SOIL AMELIORANTS TO IMPROVE SOIL CHEMICAL AND MICROBIAL BIOMASS PROPERTIES IN SOME SOUTH AFRICAN SOILS

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ABSTRACT

Rainfed field trials on effects of seed, foliar and soil amendments herein referred as industrially manufactured biological amendments (IMBAs) on selected soil chemical and microbial biomass properties were conducted from 2006/07through 2008/09 at four sites in South Africa under light and heavy-textured soils. The IMBAs were classified as growth boosters and partial or total replacements of conventional NPK fertiliser. The IMBAs were applied according to product recommendations in a randomised complete block design with four replications. An optimum conventional NPK rate at each site and untreated control were also included as check. Application of IMBAs with optimum recommended NPK fertiliser rate promoted acidity in soils compared to the IMBAs used as either partial or total replacements of conventional NPK fertiliser. The use of the different IMBA types significantly increased contents of organic C, available N and P only in light-textured soils than in the NPK check. The different IMBAs promoted higher microbial biomass-C immobilisation at 4-weeks after planting, while biomass-C mineralisation was predominant at flowering and crop harvest regardless of soil type. Farmers could apply any category of IMBAs to complement revitalisation of degraded South African soils and also minimise nutrient leaching due to synergetic effects.

Keywords: *Conventional fertiliser, fertiliser replacement, growth booster, soil productivity*

INTRODUCTION

Soils in the maize producing triangle of South Africa are sandy and light-textured and hence highly subjected to occasional nutrient leaching rendering them deficient in major plant nutrients (Laker, 1976; Mills and Fey, 2003). These soils are often associated with restricted factors such as compaction, acidity and low organic carbon stocks (Mnkeni and Mkile, 2006). This consequence in crop production to be practiced on biologically inactive and physically deteriorated soils that results in crops responding less to the use of chemical inputs (Primavesi, 1990).

The sole use of conventional NPK fertilisers to meet soil nutrient requirements often increases the rate of organic matter (OM) mineralisation and leads to a decrease in easily decomposable OM as well as a decrease in microbial biomass (Černý *et al*., 2003). Prolonged application of nitrogenous fertilisers may also lead to problems of soil acidity and nutrient imbalance (Gilani and Bahmanyar, 2008). However, sole application of organic amendments increases soil microbial biomass carbon, while no increase and/or effect resulted with inorganic NPK fertilisers (Goshal and Singh, 1995). Microbial biomass and activity directly correlate with OM, which is positively influenced by the addition of organic materials such as post-harvest crop residues and manure (Belay *et al*., 2002). Hence, microorganism activities in agricultural soils exert a profound influence on plant nutrient availability and OM transformation (Onwonga *et al*., 2010).

The need to reduce crop fertilising costs is important grounds for advocating increased use of organic amendments. Benefits arising from the use of organic materials are not

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fully exploited partly due to huge quantities required in order to satisfy the nutritional needs of crops (Hossain and Singh, 2000). Complementary use of organic manures and inorganic fertilisers has proven to be a sound soil fertility management strategy in many countries of the world (Heisey and Mwangi, 1996). In South Africa, there are many organic-based fertilisers manufactured and marketed for agriculture that advocate soil health revitalisation properties, but often without sufficient empirical information on efficacy or possible soil impacts. Limited studies report significant benefits following the use of organically-enriched amendments as alternatives or in combination with conventional NPK fertiliser (Baloyi *et al*., 2010; Kutu, 2012). These authors emphasise the possible benefits of the use of plant/soil ameliorants to improve crop growth, but only on selected soil quality indices. This study was therefore conducted to assess effects of seed, foliar and soil amendments on growth of maize and soil properties. Nonetheless, only the responses of selected soil chemical and microbial biomass properties to usage of industrially manufactured biological amendments (IMBAs) are primarily addressed in this paper.

MATERIALS AND METHODS

Site characterisation

Field trials with maize variety PAN 6479 were conducted under rainfed conditions over three cropping seasons during 2006/07 to 2008/09 at four localities. The three sites namely, Bethlehem, Bothaville and Ottosdal represented light-textured soils, while the fourth site at Potchefstroom represented heavy-textured soils (Table 01). Climatic data for the trial sites are presented in Table 02.

Treatments

Nine IMBAs classified as growth boosters (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial replacements (Crop care and Montys) or total replacements of conventional NPK fertiliser (Gromor and Promis) were selected and evaluated as recommended by the product manufacturer (Table 03). The growth boosters are distinguished as those IMBAs which received optimum recommended NPK fertiliser rate, while the partial and total replacements of NPK fertiliser are those with reduced NPK rate and no application of NPK fertiliser, respectively. An optimum conventional NPK fertiliser rate and unamended plots were also included as controls at each site. The optimum conventional NPK rate at each trial site was based on soil test results during each planting season. The sources of N, P and K were limestone ammonium nitrate, superphosphate and potassium chloride, respectively. Treatments were replicated four times and arranged in a randomised complete block design. Each treatment was applied on a 10 m x 6 m plot. Prior to application, the IMBAs were chemically analysed (Table 04). Soil-applied IMBAs were broadcast uniformly over the respective plots and lightly worked into the soil with a hand hoe, while the foliar applied IMBAs were sprayed on plants as recommended under Table 03 using a CP15 knapsack sprayer.

Land husbandry and crop history

Seedbed preparation at the different trial sites was done by mouldboard ploughing, disking and harrowing. After each harvesting time, maize stubble was ploughed in with a rotavator and the trial sites left bare until the next planting. Just after planting, trials were sprayed with a two L Dual (S-metolachlor) ha^{-1} to destroy upcoming weeds and kept weed free during the growing season through mechanical weeding when necessary. Prior to the trials, wheat was grown at Bethlehem, sunflower at Bothaville and cowpea at both Ottosdal and Potchefstroom.

Soil sampling and analyses

Chemical soil properties

Before trial establishment, 10 random soil samples were collected from 0-20 cm soil depths using a soil auger, bulked and mixed thoroughly to obtain a composite sample. Soil analyses results were shown in Table 01. A post-harvest soil sampling was also conducted at the same soil depth from all plots in each site and season. Sample determination included soil pH, organic C, available N and P. Standard procedures were used to determine pH (H_2O, 1:2.5), organic C (Walkley and Black, 1934), available N (0.1 N K_2SO_4) and Bray 1- P (Non-affiliated Soil Analyses Work Committee, 1990).

Table 01. Geographic and soil characteristics of the trial sites

Characteristics		Bethlehem	Bothaville	Ottosdal	Potchefstroom
Geographic					
Latitude		28°23’	26°62’	26°08’	27°09’
Longitude		-28°23’	-27°38’	-26°81’	-27°7’
Altitude (m)		1850	1317	1587	1355
Soil[1]					
Soil depth (m)		1.6	1.8	2.1	1.8
Soil form		Plinthic Lixisol	Plinthic Lixisol	Rhodic Ferrasal	Aeric Plinthisol
Soil textural					
Clay		14	8	12	34
Silt	%	11	1	7	17
Sand		75	91	81	49
pH (H_2O)		5.47	7.02	5.83	6.61
Organic C	(%)	0.43	0.20	0.38	0.82
N		2.9	0.9	2.8	5.7
P	mg kg^{-1}	19	22	16	56
K		112	74	135	192
ECEC	cmol (+) kg^{-1}	12.7	6.18	22.5	14.7

[1] Classified according to Soil Classification Working Group (1991) and analyses data for samples from 0-20 cm depths.

Table 02. Climatic data for the three production seasons and on the long-term at the four ecotopes

Localities	Month	Rain			Tn			Tx			A-pan		
		2006-2007	2007-2008	2008-2009	2006-2007	2007-2008	2008-2009	2006-2007	2007-2008	2008-2009	2006-2007	2007-2008	2008-2009
Bethlehem	Annual totals	321.1	693.9	1131.8	7.2	7.0	7.2	23.4	21.8	23.6	4.3	3.7	5.3
	Long-term	718	718	718	8.4	8.4	8.4	24.0	24.0	24.0	4.4	4.4	4.4
Bothaville	Annual totals	489.5	561.0	580.1	7.3	8.4	8.6	27.0	25.6	27.2	5.4	4.8	5.0
	Long-term	502	502	502	9.9	9.9	9.9	27.4	27.4	27.4	5.4	5.4	5.4
Ottosdal	Annual totals	332.6	460.4	485.9	9.3	9.1	8.8	26.4	26.9	26.3	5.5	3.9	4.1
	Long-term	593	593	593	10.3	10.3	10.3	27.1	27.1	27.1	5.5	5.5	5.5
Potchefstroom	Annual totals	643.4	651.1	547.3	10.0	10.8	9.9	26.5	25.0	26.7	5.3	4.6	4.4
	Long-term	622	622	622	10.7	10.7	10.7	25.2	25.2	25.2	5.3	5.3	5.3

Rain = annual mean rainfall (mm); Tn = Daily mean minimum temperature (°C); Tx = Daily mean maximum temperature (°C); A Pan = Daily mean evaporation (mm).

Table 03. IMBAs selected for evaluation at four sites

Category of IMBAs	IMBAs	Application method	Recommendations
Growth boosters	Biozone	Soil application	Optimum fertiliser rate (OFR) depending on soil test results of the site + 10 L ha^{-1} at planting
	Gliogrow	Seed dressing + foliar application	100% OFR + 0.2 L ha^{-1} of both Maxiflo + Trykocide + 0.1 L ha^{-1} of Teprosyn Zn/P per 25 kg seeds; 0.4 L ha^{-1} of both Maxiflo + Trykocide four weeks after emergence
	Growmax	Soil application	Blend with inorganic fertiliser to supply 100% OFR
	K-humate	Soil application	100% OFR + 20 kg ha^{-1} a week prior to planting
	Lanbac	Soil application	100% OFR + 10 L ha^{-1} MS Humate + 2 kg ha^{-1} Microboost + 2 L ha^{-1} Microbial inoculants at planting
Partial replacement of NPK fertiliser	Crop care	Soil + foliar application	70% OFR + 400 kg ha^{-1} Growmax + 5 L ha^{-1} Agri-balance at planting; 2.5 L ha^{-1} Agri-boost + Agri-Zinc at 4 weeks after planting; 2 L ha^{-1} Agri-fulbor at tasseling
	Montys	Soil application	50% OFR + 3 L ha^{-1} at planting
Total replacement of NPK fertiliser	Gromor	Soil application	2000 kg ha^{-1} at planting;
	Promis	Soil application	1000 kg ha^{-1} at planting;

Table 04. Chemical composition of the different IMBAs used for evaluation

Category of IMBAs	IMBAs	pH (H_2O)	N (mg kg^{-1})	P	K	Ca	Mg	Na	Organic C (%)
Growth boosters	Biozone	3.1	0.02	0.01	0.01	1.00	0.01	2.75	2.15
	Gliogrow	4.0	0.21	0.01	0.01	0.13	0.13	1.25	0.43
	Growmax	6.8	3.00	3.00	3.00	1.38	0.88	1.75	28.3
	K humate	9.6	6.92	17.6	101.0	7.50	1.25	12.0	>60
	Lanbac	5.1	0.38	0.58	2.50	1.00	0.38	4.25	3.80
Partial replacement of NPK fertiliser	Crop care	8.1	0.96	1.17	4.13	0.63	0.38	7.00	2.66
	Montys	9.5	0.45	1.17	0.13	1.75	0.50	5.00	3.33
Total replacement of NPK fertiliser	Gromor	6.0	3.80	16.0	20.0	0.30	5.00	1.00	35.8
	Promis	5.8	4.00	1.60	1.80	3.25	0.70	0.08	42.9

[1] Grouping of IMBAs based on conventional NPK rate used with the IMBA consist of growth boosters (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial replacements (Crop care and Montys) or total replacements of NPK (Gromor and Promis)

Microbial biomass indicators

Soil samples were taken from 0-10 cm soil depths within an area of 4 m^2 at randomly selected positions in each plot using a 10 mm diameter core sampler, pooled and thoroughly mixed to obtain a composite sample. The sampling was done first at four weeks after planting, at flowering and crop harvest for microbial biomass-C (C_{mic}) determination. All composite samples were sieved through a 2 mm stainless steel sieve to eliminate stones and plant roots, and thereafter stored at 4°C prior to analyses. Biomass-C was determined following the chloroform fumigation-extraction procedure (Vance *et al.*, 1987).

Statistical analyses

Analyses of variance using GenStat Release 14 were calculated from data obtained in the trials. Differences in treatment effects were considered to be statistically significant at $P < 0.05$ with the Tukey honestly significant difference (HSD) post-hoc test.

RESULTS AND DISCUSSION

The sites varied greatly in terms of geographic and soil characteristics (Table 01). The long-term mean annual rainfall varied between 502 mm at Bothaville and 718 mm at Bethlehem (Table 02). Equally, annual rainfall at the four sites was very variable during the study period. Average daily minimum temperature across the sites ranged from 8 to 11°C and 24 to 27°C for the mean daily maximum temperature. Mean daily evaporation at the sites conformed to the long-term daily averages of 4.4 to 5.4 mm. Table 04 present the nutritional composition of the IMBAs used in the study. The chemical analyses of the IMBAs showed a wide $pH_{(H2O)}$ range of 3.1 with Biozone to 9.6 with K-humate. The organic C content varied between 0.43% with Gliogrow and > 60% with K-humate, and with very low NPK contents across the IMBAs.

Chemical properties

Application of the IMBAs showed variable and significant ($p<0.05$) effects on selected soil quality indices such as soil pH, organic C, available N and P (Tables 05 and 06).

Soil pH

Application of the various IMBA types showed a depressive effect on post-harvest soil pH across the ecotopes and soil types than their pre-plant situation (Table 01). Only application of growth boosters such as Gliogrow and Growmax, and total replacement like Gromor showed increased soil pH values at Bethlehem ecotope (Table 05). The lower soil pH could be attributed to microbial decomposition releasing of organic acids as suggested by Fan *et al*., 2007 as well as the conventional NPK fertiliser that was either applied or contained in the IMBAs in various amounts. The ammonium released from either the inorganic or organic fraction of IMBAs may have also enhanced acidification due to possible nitrification took place (Wong *et al*., 1992; Somani and Totawat, 1996; Belay *et al*., 2002). Consequently, the lower soil pH could be ascribed to the soil's lower clay and organic C content across the ecotopes, although moderately higher clay content at Potchefstroom. Curtin and Trolove (2013) showed in a 12-year study that soil's buffer capacity (measured using KOH) was strongly correlated with soil organic C ($R^2 = 0.76$) and weakly (but significantly, $P < 0.05$) with clay content. Likewise, they showed that soil with low soil C concentrations tended to be more acidic, possibly partly due to weaker pH buffering. Amongst the IMBA categories, soil pH was higher coming to neutral range in the order total replacements > growth boosters > partial replacements. However, only Gromor and Gliogrow applications showed significantly ($P<0.05$) increased pH values than in the NPK plots both in higher rainfall and cooler sites of Bethlehem and Potchefstroom ecotopes. Equally, soil pH increased significantly regardless of the IMBA category in light textured soil of 8% clay typical of the Bothaville ecotope. The high pH in the IMBA plots at Bothaville therefore indicates that the soil was saturated to a larger extent with basic cations (Triantafilis *et al*., 2003). Notwithstanding, the Ottosdal ecotope also comprised light-textured soil of 12% clay as for Bothaville, however soil pH amongst the IMBAs decreased in many instances than in the NPK check. This decrease could be attributed to the sites soil's lower CEC concentration that could have led to the crop removal of the level of bases of calcium, magnesium, potassium, etc. in the soil water and the inability of the soil to adequately replenish the supply. Equally, the site was also previously planted to a legume. Legume crops like soybeans, cowpeas etc. tend to take up more divalent cations and as a result, excrete H^+ ions from their roots to maintain electrochemical balance within their tissues that subsequent results in a net soil acidification (Aguilar and van Diest, 1981). Soil acidity is controlled by the amount of hydrogen (H^+) and the aluminum (Al^{+++}) that is either contained in, or generated by the soil and soil components (Bolan et al., 2003).

Table 05. Average of three years values on post-harvest soil pH and organic C during three seasons at four sites as affected by IMBAs

		pH				Organic C (%)			
Category of IMBAs	**IMBAs**	Bethlehem	Bothaville	Ottosdal	Potchefstroom	Bethlehem	Bothaville	Ottosdal	Potchefstroom
Growth boosters	Biozone	5.34	6.20	5.55	5.77	0.49	0.31	0.50	0.77
	Gliogrow	5.68	6.45	5.57	6.01	0.49	0.32	0.53	0.80
	Growmax	5.56	6.24	5.48	5.97	0.48	0.30	0.51	0.79
	K-humate	5.40	6.27	5.47	5.88	0.51	0.32	0.49	0.81
	Lanbac	5.37	6.21	5.28	5.86	0.50	0.30	0.50	0.79
Partial replacement of NPK fertiliser	Crop care	5.35	6.21	5.29	5.82	0.48	0.35	0.50	0.83
	Montys	5.45	6.23	5.46	5.79	0.50	0.31	0.51	0.80
Total replacement of NPK fertiliser	Gromor	5.79	6.41	5.63	6.12	0.48	0.30	0.49	0.82
	Promis	5.43	6.24	5.67	5.92	0.49	0.32	0.49	0.82
	NPK	5.44	5.99	5.60	5.83	0.45	0.22	0.39	0.81
	Untreated Control	5.44	5.95	5.29	5.89	0.45	0.20	0.38	0.76
	SEM	0.089	0.071	0.053	0.071	0.027	0.026	0.021	0.018
	$LSD_{T(0.05)}$	0.183	0.144	0.109	0.145	0.055	0.053	0.042	0.037

Table 06. Average of three years values on post-harvest available N and P during three seasons at four sites as affected by IMBAs

		Available N (mg kg^{-1})				Available P (mg kg^{-1})			
Category of IMBAs	**IMBAs**	Bethlehem	Bothaville	Ottosdal	Potchefstroom	Bethlehem	Bothaville	Ottosdal	Potchefstroom
Growth boosters	Biozone	3.56	1.97	2.40	3.47	34.7	25.3	34.7	59.3
	Gliogrow	3.41	2.09	2.71	4.59	36.2	28.2	32.1	59.8
	Growmax	2.09	1.84	2.39	2.57	35.3	27.0	35.5	56.3
	K-humate	2.48	2.43	3.06	3.08	29.4	25.3	38.3	57.5
	Lanbac	3.67	2.19	2.14	2.86	39.2	25.0	37.3	55.1
Partial replacement of NPK fertiliser	Crop care	2.08	2.51	2.68	3.80	39.1	27.9	36.6	64.5
	Montys	2.63	1.97	2.05	3.60	30.9	27.3	31.5	62.2
Total replacement of NPK fertiliser	Gromor	2.50	1.74	1.93	2.25	34.9	25.5	31.9	60.5
	Promis	1.96	1.76	2.22	1.86	31.8	25.8	27.3	62.5
	NPK	2.44	1.95	2.03	2.91	34.8	25.4	41.6	62.6
	Untreated Control	1.47	0.80	1.53	1.13	16.9	21.8	14.8	53.7
	SEM	0.530	0.234	0.544	0.810	4.236	2.381	5.673	3.100
	$LSD_{T(0.05)}$	1.082	0.478	1.111	1.654	8.650	4.863	11.59	6.333

Organic C

The content of post-harvest organic C significantly (P<0.05) increased regardless of the IMBA type in the light-textured soils of Bothaville and Ottosdal ecotopes, while only K-humate used as a growth booster showed significant (P<0.05) higher organic C values than in the NPK check plots at the light-textured soil of Bethlehem ecotope (Table 05). Amongst the different IMBA types, post-harvest organic C content in light-textured (8-14% clay) increased by 5 to 8 units at Bethlehem, 9 to 11 units at Bothaville and 11 to 15 units at Ottosdal soils, but only increased by a unit at Potchefstroom site (34% clay) than their pre-plant contents. The fact that organic C content at Potchefstroom increased by a unit could be related to the soils moderately higher CEC and clay content indicating that the soil had a higher soil organic cation level to provide adequate crop nutrition. A substantial decrease in pH buffering (by up to 24% in top 7.5 cm) was associated with a decline in SOM following the conversion of permanent pasture (pre-trial land use) to arable cropping (Curtin and Trolove, 2013). Equally, the only increased organic C content manifested in heavier-textured soil of Potchefstroom ecotope resulted with applications of both total replacements of NPK IMBAs and the application of partial replacement like Crop care. Long-term application of organic amendments increased organic C by up to 90% and 100% when unfertilised soil and inorganic fertilised soil served as references, respectively (Diacono and Montemurro, 2010). This demonstrates that incorporation of organic fertiliser into the soil could be an efficient way of maintaining a desired soil C level (Fan *et al*., 2007).

Available N

The various IMBAs applied exerted a positive effect on post-harvest soil available N only in light-textured (8-14% clay) soil of the Bethlehem, Bothaville and Ottosdal ecotopes (Table 06). This augmented available N value is ascribed to the increased organic C content at the respective sites. Although, the Potchefstroom site's high clay content was able to retain significant quantities of the plant nutrient (Diepen and van der Wal, 1995), there was a decrease in available N content which is associated with decrease of organic C level (Okwuagwu *et al*., 2003). The available N content amongst the IMBA categories were increased in the order growth boosters > partial replacements > total replacements. The higher available N from IMBAs used either as growth boosters or partial replacements are possibly due to synergy (Bokhtiar and Sakurai, 2005; Boateng et *al*., 2006). Comparing, to the NPK standard, significantly (P<0.05) increased available N content resulted in light-textured soil with growth booster applications like Biozone and Lanbac at Bethlehem, K-humate at Bothaville, and a partial replacement of NPK IMBA like Crop care at Bothaville, while only Gliogrow showed significantly (P<0.05) increased N content in heavier-textured soil of Potchefstroom ecotope. The available N content from both total replacement of NPK plots were insignificant than in the NPK check plots and was also consistently lower than the other active ingredients of IMBAs due to their slower N releasing potential (Belay *et al*., 2002).

Available P

Significant (P<0.05) increased post-harvest available P content than in the NPK check plots manifested from applications of either growth boosters or partial replacements of NPK fertiliser respectively in higher rainfall typical of the Bethlehem and Potchefstroom ecotopes, while only Crop care applied as a partial replacement of NPK showed significant (P<0.05) increased available P content at Potchefstroom ecotope (Table 06). Application of both total replacements of NPK IMBAs showed insignificantly higher P content than any of the growth boosters in heavy-textured soil. Okwuagwu *et al*. (2003) reported higher available P in organic fertilised plots as a result of the long-term residual effect.

Microbial biomass indicators

The effect of the various categories of IMBAs showed statistical insignificant effects on biomass-C relative to the NPK check, but was significant ($P<0.05$) in few instances at both soil types and samplings compared to the untreated control (Table 07). Generally, use of the various IMBAs showed pronounced immobilisation fluxes at both soil types at 4-weeks after planting relative to the two standards. The predominant C_{mic} immobilisation at 4-weeks after planting regardless of the IMBA treatment across the ecotopes could be attributed to the resistance of biological amendments to microbial decomposition (Fan *et al*., 2007). This could further be associated to wet soil conditions (Ponnamperuma, 1972) and/or competition for nutrients by crop roots and microorganisms (Bhattacharyya *et al*. 2003).

The use of the different IMBAs generally showed higher C_{mic} mineralisation fluxes than in the two checks at flowering stage in both soil types, being generally higher in heavy-textured soil of Potchefstroom ecotope. Similar pattern manifested at crops harvest, however C_{mic} mineralisation fluxes were reduced than in the NPK check from applications of both partial replacements of NPK IMBAs, except for Montys respectively at sites previously grown to legumes typical of Ottosdal and Potchefstroom ecotopes. The higher C_{mic} mineralisation at Potchefstroom could be attributed to the site's high clay content that correspond with high nutrient levels (Van Veen *et al*., 1985). Biomass-C mineralisation fluxes in the different IMBA plots were largely greater in sites with low and erratic rainfall such as Bothaville and Ottosdal than in higher and cooler rainfall area such as at Bethlehem and Potchefstroom ecotopes. The increased C_{mic} mineralisation at flowering and crop harvest is attributed *inter alia* to drier soil conditions with higher temperatures. Neff and Hooper (2002) asserted that C_{mic} decomposition increases with temperature raising the possibility of significant C release and with microbial proliferation and activity (Hu and Cao, 2007).

Table 07. Average of three years values on microbial biomass-C (μg C g^{-1}) at three samplings during three seasons at four sites as affected by IMBAs

		4 weeks after planting				**Flowering**				**Crop harvest**			
Category of IMBAs	**IMBAs**	Bethlehem	Bothaville	Ottosdal	Potch	Bethlehem	Bothaville	Ottosdal	Potch	Bethlehem	Bothaville	Ottosdal	Potch
Growth boosters	Biozone	-137.3	-159.8	-105.4	-135.5	204.8	175.6	198.3	269.4	185.10	36.70	55.07	42.53
	Gliogrow	-73.4	-363.0	-213.6	-347.3	192.8	266.3	237.7	342.1	110.20	56.83	42.97	80.83
	Growmax	-310.1	-75.7	-150.9	-381.3	192.8	232.9	221.7	251.1	126.40	40.80	39.93	0.83
	K-humate	-194.3	-182.1	-55.6	-205.2	216.0	189.9	184.7	212.4	62.83	40.47	56.33	35.27
	Lanbac	-735.3	-433.0	-171.1	-388.2	230.0	184.0	235.9	315.8	85.00	62.77	69.73	67.37
Partial replacement of NPK	Crop care	-102.0	-163.6	-63.4	-153.1	188.3	201.7	212.4	268.2	73.23	18.83	18.07	30.43
	Montys	-395.4	-325.5	-100.7	-438.0	197.2	285.4	151.9	265.5	91.37	1.27	50.03	121.77
Total replacement of NPK	Gromor	-511.1	-367.7	-261.8	-359.0	222.3	218.8	151.3	294.6	105.87	46.80	118.23	49.10
	Promis	-246.9	-140.0	-60.8	-115.5	209.0	243.3	184.7	274.0	106.97	56.80	83.83	59.77
	NPK	-193.4	-198.3	-31.8	-196.8	226.8	141.0	197.5	245.2	73.57	20.30	28.20	42.77
	Control	-164.8	-186.0	-20.4	-48.5	165.9	107.5	133.7	208.7	13.93	-12.30	-12.97	15.10
	SEM	287.2	163.8	111.2	201.0	38.5	60.0	45.5	52.8	48.10	38.17	49.30	49.27
	$LSD_{T(0.05)}$	829.5	473.1	321.2	564.2	111.3	173.3	131.5	152.4	138.9	98.9	142.4	142.3

Potch = Potchefstroom

CONCLUSIONS

The different IMBAs exerted a profound positive effect on the selected soil quality indices of soil pH, organic C, available N and P. Application of IMBAs with optimum recommended NPK fertiliser rate (growth boosters) promoted acidity in soils compared to the use of IMBAs as either partial or total replacements of conventional NPK fertiliser. Application of all the different IMBA categories showed positive influence on organic C content only in light-textured soils. The use of IMBAs as growth boosters like Biozone, Gliogrow and K-humate, and with a partial replacement of NPK IMBA like Crop care augmented significant positive influence on available N across the sites. Soil available P was increased with application of either growth boosters or partial replacement of NPK at both soil types. The different IMBAs promoted higher C_{mic} immobilisation at 4-weeks after planting, but C_{mic} mineralisation was predominant at flowering and crop harvest, but tended to decline at crop harvest at both soil types. The steady immobilisation fluxes at 4-weeks after planting could therefore minimise leaching as nutrients are withheld until the appropriate time for crop utilisation.

Acknowledgements

This research was funded by Agricultural Research Council and Maize Trust, South Africa while technical support was provided by Molefe Thobakgale and Thato Matsela-Tsiu. The study bursary granted to the first author by Maize Trust is also immensely appreciated.

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