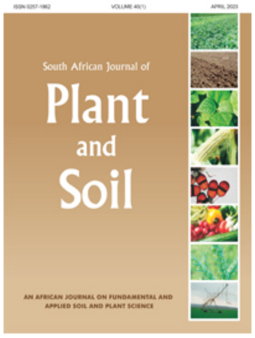

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Is the use of commercial organic ameliorants for cropping justified?

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Large areas of soils in sub-Saharan Africa are poor in organic matter and nitrogen-phosphorus-potassium (NPK) fertilisation is essential for cropping. Most farmers are smallholders who cannot afford NPK fertilisers but they could consider alternatives like commercial organic ameliorants.This applies also for commercial farmers to improve profitability. The effects of nine ameliorants on the grain yield, biomass yield and harvest index of maize were evaluated over three years at Bothaville (8% clay), Ottosdal (12% clay) and Potchefstroom (34% clay). All ameliorants were applied as manufacturers prescribe. None of the ameliorants can serve as replacement of NPK fertilisers. Active ingredients other than the small amounts of N, P and K they contain, comprised of effective microorganisms (EMs), human manure, humic acids and poultry manure, and were not able to boost crop growth as manufacturers advocated. Biozone (EMs), Gliogrow (EMs), Growmax (Human manure), K-humate (Humic acid) and Crop Care (Humic acid) that were applied with NPK fertilisation resulted in 22 to 44% instances in significantly higher grain yield (938 to 1 288 kg ha^{-1}) compared to the NPK control; however, many inconsistencies between experimental sites and years were observed. The use of commercial organic ameliorants cannot recommended to farmers without proper evaluation.

Keywords: Effective microorganisms, grain yield, humates, maize, manures

Introduction

Soils that are rich in organic matter are usually regarded as more productive than soils poor in organic matter (Peña-Mendéz et al. 2005). Recently, King et al. (2020) emphasised the importance of humic acids, which are a component of soil organic matter as a catalyst for crop production. Large areas of soils in sub-Saharan Africa (SSA) in their native state usually have low contents of organic matter (< 2% organic C according to Soudi et al. 2020) which is aggravated by unsustainable cropping practices (Usiri and Lal 2020). Conversion of such soils to cropland under prolonged conventional tillage can result in a 50–70% decline of organic C and N (Du Toit et al. 1994; Swanepoel et al. 2016; Du Preez et al. 2020). Studies have indicated that up to 65% of cropped soils in SSA have been degraded in soil fertility mainly due to continued cultivation coupled with inadequate nutrient replenishment (Zingore et al. 2015; Tindawa et al. 2020). Hence it is not surprising that conservation agriculture in some or other form by farmers is gaining momentum as a means of regenerating soil organic matter and fertility (Loke et al. 2021). The spectrum of farmers (from smallholder to commercial) in SSA generally accept to varying degrees that some form of conservation agriculture is more beneficial for their wellbeing than conventional agricultural practices (Usiri and Lal 2020). The majority of farmers in SSA are smallholders who aim to grow as many as possible of the crops that meet the needs of their households, with little or no surplus products to sell (Akongbowa et al. 2021). Commercial farmers on the other hand mainly produce crops for profit. Both kinds of farmers seek suitable ameliorants to replace NPK fertilisers either partially or fully, since smallholder farmers cannot afford adequate amounts of expensive NPK fertilisers while commercial farmers strive to reduce NPK fertilisation costs, both still aiming for optimum yields. Farmers may consider alternatives such as organic ameliorants (Palm et al. 1997) such as *Azolla carolliniana* compost (Bharali et al. 2021), *Eisena fetida* treated brick kiln coal ash (Mondal et al. 2020), municipal solid waste vermicompost (Sahariah et al. 2020) and biochar (Beusch 2021), to name a few investigated in countries around the world, each with advantages and disadvantages that must be considered before use.

The application of commercial organic ameliorants alone or in combination with various amounts of NPK fertilisers is sometimes recommended to farmers for soils with low organic matter soils to boost crop growth and ultimately yield (Ahmad et al. 2006; Nweke et al. 2013). More than 20 such organic ameliorants, manufactured by a range of companies, are available in South Africa (Baloyi et al. 2010). The products are very diverse in composition. Most of them contain effective microorganisms (EMs), manures (animal and human) and humic acids (brown coal extracts) as active ingredients (Baloyi et al. 2014), although some products may contain only two. Higa and Wididana (1991) researched the concept and theory of EM usage in cropping, and demonstrated that inoculation of the soil–plant system with cultures of EMs improves soil quality and crop response. The use of EMs is not widespread in South Africa and other SSA countries, although farmers who used the products were generally satisfied (Ncube 2008). Additions of EMs to soil–plant systems benefit the soil by improving the physical, chemical and biological environments of soil (Gomma et al. 2005), especially when applied together with manures (Hati et al. 2006). Animal manure, an agricultural commodity often available in large amounts, is an excellent source of the plant nutrients N, P and K, and can return these nutrients and other nutrients such as Ca, Mg and S to soil through mineralisation, thereby promoting soil fertility and improving quality (Belay et al. 2002). The benefits of commercial humates, which are salts of humic acids, were well documented by Ouni et al. (2014). According to them, humate application results in greater soil microbial activity and diversity, as well as improved plant growth and development. Despite these beneficial effects, Ceronio et al. (2022) are of the opinion that wheat yield increase through the use of K-humates does not compensate for the associated higher production cost. Manufacturers usually provide specific directions for usage of each organic ameliorant product, based probably on the active ingredient(s) they contain. Most of the organic ameliorants are recommended for soil application that coincide with no, partial or full NPK fertilisation; however, a few of the products are recommended for either seed and foliar or soil and foliar application (Baloyi et al. 2014).

The active ingredients of some South African organic ameliorants exerted inconsequential effects on seedling establishment and phenological growth of maize compared to the NPK control, depending on the environment and soil (Baloyi et al. 2010, 2014). Except for this information, to our knowledge no information exists on the organic ameliorants' influence concerning grain yield, biomass yield and harvest index of maize under field conditions. The question still remains whether the application of organic ameliorants is justified for cropping.

This study evaluated the performance of nine commercial organic ameliorant products, using grain yield, biomass yield and harvest index of the maize test crop as indicators. This investigation had a threefold aim: first to determine whether NPK fertilisation is beneficial for maize when cultivated on soils with relatively good fertility status; second, to compare the response of maize to organic ameliorants with a NPK control as reference; and third, to establish whether the organic ameliorants influence maize differently. Field trials were done over three years at three sites having respective clay contents of 8, 12 and 34% in the topsoil. All nine products were applied as prescribed by the manufacturers.

Materials and methods

Site description

Rainfed field trials were conducted for three consecutive cropping seasons (hereafter referred to as Years 1, 2 and 3) at three sites located in the maize-producing summer rainfall region of South Africa. Geographic and soil characteristics of the sites are given in Table 1, while Table 2 contains climatic data of the sites.

The sites were fields of commercial farmers at Bothaville, Ottosdal and at the ARC-grain experimental station at Potchefstroom. Preceding crops prior to establishment of the trials were sunflower at Bothaville and cowpea at Ottosdal and Potchefstroom. At each site, pre-planting analyses of a representative topsoil (0–200 mm) sample, composited of 50 subsamples taken with an Edelman auger across each site, were done with standard methods (Non-affiliated Soil Analysis Committee 1990): particle size (pipette method), organic C (Walkley–Black oxidation), pH (1:2.5 soil to water suspension), inorganic N (0.1 mol dm^{-3} K_2SO_4 solution), extractable P (Bray 1 solution), and exchangeable Ca, Mg, K and Na (1 mol dm^{-3} NH_4OAc solution). At all three sites the fertility status of the soils were reasonable for cropping although some fertilisation of N, P or K was required.

Based on land-type surveys and coinciding soil inventory databases of South Africa (ARC-SCW 2008), the clay content of most topsoils is < 10% at Bothaville, 10–15% at Ottosdal and > 30% at Potchefstroom. Results of this study are therefore applicable to soils falling within these categories based on the respective clay contents of 8, 12 and 34% in the topsoils at Bothaville, Ottosdal and Potchefstroom sites (Table 1). Besides clay content, other soil properties like those presented in Table 1 may also influence the performance of organic ameliorants. The soil properties are discussed later with regard to threshold values established for maize production in South Africa.

The climate experienced over the three trial years at each of the sites corresponds well with the long-term climate (Table 2). No extreme climate conditions were observed that would seriously affect the growth and development of maize. Climate conditions were therefore suitable for maize production at the three sites, favouring this investigation into the performance of organic ameliorants.

Treatments and experimental design

Nine commercial organic ameliorant products, categorised as suitable for use with full NPK fertilisation (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial NPK fertilisation (Crop Care and Monty's) and no NPK fertilisation (Growmor and Promis) were used in the study (Table 3). The organic ameliorants could also be categorised according to their active ingredients, namely EMs (Biozone and Gliogrow), composted human manure (Growmax), humic acids (K-humate, Crop Care and Monty's), poultry manure (Gromor and Promis), and a combination of EMs and humic acid (Lanbac). The elemental composition of each product is given in Table 4. Selection of the nine products was based primarily on their applications and composition to ensure that they are representative of the wider range of products available in the market.

Table 1: Geographic and soil characteristics of the three trial sites

Site	Bothaville	Ottosdal	Potchefstroom
Geographic			
Latitude	26°62′	26°08′	27°09′
Longitude	–27°38′	–26°81′	–27°07′
Altitude (m)	1 317	1 587	1 355
Soil			
Depth (m)	1.8	2.0	1.8
Soil form[a]	Avalon	Hutton	Westleigh
Textural class	Sandy loam	Loamy sand	Clay loam
Clay (%)	8	12	34
Silt (%)	1	7	17
Sand (%)	91	81	49
Organic C (%)	0.20	0.38	0.82
pH (H_2O)	7.02	5.83	6.61
N (mg kg^{-1})	0.9	2.8	5.7
P (mg kg^{-1})	22	16	56
K (mg kg^{-1})	74	135	192
Ca (mg kg^{-1})	348	317	840
Mg (mg kg^{-1})	97	102	360
Na (mg kg^{-1})	15	13	32

[a]Classified as Avalon, Hutton and Westleigh soil forms (Soil Classification Working Group 1991) or Stagnic Plinthic Cambisol, Chronic Cambisol and Ferric Stagnic Luvisol respectively (van Huyssteen 2020)

An untreated control and a NPK control (based on soil analyses and long-term yields) were also included as checks at each site. Fertiliser application rates were estimated as 100, 74 and 55 kg ha^{-1} N, P and K for Bothaville; 70, 74 and 0 kg ha^{-1} N, P and K for Ottosdal; and 80, 44 and 0 kg ha^{-1} N, P and K for Potchefstroom, respectively. These amounts were applied with the organic ameliorant products where manufacturer's directions recommended NPK fertilisation. Compared to the amounts of N, P and K applied through NPK fertilisation, the N, P and K applications by the organic ameliorants are neglible (equal to or less than 3.8, 1.6 and 20 kg ha^{-1} N, P and K, respectively) when based on the recommended rate (Table 3) and compositions (Table 4) of an organic ameliorant, except for the poultry-manure based Growmor, which amounted to 7.6, 3.2 and 40 kg ha^{-1} N, P and K, respectively. In the case of organic ameliorant products recommended for use with partial NPK fertilisation, the amounts were adjusted to prescribed levels. The sources of N, P and K were limestone ammonium nitrate (28% N), single superphosphate (10.5% P) and potassium chloride (50% K), respectively.

Treatments were replicated four times and arranged in a random complete block design. Each treatment was applied to a 10 m × 6 m plot. Prior to application, the soil-applied organic ameliorant products were broadcast uniformly over the appropriate plots and lightly worked into the soil with a spade, while the seed-applied organic ameliorant products were sprayed on the seeds before planting and the foliar-applied organic ameliorant products were sprayed on the plants after thinning using a CP15 knapsack sprayer. Where appropriate, the P and K fertilisers were band-placed at planting with 30% of the N fertiliser, while the remainder of the N fertiliser was band-placed 50 mm away from the row six weeks after planting.

Crop husbandry

Seedbed preparation at the trial sites was done by moldboard ploughing, disking and harrowing to induce a smooth soil. At each site, the trials were planted within a 6-day window period during the second half of November as recommended. All trials were planted manually using handjab planters adjusted to sow seeds at an intra-row spacing of 0.3 m with a row spacing of 1.5 m. A maize hybrid, PAN6479, was used as a test crop. Two uniform seeds were planted per stand to cater for a low seedling survival rate, and were subsequently thinned to one plant per stand when the plants had developed four fully expanded leaves, resulting in 22 222 plants ha^{-1}. Each plot comprised four rows. After each harvesting, maize stubble was incorporated into the soil with a rotavator and sites left bare until the next planting, repeated the treatments on the same plots. Dual (S-metolachlor) was sprayed at 2 l ha^{-1} as pre-emergence herbicide to destroy upcoming weeds,

Table 2: Climatic data for the three trial years and on the long-term at the three sites (ARC-SCW 2020)

		P			Tn			Tx			A-pan		
Locality	Year	1	2	3	1	2	3	1	2	3	1	2	3
Bothaville	In-season	401	369	538	9	10	11	28	27	27	5	4	4
	Pre-season	89	192	43	6	7	6	26	24	27	5	5	6
	Annual	490	562	580	7	8	9	27	26	27	5	5	5
	Long-term	502	502	502	10	10	10	27	27	27	5	5	5
Ottosdal	In-season	267	429	442	10	12	10	28	25	26	6	4	3
	Pre-season	66	32	44	9	7	7	25	28	26	6	4	6
	Annual	333	460	486	9	9	9	26	27	26	6	4	4
	Long-term	593	593	593	10	10	10	27	27	27	6	6	6
Potchefstroom	In-season	544	476	497	11	13	11	27	25	26	5	5	3
	Pre-season	99	175	51	9	9	8	26	25	27	5	5	5
	Annual	643	651	547	10	11	10	27	25	27	5	5	4
	Long-term	622	622	622	11	11	11	25	25	25	5	5	5

P = Annual mean precipitation (mm) Tn = Daily mean minimum temperature (°C)
Tx = Daily mean maximum temperature (°C) A-pan = Daily mean evaporation (mm)
Pre-season climatic data = July to October; in-season climatic data = November to June

Table 3: The nine organic ameliorants evaluated over three years at the three trial sites

Active ingredient(s)	Ameliorant	Application	Recommendation
Effective micro-organisms (EMs)	Biozone	Soil	100% OFR[a] + 10 L ha^{-1} of Biozone at planting
	Gliogrow	Seed and foliar	100% OFR + 0.2 L ha^{-1} of Maxiflo + 0.2 L ha^{-1} of Trykocide + 0.1 L ha^{-1} of Teprosyn Zn/P per 25 kg seed and 0.4 L ha^{-1} of Maxiflo + 0.4 L ha^{-1} of Trykocide at 4 weeks after emergence
Poultry manure	Gromor	Soil	2000 kg ha^{-1} at planting
	Promis	Soil	1000 kg ha^{-1} at planting
Composted human manure	Growmax	Soil	Blend with inorganic fertiliser to supply 100% OFR
Humic acid	K-humate	Soil	100% OFR + 20 kg ha^{-1} of K-humate a week prior to planting
	Crop Care	Soil and foliar	70% OFR + 400 kg ha^{-1} of Growmax + 5 L ha^{-1} of Agri-balance at planting and 2.5 L ha^{-1} Agri-boost and 2.5 L of Agri-Zinc at 4 weeks after planting and2 L ha^{-1} Agri-fulbor at tasseling
	Monty's	Soil	50% OFR + 3L ha^{-1} at planting.
EMs and humic acid	Lanbac	Soil	100% OFR + 10 L ha^{-1} of MS humate + 2 kg ha^{-1} of Microboost + 2 L ha^{-1} Microbial inoculants at planting.

[a]Optimum fertiliser rate based on soil analyses and target yields

while sites were kept weed free during the growing season through mechanical weeding when necessary. Combat pesticide was similarly applied at 4 kg ha^{-1} to protect the crop from maize stalk borer when signs of damage became noticeable from eight weeks after planting.

Measurements

During harvesting, the cobs were removed from the plants, leaves (husks) from the cobs, grain from the cobs and the resulting stover was field weighted before being slashed. Subsamples of the slashed stover were oven-dried at 65 °C to a constant weight for the estimation of stover yield. The grain was also field weighed and subsamples were dried to a constant weight, whereafter grain yield was adjusted to the prescribed 12.5% moisture content. Biomass yield (stover plus grain yield) and harvest index (grain yield/biomass yield) were then calculated.

Data analyses

A factorial analysis of variance (ANOVA) with sites, years and treatments as factors was initially done on the data, using the statistical package of Genstat 5, Release 3.2, for Windows (Payne et al. 2017). The outcome of this ANOVA was confounded due to inconsistencies between the factors included in the ANOVA (data not shown) and we were advised by the statistician who assisted us to do instead a one-way ANOVA for each year at a site. This approach led to better interpretable outcomes concerning the impact of organic ameliorant treatments on grain yield, biomass yield and harvest index of the test crop. Assumptions for ANOVA were satisfied by testing residuals for normality (Shapiro and Wilk 1965) and variance for homogeneity (Levene 1960). Tukey's post-hoc comparison test was used to calculate significant differences (HSD) at $p < 0.05$ to compare treatment means.

Results

Bothaville

The response of maize to the organic ameliorants is displayed in Figure 1. Over the three years, grain yield, biomass yield and harvest index for the untreated control ranged from 1 458 to 1 542 kg ha^{-1}, 3 861 to 5 373 kg ha^{-1} and 0.34 to 0.42, respectively. Compared to the untreated control, the NPK control resulted in a significantly higher grain yield (2 334–2 525 kg ha^{-1}), biomass yield (5 579–7 079 kg ha^{-1}) and

Table 4: Total elemental composition of the nine organic ameliorants used for evaluation

	pH (H_2O)	C (%)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})
Biozone	3.1	2.15	0.02	0.01	0.01	1.00	0.01	2.75
Gliogrow	4.0	0.43	0.21	0.01	0.01	0.13	0.13	1.25
Growmax	6.8	28.3	3.00	3.0	3.0	1.38	0.88	1.75
K humate	9.6	> 60	6.92	17.6	101.0	7.50	1.25	12.0
Lanbac	5.1	3.8	0.38	0.58	2.50	1.00	0.38	4.25
Crop Care	8.1	2.66	0.96	1.17	4.13	0.63	0.38	7.00
Monty's	9.5	3.33	0.45	1.17	0.13	1.75	0.50	5.00
Gromor	6.0	35.3	3.80	16.0	20.0	0.30	5.00	1.00
Promis	5.8	42.9	4.00	1.60	1.80	3.25	0.70	0.08

harvest index (0.37–0.47). None of the organic ameliorants resulted in significantly lower (69 kg ha^{-1} with Growmax to 514 kg ha^{-1} with Growmor) or higher (32 kg ha^{-1} with Monty's to 649 kg ha^{-1} with Gliogrow) grain yield than the NPK control in Year 1. Growmax was the only organic ameliorant that significantly affected biomass yield. Biomass yield was lowered by Growmax with 2 082, 2 609 and 1 315 kg ha^{-1} in Years 1, 2 and 3, respectively. In Year 1 Biozone (0.09) and in Year 3 Biozone (0.10), Gliogrow (0.09), K-humate (0.10) and Crop Care (0.10) increased harvest index significantly, using the NPK control as reference.

Ottosdal

The effects of organic ameliorants on grain yield, biomass yield and harvest index of maize over the three years are shown in Figure 2. As in Bothaville, grain yield, biomass yield and harvest index of the NPK control were higher than in the untreated control. The differences were however not significant for grain yield in Years 1, 2 and 3, compared to the NPK control. Only Gliogrow resulted in a significantly higher biomass yield of 3 709 kg ha^{-1} in Year 1 and a significantly lower biomass yield of 1 452 kg ha^{-1} in Year 2, using the NPK control as reference. Compared to the harvest index of the NPK control, significantly larger values were estimated for Biozone (0.09), Gliogrow (0.08) and Lanbac (0.11) in Year 1 and for Gliogrow (0.06) in Year 3.

Potshefstroom

Grain yield, biomass yield and harvest index were also influenced by organic ameliorants over the three years (Figure 3). In all three years grain yield was significantly lower in the untreated control than in the NPK control. Except for Year 1, this was also the case with biomass yield and harvest index in the next two years. In Year 1, a significantly higher grain yield of 936 kg ha^{-1} resulted from the application of Gliogrow, and a significantly lower grain yield of 849 kg ha^{-1} resulted from the application of Growmor, than in the NPK control. Compared to the NPK control, only Gliogrow in Year 1 and Growmax in Year 3 increased biomass yield significantly. In Year 1, compared to the NPK control, the harvest index was significantly increased by Gliogrow (0.06) and significantly decreased by Growmor (0.07).

Discussion

At all three sites, grain yield, biomass yield and harvest index indicate that NPK fertilisation at the estimated rates is essential for obtaining potential target yields (Figures 1, 2 and 3), despite that the fertility status of the soils before commencement of the trials was almost acceptable for cropping (Table 1), and that climate conditions during the the trials were suitable for the cultivation of dryland maize (Table 2). Substantially lower yields were measured with no NPK fertilisation, which may indicate uneconomical maize production because inputs other than fertilisation remain almost the same. Apart from fertilisation, soil fertility status and climate conditions could influence the growth and development of maize.

Soil fertility status

The suggested pH(H_2O) threshold is 6.5 while the soils' pH at Bothaville (7.02) were slightly higher and at Ottosdal (5.83) slightly lower (FSSA 2007). At Potchefstroom, the pH of the soil was 6.61, almost similar to the threshold value. Compared to the upper inorganic N threshold concentration established by Van Biljon et al. (2008), the soils' inorganic N concentrations were very low. The Bray 1 extractable P concentration at Ottosdal (16 mg kg^{-1}) was slightly lower and at Potchefstroom (56 mg kg^{-1}) much higher than the the 20 mg kg^{-1} the FSSA (2007) recommended, and at Bothaville more or less similar to the threshold. A threshold of 100 mg kg^{-1} NH_4OAc extractable K is recommended. However, the K concentration at Bothaville (74 mg kg^{-1}) was much lower and at Potchefstroom (192 mg kg^{-1}) much higher. Compared to the threshold of 400 mg kg^{-1}, the Ca concentrations at Bothaville (348 mg kg^{-1}) and Ottosdal (317 mg kg^{-1}) were lower and at Potchefstroom (840 mg kg^{-1}) much higher. The Mg concentration at Potchefstroom (360 mg kg^{-1}) was also much higher than the 100 mg kg^{-1} threshold, while at Ottosdal and Bothaville the Mg concentrations were close to the threshold. Based on the variation of the above mentioned soil fertility indicators between the three sites, it is unlikely that the performance of the organic ameliorants was influenced by soil fertility status except for clay content that would serve as a buffer.

Climate conditions

The diverse effects of the organic ameliorants over the three years on the grain yield, biomass yield and harvest index of maize (Figures 1, 2 and 3) could also be partly attributed to climate conditions that prevailed over the three years. For example, at Bothaville pre-season precipitation in Years 1 and 3 was far lower than in Year 2, while in-season precipitation was lowest in Year 2, followed by Year 1 and then Year 3 (Table 2). The pre-season precipitation at Ottosdal ranged from only 32 mm in Year 2 to 68 mm in Year 1 which was probably too little to influence the performance of the organic ameliorants. In-season precipitation differed, however, from 267 mm in Year 1 to 442 mm in Year 3 which was probably large enough to influence the organic ameliorants' performance. At Potchefstroom pre-season precipitation was lowest (51 mm) in Year 3 and highest (175 mm) in Year 2, with that of Year 1 (99 mm) intermediate. Contrary to pre-season precipitation, in-season precipitation differed by only 68 mm between the three trial years. Comprehensive research showed that the growth and development of maize are influenced by total precipitation (pre- and in-season), and especially by its distribution (Hensley and Bennie 2003). Precipitation impacts soil water content, which could help to explain the inconsistencies of the organic ameliorants on grain yield, biomass yield and harvest index of maize between sites and years. Soil water content was unfortunately not quantified.

At the three sites over the three years, the daily in-season mean minimum temperature ranged between 9 °C in Year 1 at Bothaville to 13 °C in Year 2 at Potchefstroom (Table 2). However, the daily in-season mean maximum temperature varied only from 25 °C in Year 2 at both Ottosdal and Potchefstroom to 28 °C in Year 1 at both Bothaville and

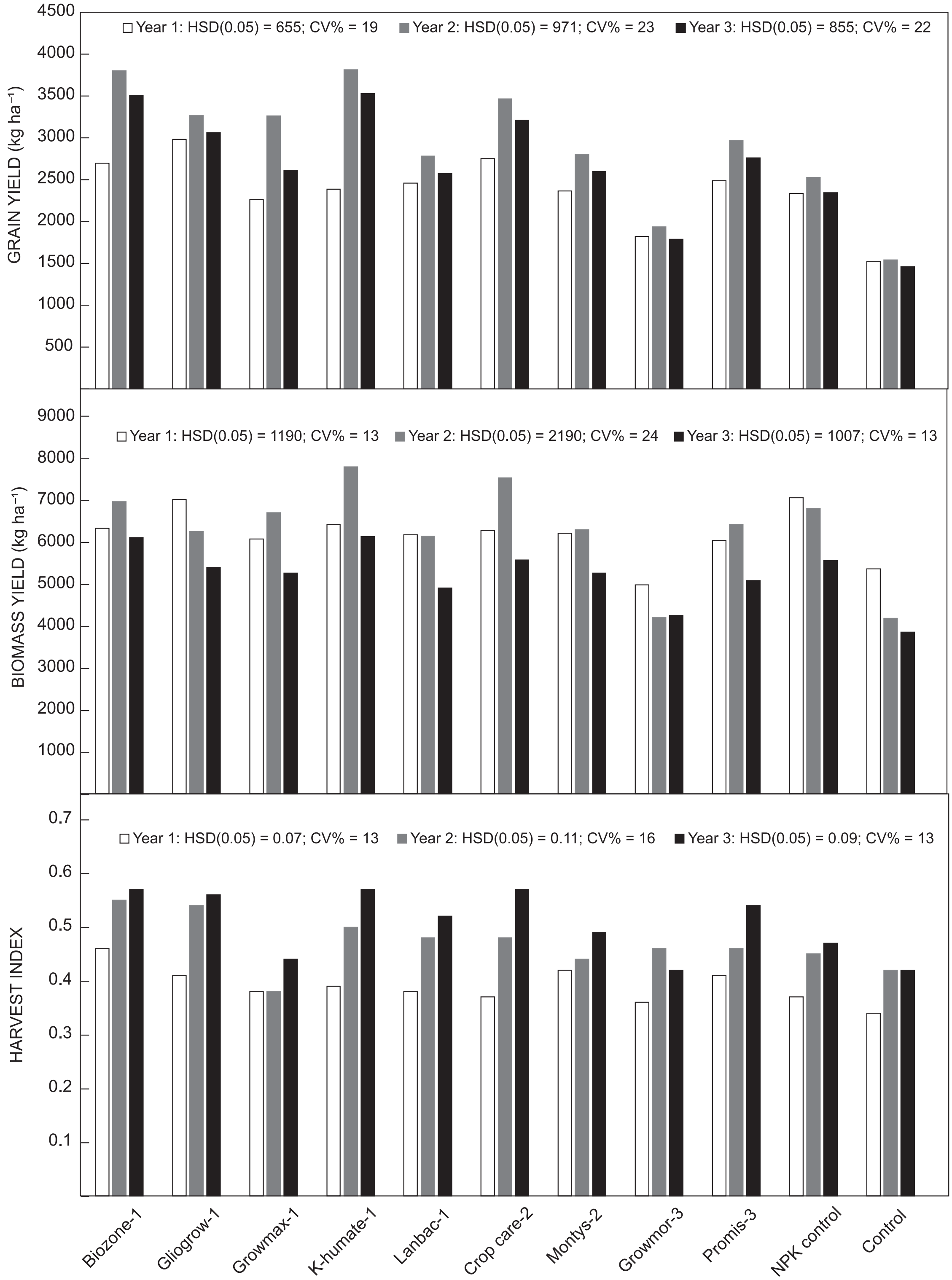

Figure 1: Influence of organic ameliorants on grain yield, biomass yield and harvest index of maize at Bothaville over three years. As recommended, full (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial (Crop Care and Monty's), and no (Growmor and Promis) NPK fertilisation were applied to the respective ameliorants

Ottosdal. The differences in temperature should have miniscule effects on the growth and development of maize, regardless of the the organic ameliorant applied.

Generally, in-season daily mean evaporation was very stable at the three sites over the three years, having probably little effect on the performance of maize due to

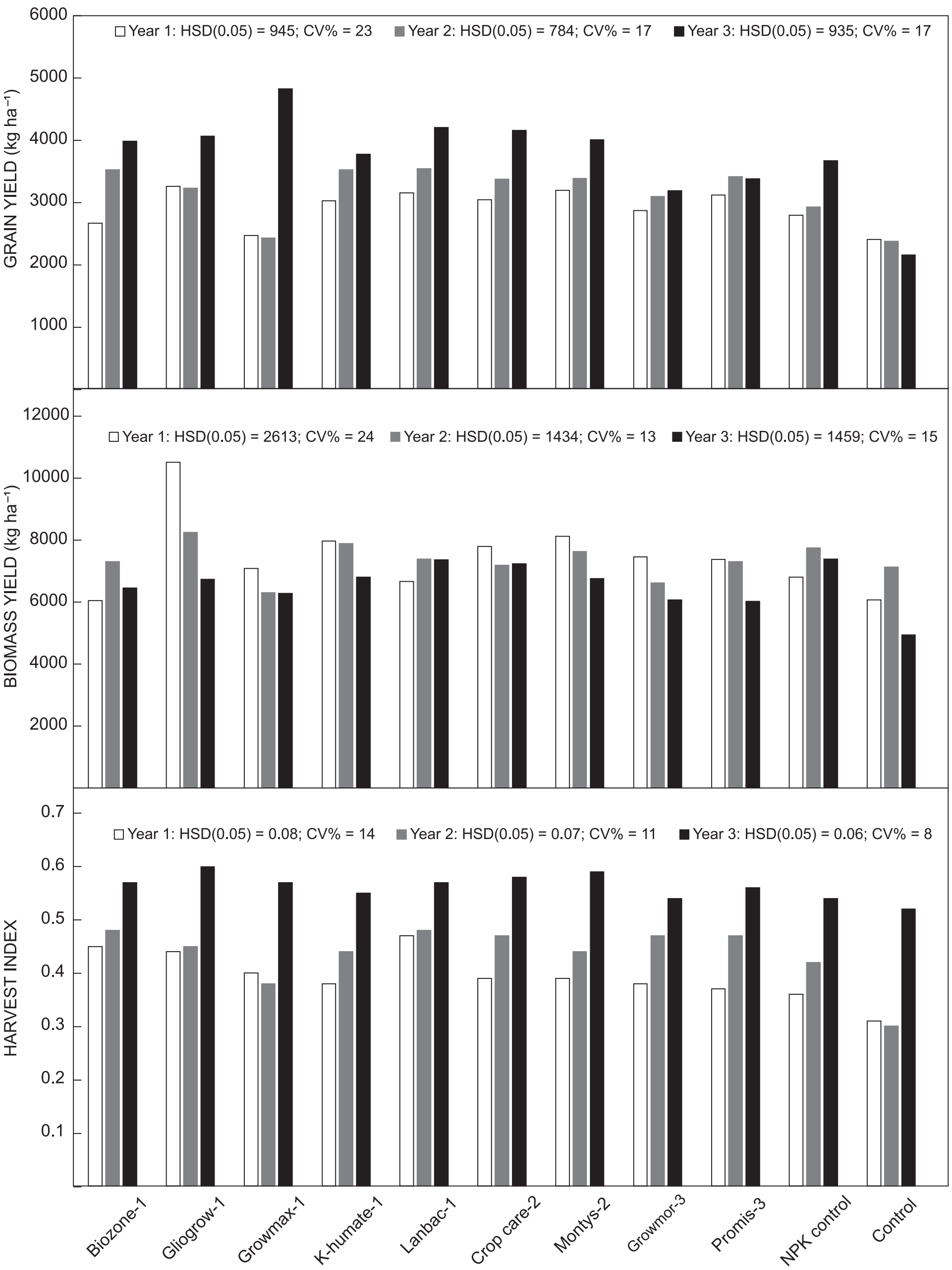

Figure 2: Influence of organic ameliorants on grain yield, biomass yield and harvest index of maize at Ottosdal over three years. As recommended full (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial (Crop Care and Monty's), and no (Growmor and Promis) NPK fertilisation were applied to the respective ameliorants

the organic ameliorant applications. Values varied only from 3 mm in Year 3 at Potchefstroom to 6 mm in Year 1 at Ottosdal (Table 2)

Organic ameliorants' performance

As five organic ameliorants, namely Biozone, Gliogrow, Growmax, K-humate and Lanbac were applied with full NPK fertisation, it can be assumed that the performance of the five organic ameliorants was not restricted by soil fertility status, while the performance of Crop Care and Monty's (applied with partial NPK fertilisation) and of Growmor and Promis (applied with no NPK fertilisation) could probably be affected by soil fertility status. Despite this variation in NPK fertilisation, the organic ameliorants are categorised as follows: Biozone and Gliogrow as EMs based, Growmax as composted human manure based, K-humate, Crop Care and Monty's as humic acid based, and Gromor and Promis as poultry manure based, Lanbac as EMs plus MS humate based (Table 3), all of which can influence the soils and crops differently.

A comparison of the organic ameliorants' performance is problematic because they were applied with full, partial or

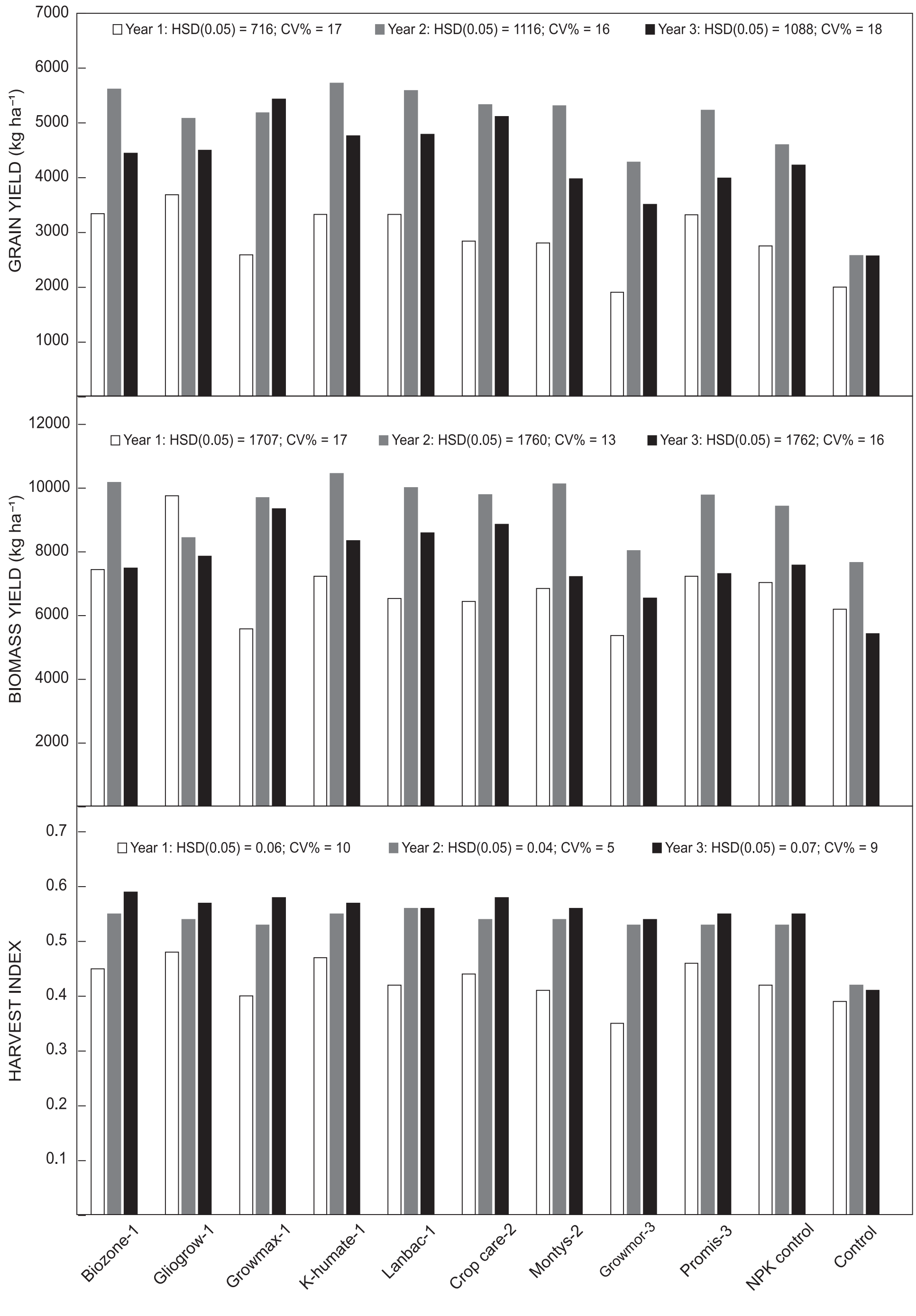

Figure 3: Influence of organic ameliorants on grain yield, biomass yield and harvest index of maize at Potchefstroom over three years. As recommended full (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial (Crop Care and Monty's), and no (Growmor and Promis) NPK fertilisation were applied to the respective ameliorants

no NPK fertilisation as recommended by the manufacturers. Compared to the untreated control, grain yields with the organic ameliorants were in 64 instances significantly higher, in 14 instances similar and in three instances significantly lower (Table 5). Almost similar trends were observed for biomass and harvest index (data not shown). Although the results of grain yield favoured the use of organic ameliorants in the short term, it should be recognised that the climate conditions (Table 2) and soil fertility status (Table 1) were of such a nature that good yields could be expected by Biozone, Gliogrow, Growmax, K-humate and Lanbac, which all coincided with full NPK fertilisation. Over the long term, nutrient mining would be likely to occur with Crop Care and Monty's (Partial NPK fertilisation), and with Growmor and Promis (no NPK fertilisation) because the total application of N, P and K through fertilisation and the four organic ameliorants are much lower than crop removal. Olupot et al. (2020) reviewed the mining of nutrients in the soils in detail, and suggested appropriate technologies to combat this depletion when inadequate NPK fertilisation is applied. The recuperation of soil fertility is usually a challenge for farmers, especially the smallholders.

In view of the nutrient mining that may occur with Crop Care, Monty's, Growmax and Promis (applied without full NPK fertilisation), it seems that the best insight concerning the performance of all organic ameliorant products can be obtained by comparing them with the NPK control. The application of the nine organic ameliorant products at the three sites had diverse effects on the maize grain yield over the three years when the NPK control serves as reference (Table 6). In most instances (65 out of 81 cases) there was no significant influence at all on the grain yield, while in fewer instances (16 out of 81 cases) a significant influence was observed. Out of the 16 significant instances, grain yield was positively influenced in ten and negatively in three by the organic ameliorants. The influence of the organic ameliorant products on grain yield, biomass yield and harvest index compared to the NPK controls at each site is discussed below.

It is noteworthy that at Bothaville, only Biozone (1 275 and 1 167 kg ha^{-1} in Years 2 and 3, respectively), K-humate (1 288 and 1 877 kg ha^{-1} in Years 2 and 3, respectively) and Crop Care (867 kg ha^{-1} in Year 3) gave significantly higher grain yields than the NPK control (Figure 1). The grain yields in all other instances were neither higher nor lower than that of the NPK control. Compared to the NPK control, Growmor resulted in Years 1, 2 and 3 in significantly lower biomass yields of 2 082, 2 609 and 1 315 kg ha^{-1}, respectively. In all other organic ameliorant treatments, biomass yields were not significantly different from the NPK control. Concerning harvest indices of Biozone (0.46 and 0.57 in Years 1 and 3 respectively, K-humate (0.57 in Year 3) and Crop Care (0.57 in Year 3) significantly exceeded that of the NPK control (0.37, 0.45 and 0.47 in Years 1, 2 and 3 respectively).

At Ottosdal, compared to the NPK control, the organic ameliorants did not affect grain yield significantly at all (Figure 2). In Year 1 Gliogrow induced a significantly higher biomass yield of 3 709 kg ha^{-1} while in Year 2 Growmor caused a significantly lower biomass yield of 1 450 kg ha^{-1}. The estimated harvest indices for Gliogrow (0.60 in Year 3) and Lanbac (0.47 in Year 1) exceeded those of the NPK control (0.36 and 0.54 in Year 1 and 3 respectively) significantly.

Application of Gliogrow in Year 1 and 3 resulted in significantly higher grain yields (936 and 1 210 kg ha^{-1}, respectively) and biomass yields (2 733 and 1 777 kg ha^{-1} respectively) than the NPK control at Potchefstroom (Figure 3). A significantly lower grain yield of 849 kg ha^{-1} was recorded in Year 1 with Growmore than that of the NPK control. Compared to the NPK control, only Gliogrow had a positively significant impact on the harvest index in Year 1.

Based on the above information, Biozone, Gliogrow, K-humate and Crop Care performed better than the other organic ameliorants, although not very consistently over sites and years. Application of Biozone, Gliogrow and K-humate coincided with full NPK fertilisation while Crop Care coincided with partial NPK fertilisation (Table 3). The NPK fertilisation could have led to an improvement of soil fertility and therefore it is impossible to attribute the performance of these organic ameliorants to either their inorganic or organic ingredients. This aspect justifies thorough investigation in future. Gromor, which was applied with no NPK fertilisation, was the poorest performer of all the organic ameliorant products, probably due to its organic constituents, the concentrations of which were not listed on the product. Use of this organic ameliorant and others that were applied with partial (Monty's) and no (Promis) NPK fertilisation may lead, in the long term, to soil fertility exhaustion.

Based on the chemical composition (Table 4) and prescribed application rates (Table 3) of the organic ameliorant products, the amounts of N, P and K applied through the organic ameliorant products were minute compared to the estimated N, P and K for the NPK control at Bothaville (100, 74 and 55 kg ha^{-1} of N, P and K, respectively), Ottosdal (70, 74 and 0 kg ha^{-1} of N, P and K, respectively) and Potchefstroom (80, 44 and 0 kg ha^{-1} of N, P and K, respectively). The application of N, P and K were lowest with Biozone (0.2, 0.1 and 0.1 mg ha^{-1} of N, P and K, respectively) and highest with Growmor (7.6, 32 and

Table 5: Organic ameliorants that resulted in significant lower (–), no significantly different (0) and significantly higher (+) grain yields than the untreated control

Ameliorant	Bothaville			Ottosdal			Potchefstroom		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Biozone [a]	+	+	+	0	+	+	+	+	+
Gliogrow [a]	+	+	+	0	+	+	+	+	+
Growmax [a]	+	+	+	0	0	+	0	+	+
K-humate [a]	+	+	+	0	+	+	+	+	+
Lanbac [a]	+	+	+	0	+	+	+	+	+
Crop Care [b]	+	+	+	0	+	+	+	+	+
Monty's [b]	+	+	+	0	+	+	+	+	+
Growmor [c]	0	–	0	0	0	+	–	+	–
Promis [c]	+	+	+	0	+	+	–	+	+

[a] Full NPK fertilisation [b] Partial NPK fertilisation [c] No NPK fertilisation

Table 6: Organic ameliorants that resulted in significant lower (–), no signicant different (0) and significant higher (+) grain yields than the NPK control

Ameliorant	Bothaville			Ottosdal			Potchefstroom		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Biozone [a]	0	+	+	0	0	0	0	0	0
Gliogrow [a]	0	0	0	+	0	0	+	0	0
Growmax [a]	0	0	0	0	0	+	0	0	+
K-humate [a]	0	+	+	+	0	0	0	+	+
Lanbac [a]	0	0	0	+	0	0	0	0	0
Crop Care [b]	0	0	+	+	0	0	0	0	0
Monty's [b]	0	0	0	+	0	0	0	0	0
Growmor [c]	0	0	0	0	0	0	–	0	0
Promis [c]	0	0	0	+	0	0	0	0	0

[a] Full NPK fertilisation [b] Partial NPK fertilisation [c] No NPK fertilisation

40 g ha^{-1}, respectively). It is not therefore surprising that manufacturers recommended full NPK fertilisation for Biozone, Gliogrow, Growmax, K-humate and Lanbac. However, partial NPK fertilisation for Crop Care and Monty's, and no NPK fertilisation for Growmor and Promis are suggested by the manufacturers. The beneficial effects of the organic ameliorant products as claimed by the manufacturers could be attributed to ingredients other than the nutrients they comprised of as given in Table 3. These ingredients have apparently little effect on the grain yield, biomass yield and harvest index of maize.

Concerning the EMs-based organic ameliorants (Biozone and Gliomore), only Biozone resulted in a significantly higher grain yield (Years 2 and 3) and harvest index (Years 1 and 3) than the NPK control, indicating that soil application of Biozone's *Brevibacillus latirosporus* was more effective than Gliogrow's foliar application of *Epipolitheeodioxperazim* spp. Either the kind of application or the EMs culture of Gliogrow could have resulted in a lower influence on grain yield and harvest index of maize than that of Biozone.

Although Gromor and Promis both have poultry manure as active ingredient and are applied at relatively high rates to soil at planting (Table 3), the grain yield, biomass yield and harvest index of maize did not respond with positive significance to the application of these two organic ameliorant products compared to the NPK control (Figures 1, 2 and 3). This could be ascribed on the one hand to no NPK fertilisation being applied and on the other hand to mineralisation of the poultry manure that was insufficient to provide the nutrient requirements of maize. In this regard, Belay et al. (2002) indicated that after manure is added to soil it is initially mineralised rapidly until the labile compounds are exhausted, after which the mineralisation rate declines with the formation of more stable organic substances. Similarly, Baloyi et al. (2014) reported that maize plants treated with the same two poultry manure based organic ameliorant products had vigorous growth at ninth leaf stage but revealed a reduced plant stature at silking stage compared with the NPK control plants.

Similar to Growmor and Promis, the composted human manure based Growmax also had no significant influence on the grain yield, biomass yield and harvest index of maize, although NPK fertilisation was applied. This is a strange phenomenon and no obvious explanation can be given.

In the case of the humic acid based organic ameliorant products K-humate, Crop Care, Lanbac and Monty's, only K-humate (Years 2 and 3) and Crop Care (Year 3) resulted in grain yields that significantly exceeded that of the NPK control. The harvest index induced by K-humate and Crop Care, compared to the NPK control was also higher in Year 3. Biomass yield was not influenced by the two organic ameliorant products at all. Several studies variously reported that humates had positive, negative and no effects on either soils and crops, probably due to the wide range of extraction methods and processes used for the production, together with poor characterisation of the products (Nardi et al. 2002).

The soil fertility status of the land of smallholder farmers is usually lower than that of commercial farmers (Oluput et al. 2020). Due to financial constraints the use of commercial organic ameliorant products by smallholder farmers is more risky than for commercial farmers. As established in this study, NPK fertilisation cannot be replaced by organic ameliorants. At best, organic ameliorants can be used supplementally to NPK fertilisation. The increases in grain yield that resulted from Biozone, Gliogrow, K-humate and Crop Care, which coincide with NPK fertilisation, although not consistent over experimental sites and years, may be significant enough to justify the additional cost associated with these products. A thorough investigation into the economic viability of Biozone, Gliogrow, K-humate and Crop Care is thus essential before it can be recommended to farmers.

Conclusions

Potential users of commercial organic ameliorants to enhance crop production must be cautious about the claims made by manufacturers of the products. All nine organic ameliorant products that were evaluated contain a very small fraction of the N, P and K needed by crops. The organic ameliorants therefore cannot serve as a replacement for NPK fertilisation, as is often claimed. Active ingredients other than N, P and K are apparently not able to enhance crop growth to the extent manufacturers claimed. The use of five organic ameliorant products, namely Growmax, Lanbac, Monty's, Growmor and Promis, were not deemed to demonstrate significant value. Only organic ameliorant products that coincide with sufficient NPK fertilisation were deemed worth considering for use, namely Biozone, Gliogrow, K-humate and Crop Care. These four organic ameliorant products resulted in only 22–44% instances of significantly higher grain yield compared to the NPK control. Increases in grain yield were relatively small and an investigation into the economic viability of the four organic ameliorant products is therefore essential before Biozone, Gliogrow, K-humate and Crop Care can be recommended to farmers, especially smallholders.

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