a silicate slag produced as a by-product in the steel industry. Langfos is a sedimentary phosphate rock, in which the phosphate is claimed to be in the form of various calcium phosphate minerals. Granular CMS is a new product yet to be commercialised in South Africa; it consists of evaporated and granulated CMS which is 'spiked' with inorganic fertilisers.

The inorganic products were analysed at the FAS using X-ray fluorescence (Rigaku, ZSX Primus II) for P, K, Ca, Mg and Si (Table 2). The organic products were analysed for total C, total N, P, K, Ca and Mg. Total C and N were determined by automated (Dumas) dry combustion using a Leco Analyzer (Leco Corporation, St Joseph, Michigan), while the mineral elements were determined by ICP (ICP-OES, VARIAN ICP 720-ES) analysis after acid digestion.

Table 2. Description of the products used in the pot trial, their rate of application, and nutrient contents.

Product	Description	Rate (tons/ha)	Total C (%)	Total N (%)	C:N	P (%)	K (%)	Ca (%)	Mg (%)	Si (%)
Lime	Kulu dolomitic lime	10				0.02	0.03	28.50	10.10	4.92
Gypsum	Gypsum	10				0.35	0.03	22.70	0.50	0.78
Calmasil	Calmasil	10				0.02	0.03	26.70	6.16	10.14
Langfos	Langfos	1.6				5.23	0.20	8.48	0.12	14.22
Q dust	Quarry dust (dwyka tillite)	15				0.15	2.12	3.06	2.08	24.47
CL	Chicken litter	10	27.03	3.00	9.01	0.62	2.08	1.52	3.12	
SMS	Spent mushroom compost substrate	10	12.68	1.00	12.68	0.26	1.28	3.11	1.55	
Flyash	Flyash	50	-	0.13	-	0.09	0.36	0.31	1.58	
Filterpress	Filterpress	50	6.62	0.32	20.62	0.24	0.11	0.50	1.55	
Vermicast	Vermicast	10	3.94	0.64	6.17	0.47	0.38	0.91	0.26	
CMS_L	Liquid CMS	6.0	-	0.85	-	0.11	8.59	-	-	
CMS_G	Granular CMS	1.0	1.67	11.63	0.14	7.03	14.96	0.34	0.33	

Pot trial

The pot trial included three replicates of the twelve products, plus a control (un-amended soil). The products were applied at the rates shown in Table 2. Amendments were thoroughly mixed with the soil (1 L per pot), wetted to field capacity (FMC) and kept at 25°C for eight weeks. Water was added weekly to restore moisture status to FMC.

After eight weeks, soils from individual pots were analysed for pH ($CaCl_2$), exchangeable Al+H, extractable K, Ca, Na, and Mg using the Ambic method, Troug-P, resin-P, extractable Si (0.01 *M* $CaCl_2$ extraction), ammonium-N, nitrate-N and three-day CO_2 flush. Soil acid saturation was calculated as:

$$\text{Acid Sat \%} = \frac{(Al + H)}{(Al + H) + Ca + Mg + K + Na} * 100$$

Experiment results were subjected to analysis of variance (Genstat version 18). Least significance differences (LSD) are reported at the 5% level.

Results and Discussion

Soil pH, acid saturation, Ca, Mg and Si

The liming agents, dolomitic lime and Calmasil, as expected, significantly increased soil pH (Table 3). The soil treated with Calmasil had the highest pH, which may be explained by the superior liming capacity of Si sources compared to other liming materials (Matichenkov *et al.*, 2001). Calmasil (Table 2) contains silicate minerals whose dissolution results in the consumption of H^+ ions and thus an increased pH (Haynes, 2001; Titshall, 2007). Dolomitic lime also resulted in a significant increase in pH, with this being in accord with results from field studies (Nixon *et al.*, 2003). Although quarry dust and Langfos had high total Si content, their liming capacity was minimal. This is probably due to the low solubility of the silicate minerals present in these products.

The organic products had variable effects on soil pH. Both chicken litter and CMS_G significantly decreased pH, due probably to nitrification of the ammoniacal N in these products. SMS, flyash, filterpress and CMS_L all resulted in small though significant increases in pH.

Table 3. The effects of inorganic and organic products on soil pH. Application rates are listed in Table 2.

Inorganic products	pH ($CaCl_2$)	Organic products	pH ($CaCl_2$)
Control	4.49	CL	4.26
Lime	6.30	SMS	4.59
Gypsum	4.54	Flyash	4.73
Calmasil	7.71	Filterpress	4.83
Langfos	4.42	Vermicast	4.50
Q Dust	4.61	CMS_L	4.67
		CMS_G	3.94
$LSD_{0.05}$	0.05		0.05

Acid saturation was significantly decreased by most of the inorganic products but was not affected by the application of Langfos (Figure 1A). The presence of Ca, Mg, carbonates, sulphates, phosphates and silicates in the products would all be expected to contribute to reductions in acid saturation. The high content of Ca and Mg in liming agents (Table 2) elevated exchangeable Ca and Mg in soils (Figures 2 and 3) which will in turn reduce acid saturation (Nixon *et al.*, 2003). The carbonates, sulphates, phosphates, and silicates can complex Al^{3+} which will reduce the concentration of exchangeable Al^{3+} (Haynes, 2001; Matichenkov *et al.*, 2001; Dee *et al.*, 2002). Calmasil had the greatest effect on acid saturation followed by lime and then gypsum. These products have different modes of action. Calmasil acts through the combined effect of Ca, Mg, carbonates and silicates while mode of action of lime is through its high Ca, Mg and carbonates content. The mode of action for gypsum is through high Ca and sulphate content.

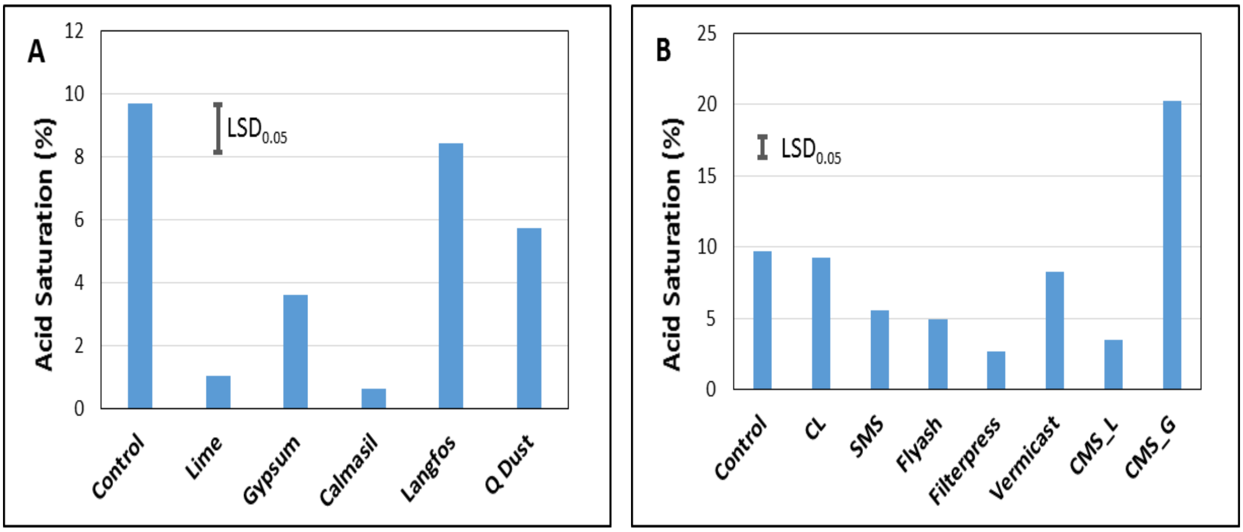

Figure 1. The effects of inorganic (A) and organic products (B) on soil acid saturation. Application rates are listed in Table 2.

Acid saturation was decreased by the application of SMS, flyash, filterpress, and CMS-L, but increased with the application of CMS_G (Figure 2B). Organic products are reported to detoxify soluble and exchangeable Al^{3+} (Haynes and Mokolobate, 2001; Judge, 2001). This occurs through the complexation of Al^{3+} by soluble organic molecules such as organic acids and humic substances which are produced during the decomposition of the organic products (Haynes and Mokolobate, 2001). Flyash has also been found to reduce acid saturation through the precipitation of Al^{3+} as hydroxyl-Al species (Dee *et al.*, 2002; Ndoro, 2008). The high K content of CMS_L could contribute to a reduction in acid saturation through a resultant higher total cation content in the soil.

The increase in acid saturation with the application of CMS_G was, as noted earlier, probably due to nitrification of ammoniacal N in the product. Nitrification of ammonium to nitrate produces acidity, which increases the solubility of Al^{3+} (Haynes and Mokolobate, 2001). Acidification of the soils due to nitrification could also counteract the liming effect of CL which would account for CL having no effect on acid saturation. The elevated exchangeable acidity in soils treated with CL and CMS_G (data not shown) supports the contention of an increase in Al^{3+} solubility.

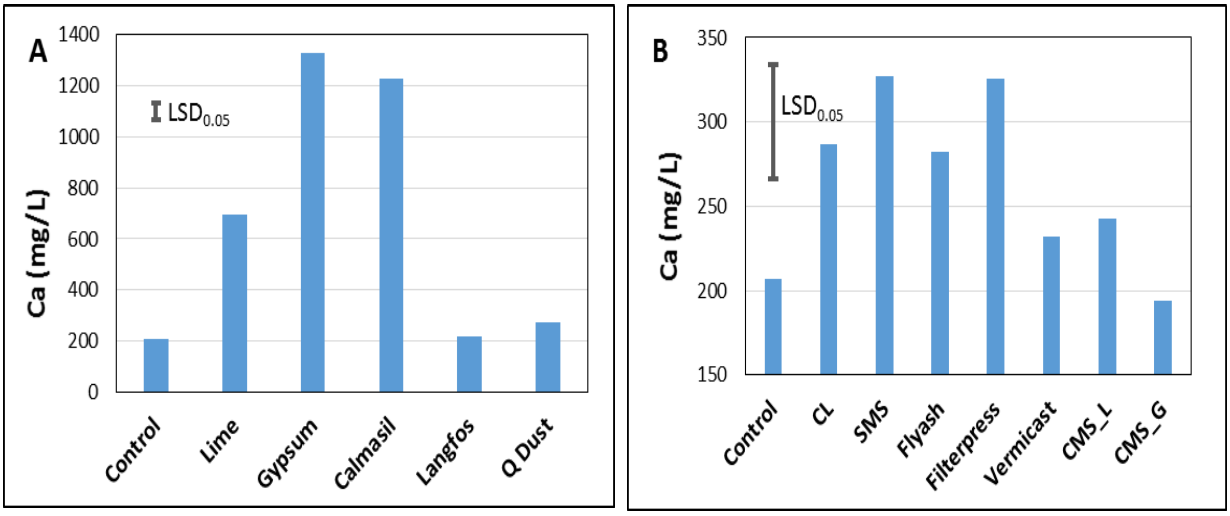

Figure 2. The effects of inorganic (A) and organic products (B) on extractable calcium (Ca). Application rates are listed in Table 2.

The effects of the products on soil Ca, Mg and Si levels are shown in Figures 2, 3 and 4. Release of these elements would be closely related to the composition and solubilities of the various products. Thus, although lime had a higher total Ca content than gypsum, the higher solubility of gypsum (Sumner, 2012) resulted in higher exchangeable Ca levels in the soil (Figure 2A). Similarly, the application of Calmasil resulted in higher concentrations of extractable Si compared to Langfos and quarry dust, which have higher Si content. Amongst the organic products, only flyash resulted in a significant increase in extractable Si.

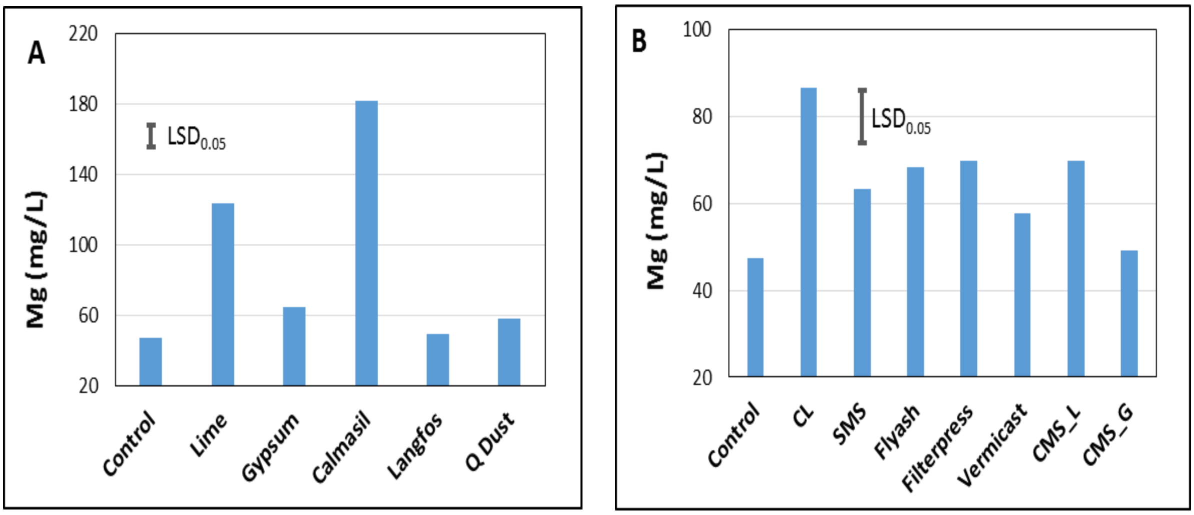

Figure 3. The effects of inorganic (A) and organic products (B) on extractable magnesium (Mg). Application rates are listed in Table 2.

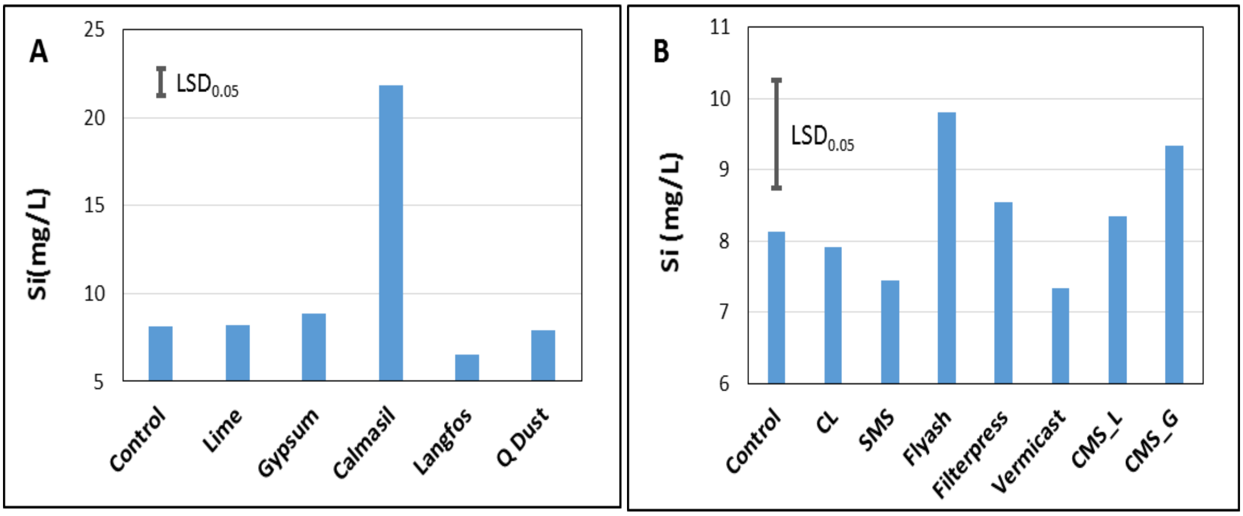

Figure 4. The effects of inorganic (A) and organic products (B) on extractable silicon (Si). Application rates are listed in Table 2.

Macronutrients

Ammonium-N was not affected by the inorganic products while nitrate-N increased significantly with the application of lime and Calmasil (Figure 5A). These products, because of their high pH, facilitate decomposition of organic matter and enhance mineralization of nitrogen (Otto and van Zyl, 2001). The high nitrate levels indicate that the ammonium released in the mineralization process had evidently already undergone nitrification by the end of the eight-week incubation.

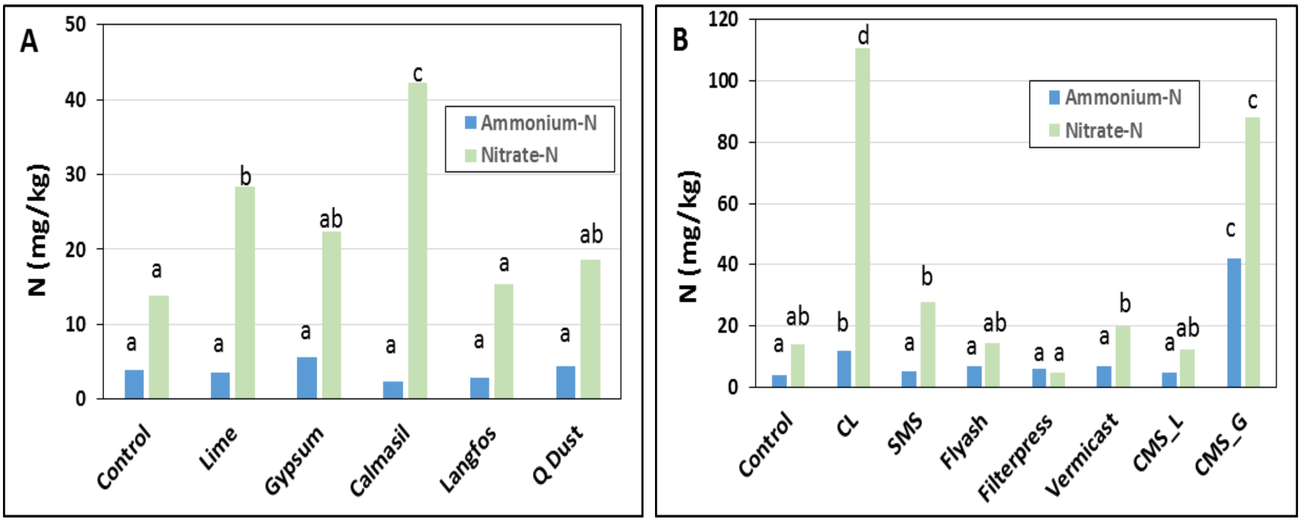

Figure 5. The effects of inorganic (A) and organic products (B) on extractable ammonium-N and nitrate-N. Ammonim-N or nitrate-N means associated with the same letter are not significantly different (P≤0.05). Application rates are listed in Table 2.

Most of the organic products had no effect on mineral-N concentration except for CL and CMS_G which significantly increased both ammonium-N and nitrate-N (Figure 5B). Both CL and CMS_G had high N content (Table 2) which may explain the increase in mineral-N with the application of these products. The significantly greater release of N from CL relative to

SMS is noteworthy, given that the latter product tends to be viewed by growers as being equivalent to CL in terms of its nutrient-supplying power.

Results for Troug-P were higher than those extracted with resin-P for all products (Figure 6). The acidic Troug-P extractant (0.02 *N* H_2SO_4) dissolves sparingly soluble Ca-phosphates resulting in higher P test values, while resin extraction provides more reliable estimates of available P (Miles *et al.*, 2013). Consequently, Troug-P significantly increased with the application of inorganic products containing Ca-phosphates, while resin-P remained unaffected (Figure 6A). Although lime and Calmasil had low P contents (Table 2) Troug-P was elevated. These two products increased both pH and Ca content which can enable residual Al and Fe-phosphates to convert to Ca-phosphates which are then solubilised by the acidic Troug test (Lindsay, 1979).

Calmasil was the only inorganic product that increased resin-P, possibly due to Si in the product enhancing the availability of P. Higher solubility of Si-bearing minerals in Calmasil (as discussed above) can promote release of P from soil colloids and/or block P fixation sites, resulting in increasing concentrations of available P (Sanchez, 1976; Ma *et al.*, 2001; Matichenkov and Bocharnikova, 2001).

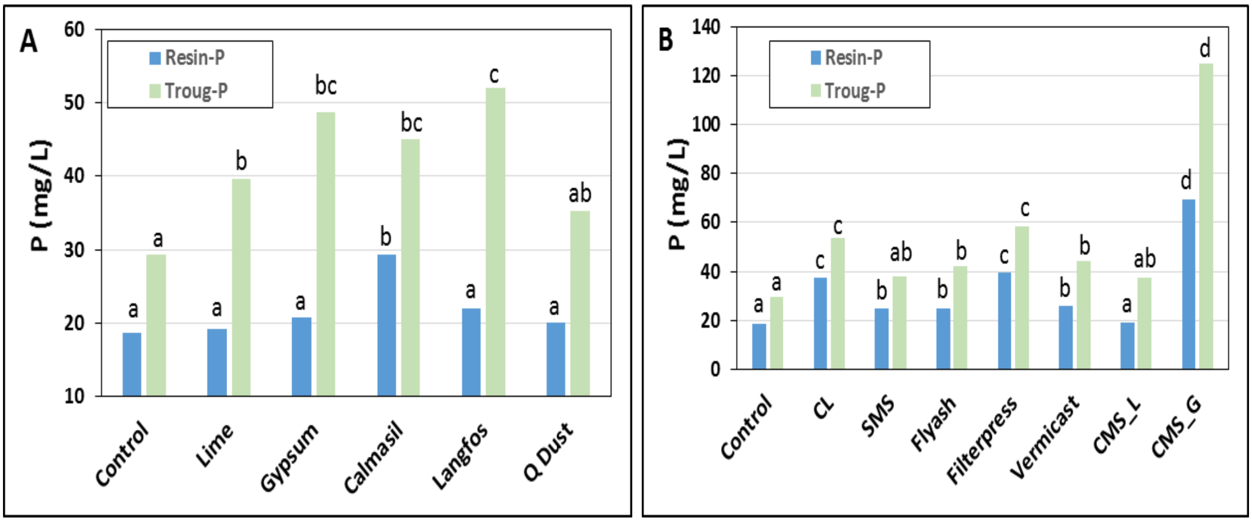

Figure 6. The effects of inorganic (A) and organic products (B) on Troug and resin extractable phosphorus (P). Troug or resin P means associated with the same letter are not significantly different (P≤0.05). Application rates are listed in Table 2.

Most organic products, on the other hand, significantly increased both Troug and resin-P (Figure 6B). Values obtained by subtracting resin P from Troug-P were not significantly different between control and soils treated with organic products, with the exception of soil treated with CMS_G (data not shown). This suggests that the application of organic products increased the available P and not the less soluble P (which would be solubilised by the Truog test). Organic products are known to increase P availability (Haynes and Mokolobate, 2001; Miles and van Antwerpen, 2015). The increase in available P is caused by the blockage of P adsorption sites by humic substances and organic acids, complexation and precipitation of soluble Al by humic substances and organic acids, and by an increase in soil pH (Haynes and Mokolobate, 2001). The high value of Troug minus resin-P in CMS_G treated soil is probably due to the presence of less soluble phosphates in the product.

Potassium levels were unaffected by inorganic products but increased with the application of CL, SMS, flyash, filterpress and CMS_L (Figure 7). The effects of the products on K is influenced by the levels of K present and the solubility of K-bearing minerals in the products. Somewhat surprisingly, CMS_G, which had 15% K, did not affect extractable K levels in the soil; indications are that the K in this product was therefore insoluble.

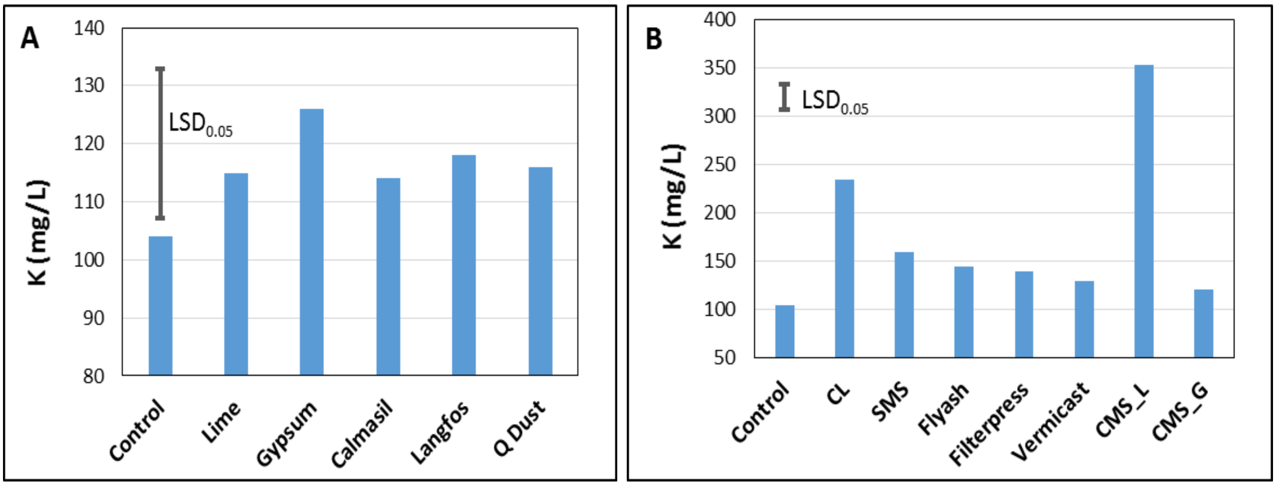

Figure 7. The effects of inorganic (A) and organic products (B) on extractable potassium (K). Application rates are listed in Table 2.

Carbon dioxide

Short term (3-day) CO_2 release, a sensitive indicator of biological activity (van Antwerpen *et al.*, 2003), increased significantly with the application of the lime, Calmasil, filterpress, CL and flyash (Figure 8). Biological activity in soils is affected by organic carbon, soil pH, and the supply of macronutrients such as Ca, Mg, K and P (Dee *et al.*, 2002). The increase in CO_2 release with the application of lime and Calmasil is, therefore, due to pH increases along with supplies of Ca and Mg. Filterpress, CL and flyash on the other hand, increased CO_2 release apparently through the additions of organic carbon, Ca, Mg and P. Filterpress also had the highest release of CO_2 compared to other organic products, which is in agreement with a field study where filterpress had the greatest improvement on soil biological properties (van Antwerpen *et al.*, 2003).

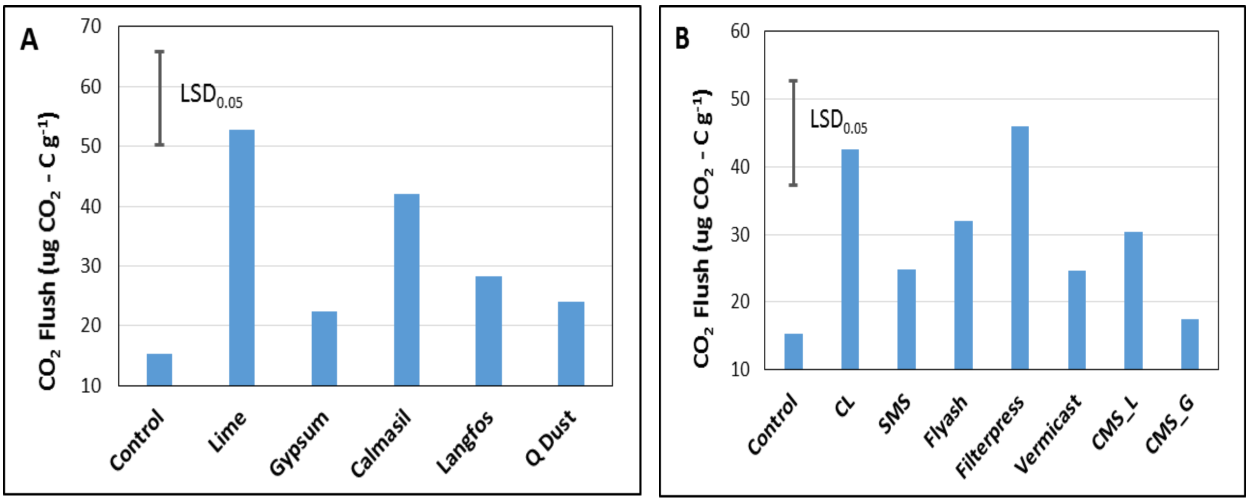

Figure 8. The effects of inorganic (A) and organic products (B) on carbon dioxide (CO_2) release. Application rates are listed in Table 2.

Summary of effects

The effects of various products on soil chemical and biological properties are summarised in Table 4. Amongst the inorganic products, lime and Calmasil had the most widespread effects on soil properties, while Langfos and quarry dust were the least effective. Chicken litter, flyash, and SMS were the most effective of the organic products while vermicast, CMS_L, and CMS_G were the least effective. Of interest is that, of all the products tested, only Calmasil and flyash improved Si availability.

Table 4: Summarised effects of various products on soil chemical and biological properties. The effects were summarised as positive (+), negative (-) and no effect (NE).

Product	**Parameter**									
	pH	**Acid Sat**	**Ca**	**Mg**	**Si**	**N**	**Troug P**	**Resin P**	**K**	**CO_2 release**
Lime	+	+	+	+	NE	+	+	NE	NE	+
Gypsum	NE	+	+	+	NE	+	+	NE	NE	NE
Calmasil	+	+	+	+	+	+	+	+	NE	+
Langfos	NE	NE	NE	NE	NE	NE	+	NE	NE	NE
Q dust	+	+	NE	NE	NE	+	+	NE	NE	NE
CL	-	NE	+	+	NE	+	+	+	+	+
SMS	+	+	+	+	NE	+	+	+	+	NE
Flyash	+	+	+	+	+	NE	+	+	+	+
Filterpress	+	+	+	+	NE	-	+	+	+	+
Vermicast	NE	NE	NE	NE	NE	+	+	+	+	NE
CMS_L	+	+	NE	+	NE	NE	+	NE	+	+
CMS_G	-	-	NE	NE	NE	+	+	+	NE	NE

Conclusions

The effect on soil properties of the different products was investigated and was found to vary widely between products. The impact of a product is influenced by the product's composition and solubility; importantly, as reflected in the data for Langfos and quarry dust, it is clearly not possible to predict the impact of particular products on soil properties on the basis of their total elemental composition. In the case of organic products, the findings of this study underline the significant differences between products in terms of their nutrient supplying capacities and impacts on soil health; growers need to be wary of the often extravagant claims made in promoting particular products.

It is concluded that short-term incubation studies of this kind provide a useful alternative to more costly field trials for characterising the efficacies and modes of actions of various soil ameliorants.

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