Journal of Geoscience and Environment Protection, 2023, 11, 102-125
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Impact of Commercial Organic Ameliorants on Nitrogen and Phosphorus Concentrations of Maize Biomass at Ninth Leaf and Silking Growth Stages

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How to cite this paper: Baloyi, T. C., Kutu, F. R., & du Preez, C. C. (2023). Impact of Commercial Organic Ameliorants on Nitrogen and Phosphorus Concentrations of Maize Biomass at Ninth Leaf and Silking Growth Stages. *Journal of Geoscience and Environment Protection, 11,* 102-125.
https://doi.org/10.4236/gep.2023.115006

Received: March 28, 2023
Accepted: May 26, 2023
Published: May 29, 2023

Abstract

The response of grain yield, biomass yield and harvest index of maize to the application of commercial organic ameliorants was inconsistent and poor. Hence it was hypothesized that the supply of N and P to maize plants was inadequate during vegetative growth, resulting in low concentrations of the two nutrients in maize biomass. The effects of nine ameliorants on the N and P concentrations of maize plants at ninth leaf (V9) and silking (R1) stages of maize were studied over three years at Bothaville (8% clay), Ottosdal (12% clay) and Potchefstroom (34% clay). All ameliorants were applied as prescribed by manufacturers. The N and P concentrations in maize biomass of the ameliorants at V9 and R1 were lower, comparable or higher, showing that the inconsistent and poor response of yield parameters can not be ascribed to inadequate uptake of N and P. A matter of concern that justifies thorough investigation, is the prescribed use of Crop care and Growmor with partial and of Montys and Promis with no NPK fertilization, an unsustainable practice over the long term. Characterization of the active ingredient(s) of the ameliorants is deemed also of importance for better insight.

Keywords

Field Trials, Grain Yield, Primary Nutrients, Reproductive Growth, Vegetative Growth

1. Introduction

The use of commercial organic ameliorants (hereafter refer to ameliorants) is sometimes advocated to enhance the growth and development of maize (Ahmad et al., 2006; Nweke et al., 2013). These products are diverse in composition, however, most of these products are comprised of effective microorganisms (EMs), manure (Animal and human) and humic acids (Brown coal extracts) as active ingredients (Baloyi et al., 2010). In some instances, two or more of the ingredients are combined in a product.

The concept and theory of EMs usage in cropping are dealt extensively by Higa and Wididana (1991). Research showed that inoculation of the soil-plant system with cultures of EMs improves soil quality and crop response. 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 manure (Palm et al., 1997). Manure an agricultural commodity available in large amounts is an excellent source of the plant nutrients N, P and K and subsequently returns part of these nutrients and other nutrients such as Ca, Mg and S to soil through mineralization, promoting soil fertility and quality (Belay et al., 2002). The benefits of commercial humates which are salts of humic acids, were well documented by Ouni et al. (2014). Application of humates results not only in more soil microbial activity and diversity but also in better plant growth and development (Nardi et al., 2002). Conversely, Ceronio et al. (2022) found no better wheat growth and development after the application of potassium humate.

Manufacturers of the ameliorants provide usually specific prescriptions for the usage of each, based probably on the active ingredient(s) they contain. Most of the ameliorants are recommended for soil application that coincide with no, partial or full NPK fertilization. Some of the products are recommended, however, for a combination of either seed and foliar or soil and foliar application (Baloyi et al., 2014).

Nine of the ameliorants that are commercially available in South Africa were evaluated by Baloyi et al. (2023) over three years in a field study at three sites having topsoil clay contents of 8%, 12% and 34%, respectively. The ameliorants comprised of Biozone, Gliogrow, Growmax, K-humate, Lanbac, Crop care, Montys, Growmor and Promis. Each of the ameliorants was applied to the soil-plant system as prescribed by the manufacturer. Hence, the application of Biozone, Gliogrow, Growmax, K-humate and Lanbac coincide with full NPK fertilization, while the other four ameliorants coincide with partial (Crop care and Montys) and no (Growmor and Promis) NPK fertilization. Maize was planted as a test crop and the response of grain yield, biomass yield and harvest index were quantified. Compared to the recommended NPK fertilization, the impact of the ameliorants on the three measured indicators was disappointedly inconsistent and poor. Only Biozone, Gliogrow, K-humate and Crop care are deemed worthwhile to consider for use.

The concentration and uptake of either N or P by maize at V9 and R1 (see Aldrich et al., 1986 and Hoeft et al., 2000 for detail) may shed some light on the inconsistent and poor performance of the ameliorants. Both N and P are regarded as essential primary plant nutrients (Bennett, 1993; Havlin et al., 2014). For maize, N absorption peaked approximately two weeks before flowering whilst P absorption peaked at flowering (FERTASA, 2016). Hence sufficient supply of N and P from V7 to R1 (Hoeft et al., 2000) is critical because during this period the fixation of the potential yield of maize happens (O'Keefe, 2009; Bender et al., 2013).

Nitrogen is a very dynamic nutrient in the soil-plant system. Usually, only a portion of the N requirement of maize is applied at planting. The remaining N is then either side- or top-dressed during the initiation of the ears (V7 to V11). This management strategy is followed to avoid excessive losses of applied N which could be environmentally detrimental and to ensure that sufficient N is available for the crop before commencement of R1. As indicated earlier, from V7 to R1 the potential yield of maize is fixed during this period (Fagaria et al., 2011).

Compared to N, is P in the soil-plant system very immobile and band-placed therefore at planting when a soil has a threshold P concentration of 95% relative yield (FERTASA, 2016). A soil's threshold P concentration decreased with higher silt-plus-clay content. Band placement of P within the root zone is recommended for effective utilization of the nutrient by maize.

The aim of this study was to establish whether the inconsistent and poor performance of the nine ameliorants could be ascribed probably to the concentration of either N or P in maize biomass when fixation of potential yield takes place from V7 to R1. This kind of research on ameliorants was not done yet to our knowledge. Hence, results of either N or P concentration at V9 and R1 of maize from a field study that ran over three years at three sites are reported. These nutrient concentrations were used to determine first whether NPK fertilization is beneficial for maize when cultivated on soils with relatively good fertility status, second to compare the response of maize to the ameliorants with NPK control as reference, and third to establish whether the ameliorants influence maize differently.

2. Materials and Methods

2.1. Site Description

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

The sites were commercial farmers' fields at Bothaville and Ottosdal and on experimental station at Potchefstroom. Preceding crops prior to establishment of the trials were sunflower at Bothaville and cowpea at either Ottosdal or Potchefstroom. Pre-planting analyses of a representative topsoil (0 - 200 mm) sample composited of 50 subsamples taken with an Edelman auger across a site, were

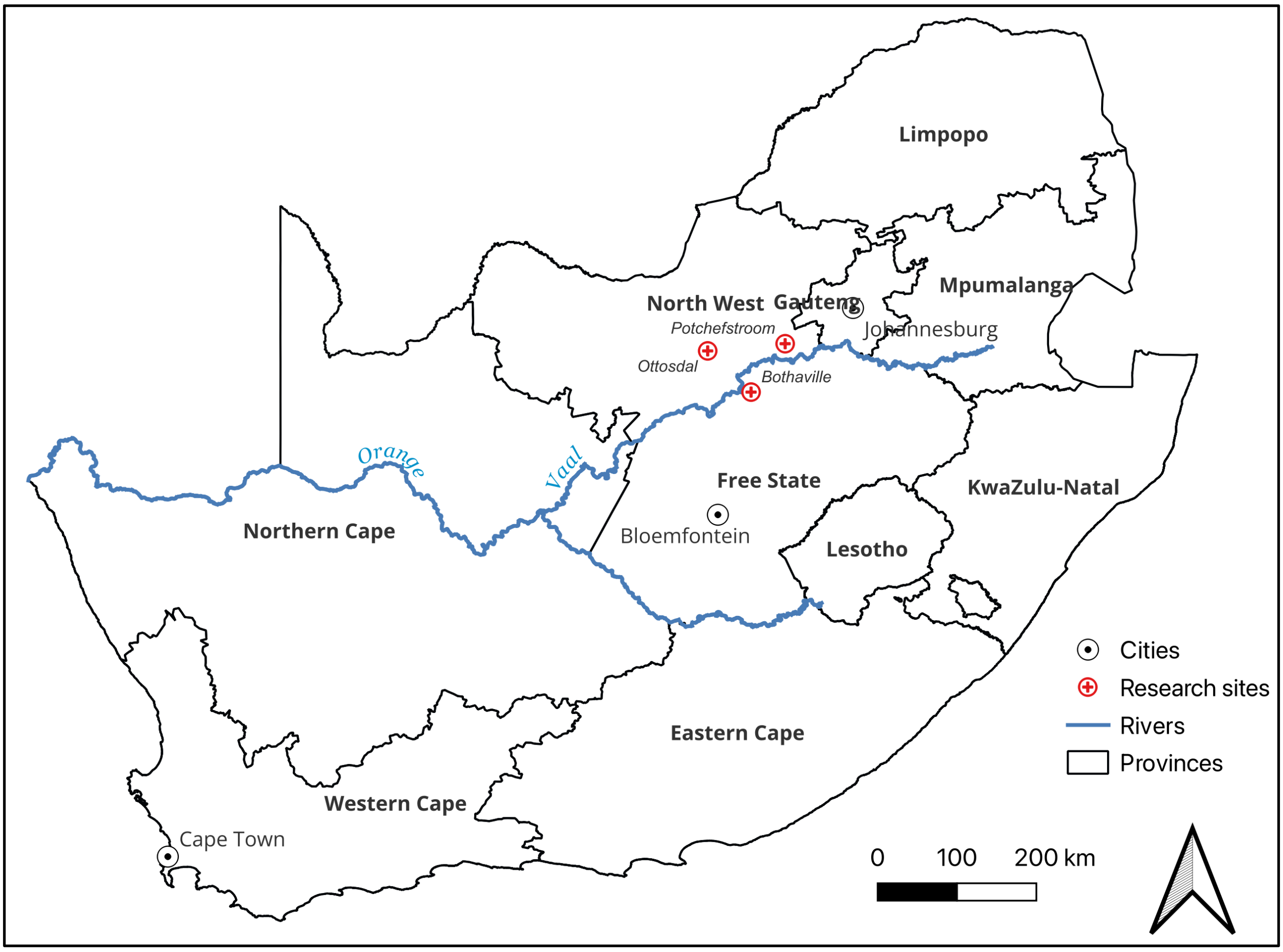

Figure 1. Location of the Bothaville, Ottosdal and Potchefstroom study sites in South Africa.

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 was reasonable for cropping although some fertilization of of N, P or K is required.

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

The climate experienced for the three trial years at each of the sites corresponds well with the long-term climate (**Table 2**). As discussed later, no extreme values were observed which would affects the growth and development of maize

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)	1317	1587	1355
Soil			
Depth (m)	1.8	2.0	1.8
Soil form[1]	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 ($mg \cdot kg^{-1}$)	0.9	2.8	5.7
P ($mg \cdot kg^{-1}$)	22	16	56
K ($mg \cdot kg^{-1}$)	74	135	192
Ca ($mg \cdot kg^{-1}$)	348	317	840
Mg ($mg \cdot kg^{-1}$)	97	102	360
Na ($mg \cdot kg^{-1}$)	15	13	32

[1]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).

seriously. The climate conditions were therefore suitable for maize production at the three sites, favouring this investigation into the performance of the ameliorants.

2.2. Treatments and Experimental Design

Nine ameliorants, categorized as those that coincide with full NPK fertilization (Biozone, Gliogrow, Growmax, K-humate and Lanbac), partial NPK fertilization (Crop care and Montys) and no NPK fertilization (Growmor and Promis) were used in the study (**Table 3**). The ameliorants can be categorized also according to the active ingredients that they comprised of, namely EMs (Biozone and Gliogrow), composted human manure (Growmax), humic acids (K-humate, Crop care and Montys), poultry manure (Gromor and Promis), and a combination of EMs and humic acid (Lanbac). Selection of the nine ameliorants were based primarily on their application and composition to ensure that they are representative of the wide range of products available in the market. The total elemental composition of each ameliorant is given in **Table 4**. Standard procedures

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

Locality	Year	P			Tn			Tx			A-pan		
		1	2	3	1	2	3	1	2	3	1	2	3
Bothaville	In-season	400.6	369.1	537.5	8.5	9.9	11.1	27.8	26.9	27.1	5.4	4.8	4.1
	Pre-season	88.9	191.9	42.6	6.1	6.8	6.1	26.2	24.2	27.3	5.3	4.7	5.8
	Annual	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	In-season	267.1	428.5	442.3	9.9	11.6	10.3	27.8	25.4	26.4	5.5	3.9	2.7
	Pre-season	65.5	31.9	43.6	8.6	6.6	7.2	24.9	28.4	26.2	5.5	3.8	5.5
	Annual	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	In-season	544.1	476.3	496.6	11.2	12.7	11.4	27.2	25.4	26.4	5.4	4.6	3.4
	Pre-season	99.3	174.8	50.7	8.7	8.8	8.4	25.7	24.5	27.0	5.1	4.6	5.4
	Annual	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

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[1] + 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 fertilizer 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 and 2 L·ha^{-1} Agri-fulbor at tasseling.
	Montys	Soil	50% OFR + 3 L·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.

[1]Optimum fertilizer rate based on soil analyses and target yields.

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

	pH (H_2O)	C (%)	N ($mg\cdot kg^{-1}$)	P ($mg\cdot kg^{-1}$)	K ($mg\cdot kg^{-1}$)	Ca ($mg\cdot kg^{-1}$)	Mg ($mg\cdot kg^{-1}$)	Na ($mg\cdot kg^{-1}$)
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	3.00	3.00	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	3.80	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
Montys	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

(Described in Non-Affiliated Soil Analysis Committee, 1990 and AgriLASA, 2007) were used for the determination of the elements. The total elemental composition of each ameliorant is given In **Table 4**. Standards procedures (Non-Affiliated Soil Analysis Committee, 1990; AgriLASA, 2007) were used for the determination of the elemental concentration of each ameliorant.

An untreated control and a NPK control (based on soil analyses and long-term yields) were also included as checks at each site. Fertilizer application rates were estimated as 100, 74 and 55 $kg\cdot ha^{-1}$ N, P and K for Bothaville, 70, 74 and 0 $kg\cdot ha^{-1}$ N, P and K for Ottosdal, and 80, 44 and 0 $kg\cdot ha^{-1}$ for Potchefstroom, respectively. These amounts were applied with the organic ameliorants when NPK fertilization is recommended. Compared to the amounts of N, P and K applied through NPK fertilization, the N, P and K applications by the ameliorants are neglible little (Equal to or less than 3.8, 1.6 and 20 $kg\cdot ha^{-1}$ N, P and K, respectively) when based on the recommended rate (**Table 3**) and elemental composition (**Table 4**) of an ameliorant, except for the poultry manure based Growmor which amounted to 7.6, 3.2 and 40 $kg\cdot ha^{-1}$, respectively. In the case of ameliorants that coincide with partial NPK fertilization, 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 randomly complete block design. Each treatment was applied to a 10 m × 6 m plot. Prior to application, the soil-applied ameliorants were broadcast uniformily over the appropriate plots and lightly worked into the soil with a spade, while the seed applied ameliorants were sprayed on the seeds before planting and the foliar-applied ameliorants were sprayed on the plants after thinning, using a CP15 knapsack sprayer. The P and K fertilizers where appropriate, were band-placed at planting with 30% of the N fertilizer, while the remaining of the N fertilizer was band-placed 50 mm away from the row six weeks after planting.

2.3. 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 and 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 of 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 $L \cdot ha^{-1}$ as pre-emergence herbicide to destroy upcoming weeds, while sites were kept weed free during the growing season through mechanical weeding when necessary. Combat pesticide was similarly applied at 4 $kg \cdot ha^{-1}$ to protect the crop from maize stalk borer when a sign of damage becomes noticeable from eight weeks after planting.

2.4. Measurements

At V9 and R1, all plants within a 1 m^2 area from four rows in each plot were cut just above ground level with a sharp cutting edge slash. These plants were washed with a 0.3% dertergent solution, thoroughly rinsed with distilled water and oven-dried at 65˚C to constant weight. After weighing, the plants were milled to pass through a 0.5 mm sieve and then stored for tissue N and P analyses. The analyses were done using standard laboratory procedures described in AgriLASA (2007). Determination of tissue N concentration was accomplished with steam distillation and titration after the samples were digested with H_2SO_4 using a Micro-Kjeldahl procedure. For the determination of tissue P concentration, samples were digested in a mixture of HNO_3, H_2SO_4 and $HClO_4$, whereafter the P in solution was measured colorimetrically.

2.5. Data Analyses

A factorial analysis of variance (ANOVA) with sites, years and treatments as factors was done initially 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). We were advised therefore by the statistician who assisted us to do rather a one-way ANOVA which lead to more interpretable outcomes. Assumptions for ANOVA were satisfied by testing residuals for normality (Shapiro & 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.

3. Results

3.1. Nitrogen Concentration

At each site over the three years, the N concentrations of maize biomass for both growth stages were higher in the NPK control than the untreated control, although not always significant (Figures 2-4). The N concentration of maize biomass in the untreated control varied from 13.3 g·kg^{-1} in year 1 to 33.8 g·kg^{-1} in year 3 at Potchefstroom for V9, and from 6.5 g·kg^{-1} in year 1 at Bothaville to 18.2 g·kg^{-1} in year 3 at Ottosdal for R1. In the NPK control, N concentration of maize biomass ranged from 18.3 g·kg^{-1} in year 1 to 35.0 g·kg^{-1} in year 3 at Pothefstroom for V9, and from 8.4 g·kg^{-1} in year 1 at Bothaville to 19.9 g·kg^{-1} in year 3

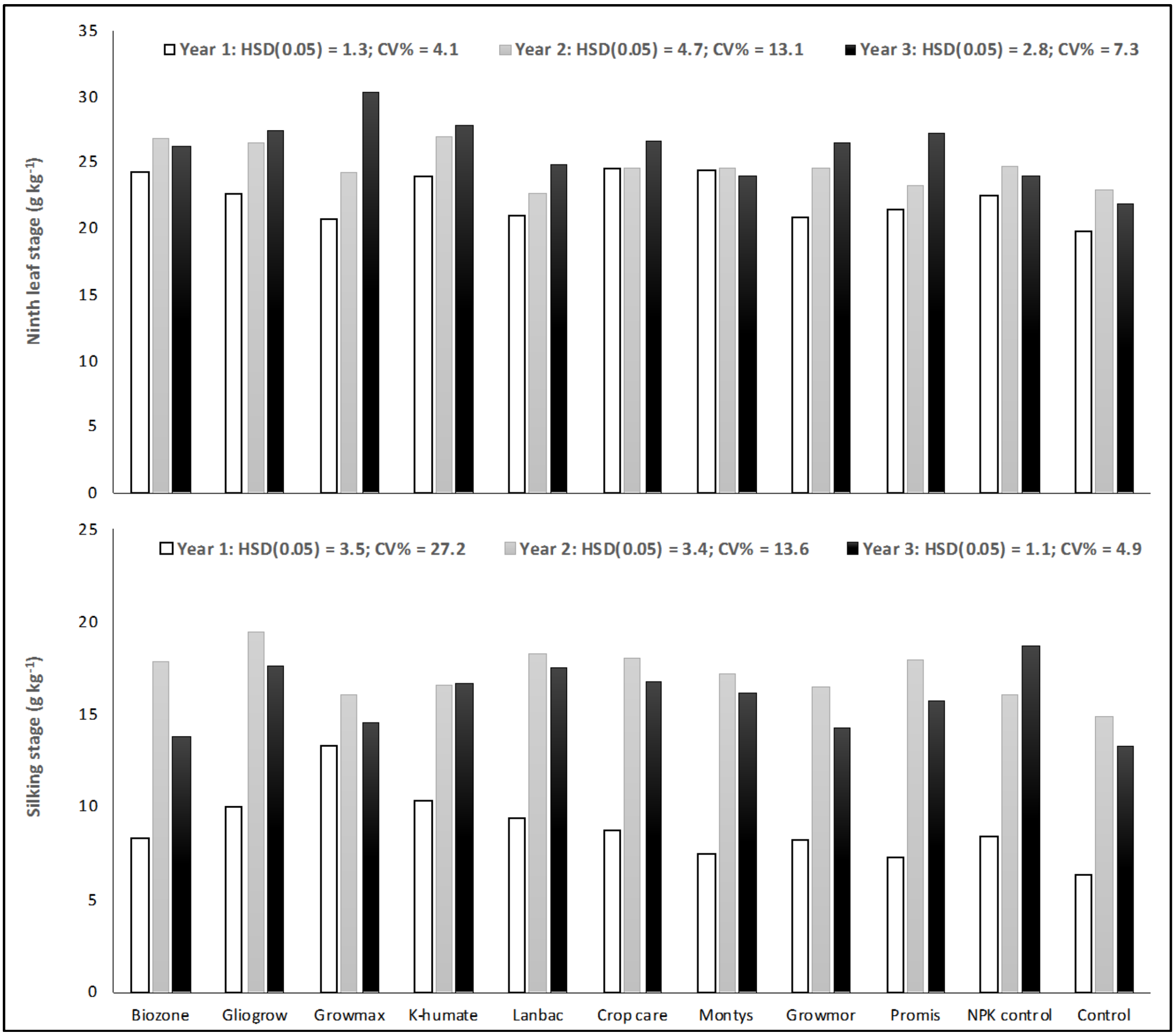

Figure 2. Influence of organic ameliorants on nitrogen concentration in maize biomass for ninth and silking growth stages at Bothaville over three years.

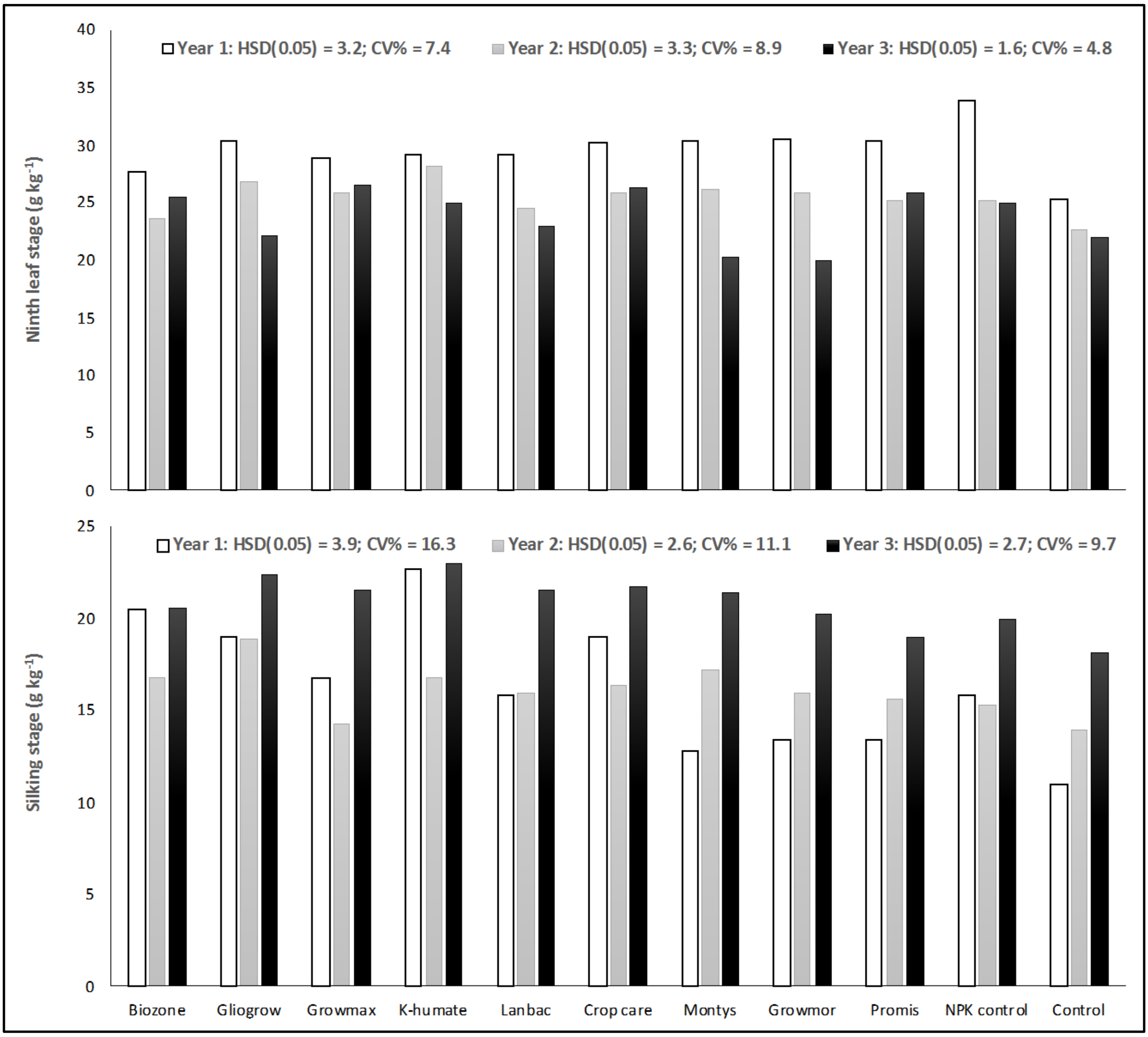

Figure 3. Influence of organic ameliorants on nitrogen concentration in maizw biomass for ninth leaf and silking growth stages at Ottosdal over three years.

at Ottosdal for R1. Differences between the untreated and NPK control ranged between 1.1 g·kg^{-1} in year 2 at Potchefstroom and 8.6 g·kg^{-1} in year 1 at Ottosdal for V9. The N concentrations differed in maize biomass between the untreated and NPK control from 1.1 g·kg^{-1} in year 2 to 5.4 g·kg^{-1} in year 3 at Bothaville for R1.

3.1.1. Bothaville

At V9, compared to the NPK control (22.5 g·kg^{-1}), only Biozone (24 2 g·kg^{-1}), K-humate (24.0 g·kg^{-1}), Crop care (24.6 g·kg^{-1}) and Montys (24.4 g·kg^{-1}) resulted in significant higher N concentrations of maize biomass in year 1 (**Figure 2**). No significant differences in N concentrations of maize biomass were measured in year 2 between the NPK control and any of the ameliorants. In year 3, however,

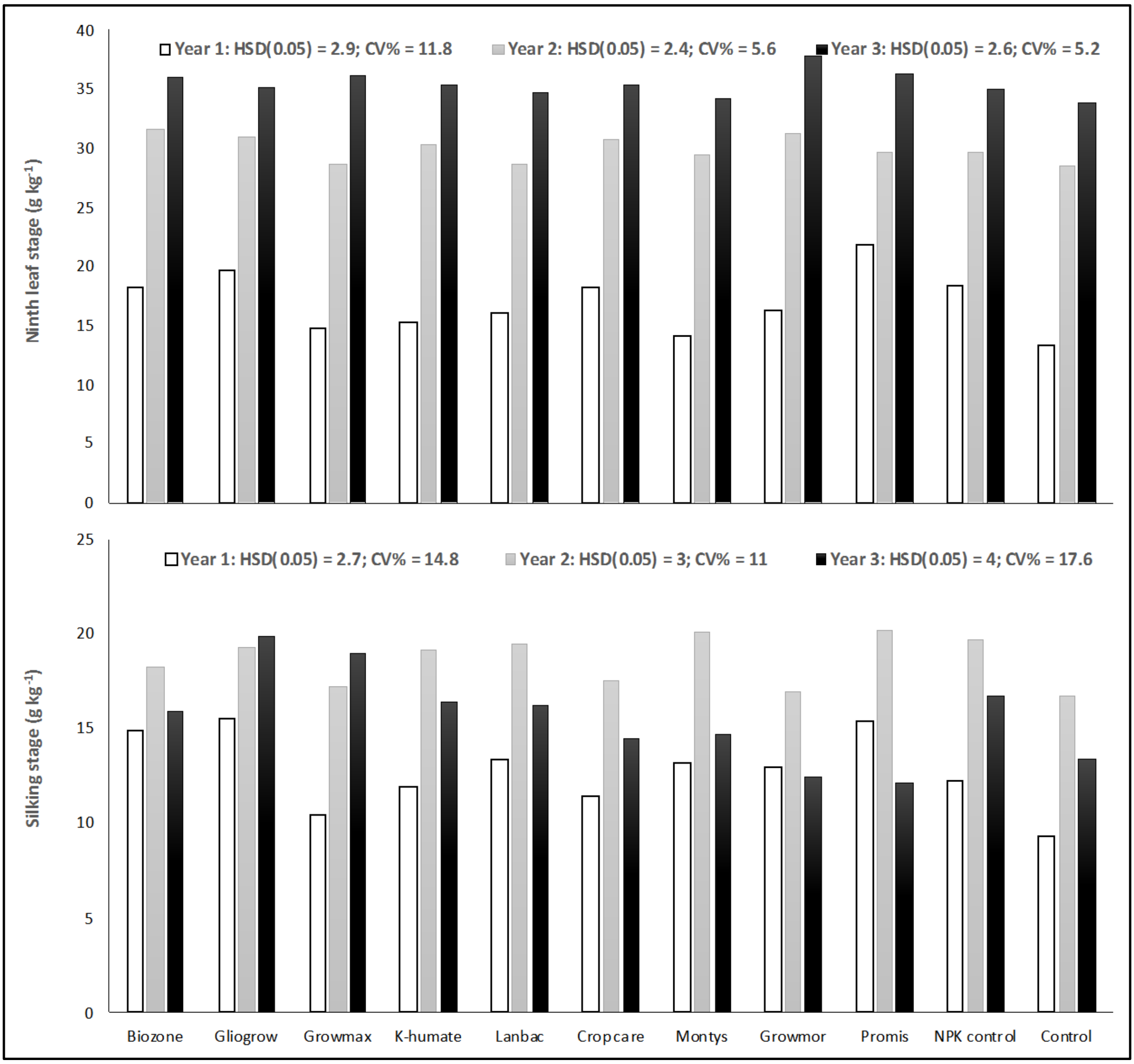

Figure 4. Influence of organic ameliorants on nitrogen concentration in maizw biomass for ninth leaf and sliking growth stages at Potchefstroom over three years.

the N concentrations in maize biomass of Gliogrow (27.4 g·kg^{-1}), Growmax (30.3 g·kg^{-1}), K-humate (27.3 g·kg^{-1}) and Promis (27.3 g·kg^{-1}) exceeded that of the NPK control (24.0 g·kg^{-1}) significantly.

The ameliorants caused no significant higher N concentrations in maize biomass than the NPK control at R1, except for Growmax in year 1 where a difference of 4.9 g·kg^{-1} was recorded (Figure 2). Neither at V9 nor at R1 the ameliorants manifested in significant lower N concentrations of maize biomass.

3.1.2. Ottosdal

The ameliorants caused no significant higher N concentrations in maize biomass than the NPK control for V9 in any year (Figure 3). Compared to the NPK control (34.0 g·kg^{-1}) in year 1, all nine ameliorants resulted in significant lower N concentrations (27.7 to 30.5 g·kg^{-1}) in year 1 for V9. At this growth stage, none of the ameliorants caused a significant lower N concentration than the NPK control in year 2 and 3.

Concerning R1, in year 1 Biozone (20.5 g·kg^{-1}) and K-humate (22.7 g·kg^{-1}), in year 2 Gliogrow (18.9 g·kg^{-1}), and in year 3 K-humate (23.0 g·kg^{-1}) resulted in significant higher N concentations in maize biomass than the NPK control (15.8, 15.3 and 19.9 g·kg^{-1}, respectively) as depicted in **Figure 3**. None of the ameliorants caused significant lower N concentrations in maize biomass in any of the years at R1.

3.1.3. Potchefstroom

At V9, Promis (21.8 g·kg^{-1}) resulted in a significant higher N concentration in maize biomass than the NPK control in year 1 (**Figure 4**). Significant lower N concentrations were recorded in maize biomass with Growmax, K-humate and Montys (14.1 to15.3 g·kg^{-1}) than with the NPK control (18.3 g·kg^{-1}) in year 1 at V9. At this gowth stage, the ameliorants had no significant influence on the N concentrations of maize biomass, compared to the NPK control.

Concerning R1 as showed in **Figure 4**, Gliogrow (15.5 g·kg^{-1}) and Promis (15.4 g·kg^{-1}) in year 1 significantly exceeded that of the NPK control (12.3 g·kg^{-1}). In year 2 and 3 no ameliorant resulted in significantly higher N concentrations in maize biomass than the NPK control. None of the ameliorants caused significantly lower N concentrations in maize biomass in year 1, 2 and 3 at R1.

3.2. Phosphorus Concentration

Like N concentrations, were the P concentrations of maize biomass higher in the NPK control than the untreated control, except in year 2 for Bothaville and Ottosdal at R1 (**Figures 5-7**). The P concentration of maize biomass in the untreated control ranged from 2.80 g·kg^{-1} in year 3 at Ottosdal to 5.13 g·kg^{-1} in year 1 at Potchefstroom, and from 1.30 g·kg^{-1} in year 1 at Ottosdal to 3.65 g·kg^{-1} for V9. In the NPK control, the P concentration of maize biomass varied from 2.80 g·kg^{-1} in year 3 at Ottosdal to 5.85 g·kg^{-1} in year 3 at Potchefstroom for V9, and for R1 from 1.40 g·kg^{-1} in year 1 at Bothaville to 3.80 g·kg^{-1} in year 3 at Potchefstroom. The differences in P concentrations between the untreated and NPK control were 0.10 g·kg^{-1} in year 1 for either Bothaville or Ottosdal and 0 72 g·kg^{-1} in year 2 for Potchefstroom concerning V9. At R1 differences in maize biomass between the untreated and NPK control were between 0.05 g·kg^{-1} in year 1 for Bothaville and 0.70 g·kg^{-1} in year 3 of either Bothaville or Ottosdal.

3.2.1. Bothaville

Compared to the NPK control, none of the ameliorants induced significantly higher P concentrations in maize biomass in year 1 and 2 at V9 (**Figure 5**). At this growth stage the P concentrations in maize biomass in year 3 were significantly higher where Biozone, Gliogrow, Growmax, K-humate, Montys and Promis

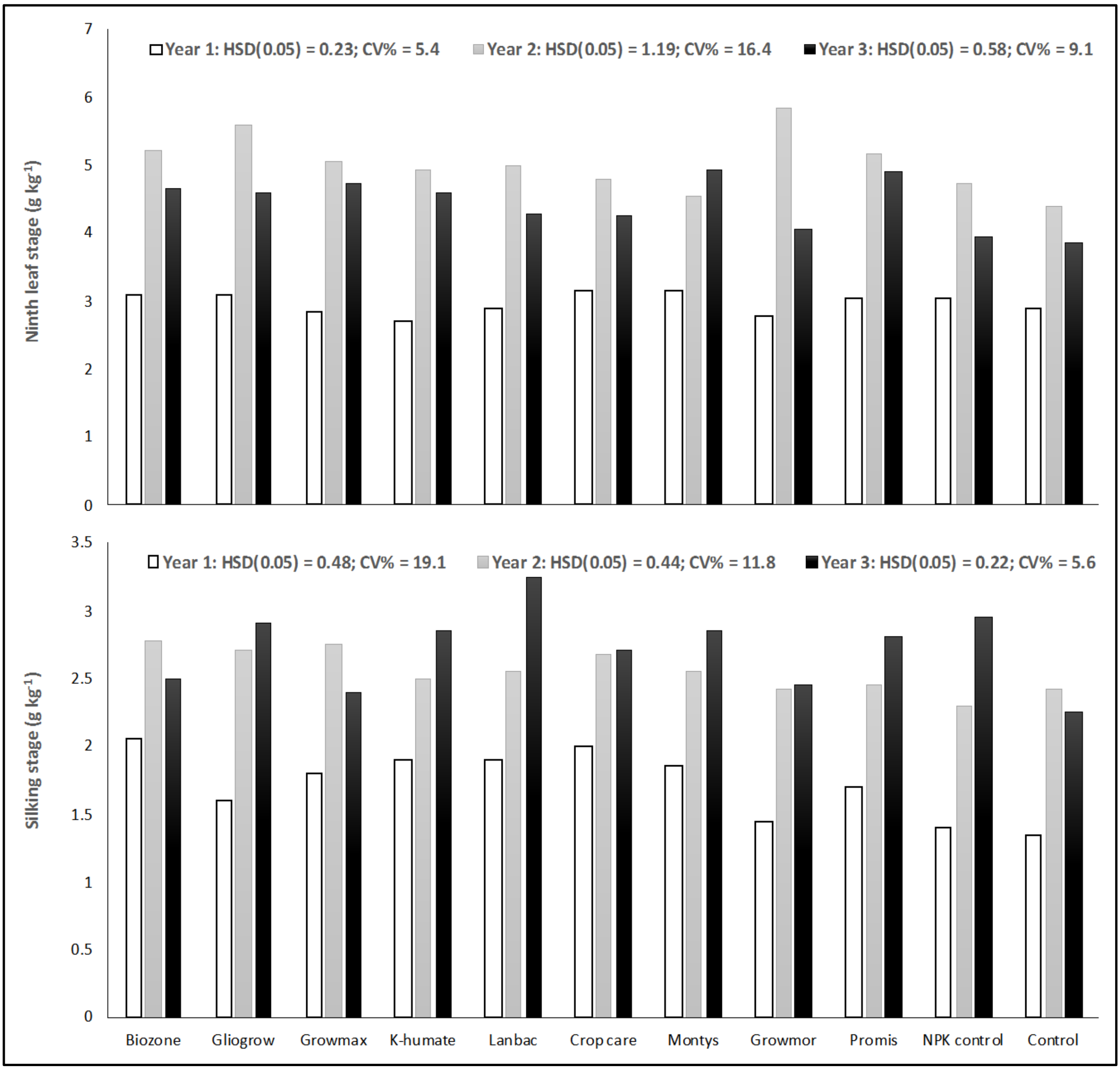

Figure 5. Influence of organic ameliorants on phosphorus concentration in maize biomass for ninth leaf and silking growrh stages at Bothaville over three years.

(4.60 g·kg^{-1} and higher) were applied compared to the NPK control (3.95 g·kg^{-1}). None of the ameliorants resulted in significantly lower P concentrations of maize biomass than the NPK control at V9 in year 2 and 3. In year 1 the P concentrations of maize biomass from K-humate (2.70 g·kg^{-1}) and Growmor (2.80 g·kg^{-1}) were significantly lower than the NPK control (3.05 g·kg^{-1}).

Concerning R1, none of the ameliorants manifested in significant lower P concentrations in maize biomass of year 1, 2 and 3 than the NPK control (Figure 5). Compared to the NPK control (1.40 g·kg^{-1} and 2.30 g·kg^{-1} in year 1 and 2, respectively), Biozone (2.05 g·kg^{-1}), K-humate (1.90 g·kg^{-1}) and Crop care (2.00 g·kg^{-1}) in year 1, and Growmax (2.00 g·kg^{-1}) in year 2 resulted in significant

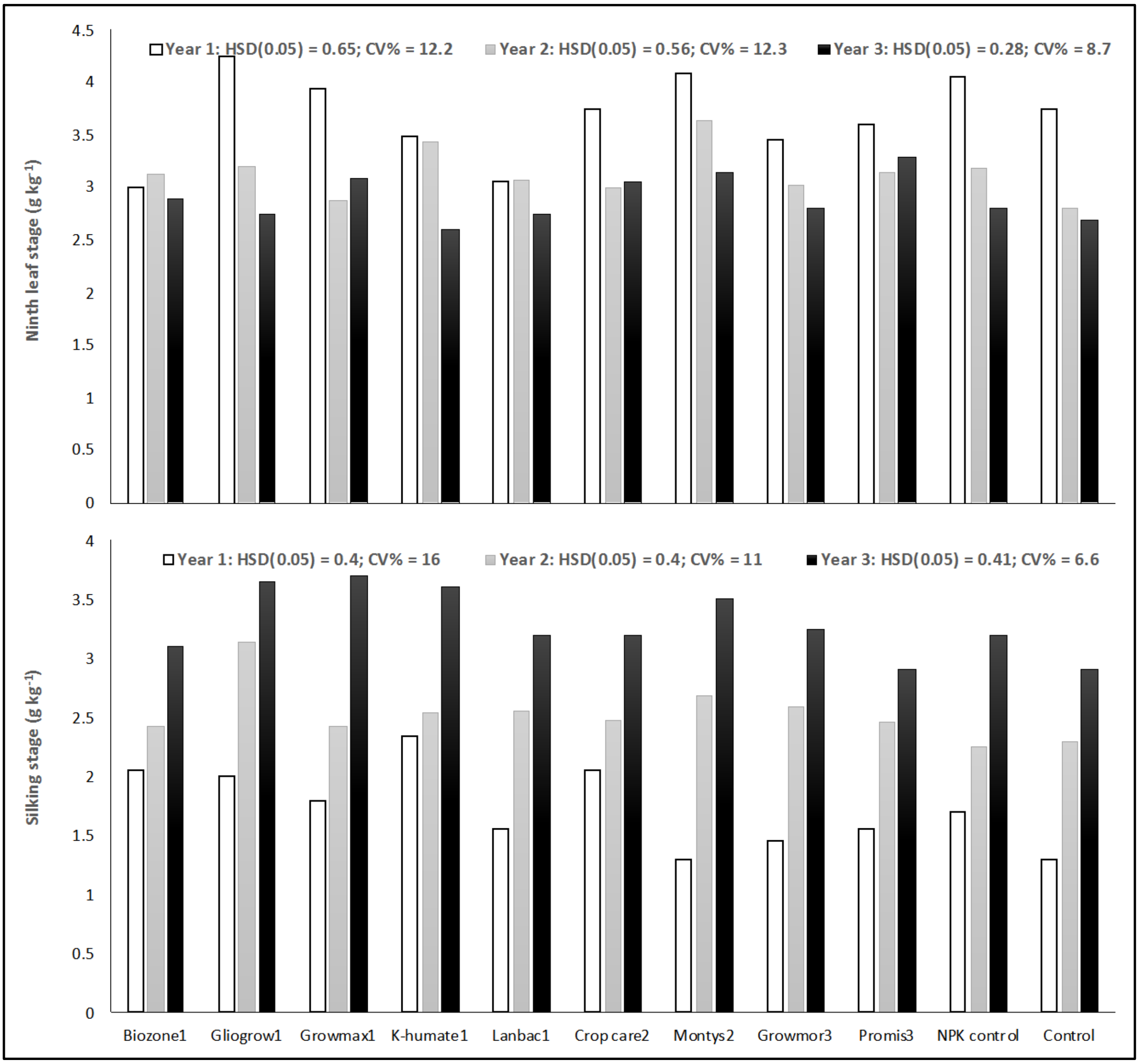

Figure 6. Influence of organic ameliorant on phosporus concentration in maize biomass for ninth leaf and silking growth stages at Ottosdal over three years.

higher P concentrations of maize biomass. However, in year 3 at R1 the P concentrations of maize biomass were not significantly higher than the NPK control.

3.2.2. Ottosdal

In year 1 and 2, none of the ameliorants induced at V9 significantly higher P concentrations in maize biomass than the NPK control (Figure 6). At this growth stage Growmax (3.10 $g \cdot kg^{-1}$) and Montys (3.15 $g \cdot kg^{-1}$) in year 3 resulted in significantly higher P concentrations of maize biomass than the NPK control (2.80 $g \cdot kg^{-1}$). Significantly lower P concentrations in maize biomass were recorded with Biozone (3.00 $g \cdot kg^{-1}$) and Lanbac (3.05 $g \cdot kg^{-1}$) than with the NPK

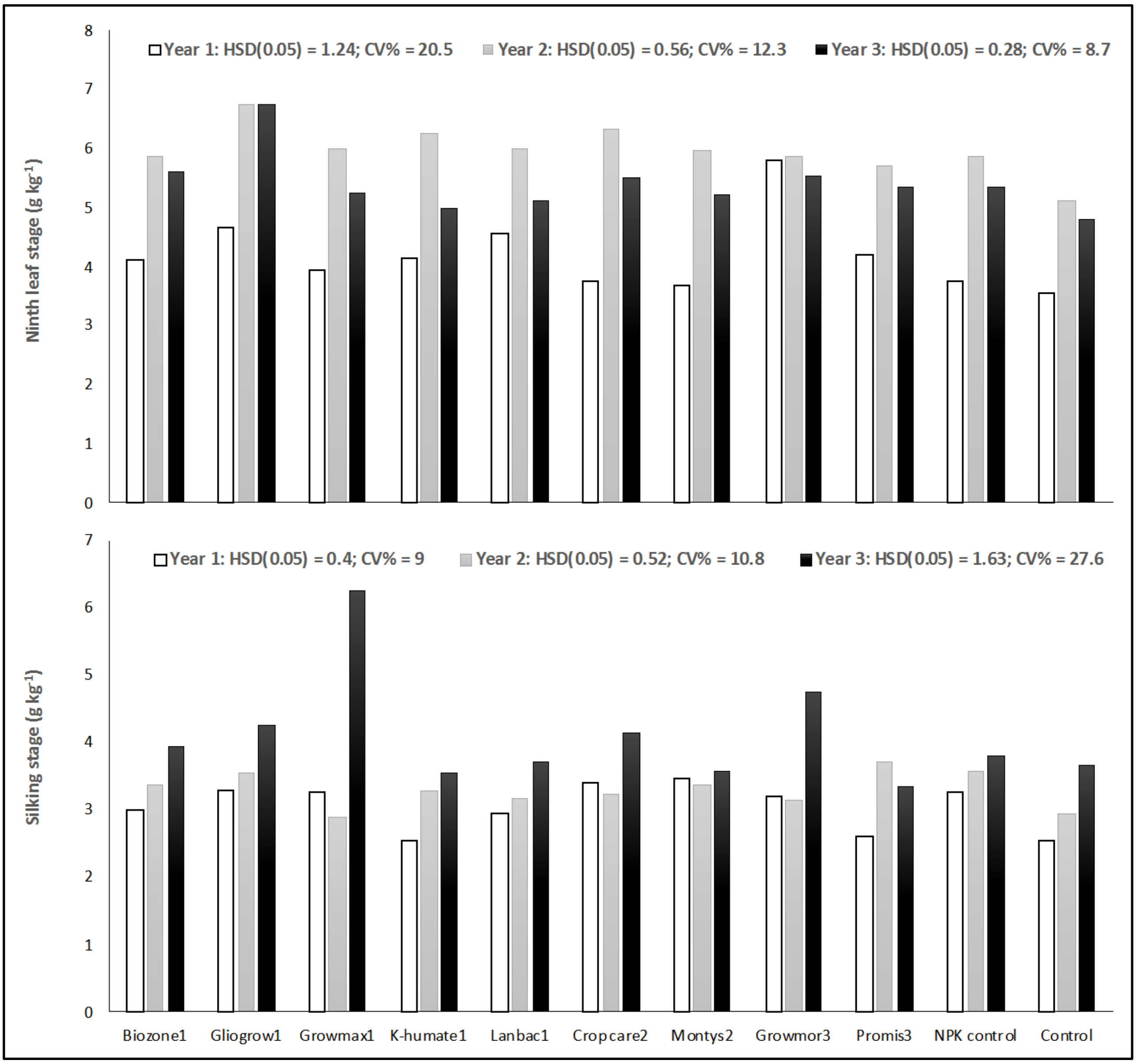

Figure 7. Influence of organic ameliorants on phosphorus concentration in maize biomass for ninth leaf and silking growth stages at Potchestroom over three years.

control in year 1 for V9. Neither in year 2 nor in year 3, induced the ameliorants significantly lower P concentrations in maize biomass at V9.

Concerning R1, in no year the ameliorants manifested in significantly lower P concentrations of maize biomass compared to the NPK control (Figure 6). At this growth stage, in year 1 K-humate (2.35 g·kg^{-1}), in year 2 Gliogrow (3.13 g·kg^{-1}) and Montys (2.68 g·kg^{-1}), and in year 3 Gliogrow (3.13 g·kg^{-1} and Growmax (3.70 g·kg^{-1}) caused significantly higher P concentrations in maize biomass than the NPK control (1.70, 2.25 and 3.20 g·kg^{-1} in year 1, 2 and 3, respectively).

3.2.3. Potchefstroom

In year 1 and 2 at V9, none of the ameliorants resulted in either significantly lower or higher P concentrations of maize biomass compared to the NPK control (**Figure 7**). At this growth stage, in year 3 K-humate (5.00 g·kg^{-1}) and Gliogrow (6.75 g·kg^{-1}) caused respectively a significant lower and higher P concentration in maize biomass than the NPK control (5.35 g·kg^{-1}).

At R1, Promis (2.60 g·kg^{-1}) in year 1 and Growmax (2.90 g·kg^{-1}) in year 2 caused significant lower P concentrations in maize biomass than the NPK control (3.25 g·kg^{-1} in year 1 and 3.58 g·kg^{-1} in year 2). Neither in year 1 nor in year 2 had the ameliorants induced significant higher P concentrations in maize biomass than the NPK control for this growth stage. In year 3 only Growmax (6.25 g·kg^{-1}) resulted in a significant higher P concentration in maize biomass than the NPK control (3.80 g·kg^{-1}).

4. Discussion

At either V9 or R1 the N (**Figures 2-4**) and P (**Figures 5-7**) concentrations of maize biomass varied inconsistently between sites, years and treatments. Neither the untreated controls nor the NPK controls were an exception concerning the sites and years. However, the N and P concentrations in maize biomass of both controls declined from V9 to R1, which support other reports (e.g. Voss, 1993; Mengel et al., 2001; Haygarth et al., 2013; Havlin et al., 2014). The decline of N and P concentrations that coincide with growth and development of maize is ascribed to the dilution of the two nutrients when maize biomass increased. Hence the pertinent recommendation is that N and P concentrations in maize biomass are investigated at comparable growth stages (e.g. Bergmann, 1992; Campbell & Plank, 2011). The average N (**Figures 2-4**) and P (**Figures 5-7**) concentrations of maize biomass at V9 were slightly lower than the suggested critical values of 30 g·kg^{-1} for N and 3.5 g·kg^{-1} for P (Bergmann, 1992; Campbell & Plank, 2011). At R1, average N and P concentrations in maize biomass (**Figures 2-7**) were also somewhat lower than than the suggested critical values of 20 g·kg^{-1} for N and 3 g·kg^{-1} for P (Bergmann, 1992; Campbell & Plank, 2011).

Noteworthy, in all instances N concentrations in maize biomass were lower in the untreated controls than the NPK controls (**Figures 2-4**). This applied also for the P concentrations in maize biomass, except for three instances (**Figures 5-7**). The implication is that NPK fertilization deemed a necessity to ensure proper growth and development of maize in the soils of the trial sites. Either soil fertility status or prevailing climate conditions could be contributed to the observed N and P concentrations of maize biomass of the untreated and NPK controls.

4.1. Soil Fertility Status

The buffer capacity of the soils differed as indicated by the 8% (Bothaville), 12% (Ottosdal) and 34% (Potchefstroom) clay contents (**Table 1**). The suggested pH (H_2O) threshold is 6.5 (FSSA, 2007) while the soils' pH at Bothaville (7.02) were slightly higher and at Ottosdal (5.83) slightly lower. 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 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}) is much lower and at Potchefstroom (192 mg·kg^{-1}) mush higher. Compared to the threshold of 400 mg·kg^{-1} for Ca, the Ca concentration 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 concentration were close to the threshold.

4.2. Climate Conditions

Concerning climate conditions for the trial period (**Table 2**), at Bothaville pre-season precipitation in year 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. The pre-season precipitation at Ottosdal ranged only from 32 mm in year 2 to 63 mm in year 1 and was probably to little for influencing the N and P concentrations of maize biomass in the controls. In-season precipitation differed, however, from 267 mm in year 1 to 442 mm in year 3 which was probably large enough for influencing the N and P concentrations of maize biomass in the controls. At Potchefstroom pre-season precipitation was lowest (51 mm) in year 3 and highest (175 mm) in year 2, and that of year 1 (99 mm) intermediate. Contrary to pre-season precipitation, in-season precipitation differed only with 68 mm between the three trial years. Comprehensive research showed that the growth and development of maize is influenced by the total (pre-season and in-season) precipitation, especially the distribution thereof (Hensley & Bennie, 2003). This precipitation impacts soil water content which could help to explain the higher N and P concentrations in maize biomass from the NPK controls than from the untreated controls. Precipitation had apparently a larger impact on N (**Figures 2-4**) and P (**Figures 5-7**) concentrations of maize biomass at V9 than at R1 when planted at the three sites. The concentrations of either N or P ranged considerable between the three experimental years per site, probably due to rainfall distribution between the growing seasons because the total precipitation differed not much (**Table 2**).

At the three sites over the three years, in-season daily mean minimum temperature ranged between 9˚C in year 1 at Bothaville to 13˚C in year 2 at Potchefstroom (**Table 2**). In-season daily mean maximum temperature varied only from 25˚C in year 2 at either Ottosdal or Potchefstroom to 28˚C in year 1 at either Bothaville or Ottosdal. The differences in temperature should have miniscule effects on the N and P concentrations of maize biomass between the untreated and NPK controls.

Generally, in-season daily mean evaporation was very stable at the three sites over the three years (Table 2), having probably little effect on the N and P concentrations of maize biomass in the controls. Values varied from 3 mm in year 3 at Potchefstroom to 5 mm in year 1 at Ottosdal.

4.3. Organic Ameliorants' Performance

Like with grain yield, biomass yield and harvest index of maize (Baloyi et al., 2023), the measured N (Figures 2-4) and P (Figures 5-7) concentrations of maize biomass were also inconsistent over years and sites at both growth stages. A comparison of the ameliorants' impacts on the N and P concentrations is problematic because they were applied with full, partial or no NPK fertilization as recommended by the manufacturers. We are opinion however that the best insight concerning the impacts of the nine ameliorants is obtained by comparing them with the NPK controls because N and P concentrations of maize biomass should be close to the suggested critical values.

At V9 and R1 the ameliorants induced for 162 instances only in 15 (V9) and 7 (R1) significant higher values when the NPK controls serve as reference (Table 5). The 8% clay content soil of Bothaville was most responsive to the the application of organic ameliorants (9 at V9 and 2 at R1) while the soils of Ottosdal (6 at V9 and 2 at R1) and Potchefstroom (2 at either V9 or R1) were less responsive to the ameliorant applications. Interesting, the ameliorants that coincide with full (Biozone, Gliogrow, Growmax and K-humate), partial (Crop care and Montys) and no (Growmor and Promis) NPK fertilization all increased in some instances the N concentrations of maize biomass significantly compared to the NPK control.

The ameliorants caused in 19 (V9) and 18 (R1) out of 162 instances significantly lower N concentrations of maize biomass when the NPK control serves as reference. The significant reduction of N concentrations in maize biomass amounted to 3 at V9 and 9 at R1 for Bothaville, 13 at V9 for Ottosdal, and 3 at V9 and 2 at R1 for Potchefstroom.

In the majority of instances, the ameliorants had no significant influence on the N concentrations of maize biomass. The instances were 15 at V9 and 16 at R1 for Bothaville, 6 at V9 and 3 at R1 for Ottosdal, and 2 at V9 and 16 at R1 for Potchefstroom.

Concerning the P concentrations in maize biomass, similar trends were observed (Table 6). Compared to the NPK controls in 11 (V9) and 13 (R1) of the 162 cases, the ameliorants manifested in significant higher P concentrations in maize biomass. This amounted for V9 to 6, 4 and 2 cases and for R1 to 7, 5 and 1 cases at Bothaville, Ottosdal and Potchefstroom, respectively. The ameliorants involved were Biozone, Gliogrow, Growmax, K-humate, Lanbac all applied with full NPK fertilization, Crop care and Monty both applied with partial NPK fertilization, and Growmor and Promis both applied with no NPK fertilization.

Table 5. Organic ameliorants that resulted in significant lower (−), no significant different (0) and significant higher (+) nitrogen concentrations in maize biomass at ninth leaf (V9) and silking (R1) growth stages than the NPK control.

Site	Ameliorant	V9			R1		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Bothaville	Biozone	+	0	0	0	0	−
	Gliogrow[1]	0	0	+	0	+	−
	Growmax[1]	−	0	+	+	0	−
	K-humate[1]	+	0	+	0	0	−
	Lanbac[1]	−	0	+	0	0	−
	Crop care[2]	+	0	0	0	0	−
	Montys[2]	+	0	0	0	0	−
	Growmor[3]	−	0	0	0	0	−
	Promis[3]	0	0	+	0	0	−
Ottosdal	Biozone[1]	−	0	0	+	0	0
	Gliogrow[1]	−	+	−	0	+	0
	Growmax[1]	−	+	0	0	0	0
	K-humate[1]	−	+	0	+	0	+
	Lanbac[1]	−	0	−	0	0	0
	Crop care[2]	−	+	0	0	0	0
	Montys[2]	−	+	−	0	0	0
	Growmor[3]	−	+	−	0	0	0
	Promis[3]	−	0	0	0	0	0
Potchefstroom	Biozone	0	0	0	0	0	−
	Gliogrow[1]	0	0	0	+	0	−
	Growmax[1]	−	0	0	0	0	−
	K-humate[1]	−	0	0	0	0	−
	Lanbac[1]	0	0	0	0	0	−
	Crop care[2]	0	0	0	0	0	−
	Montys[2]	−	0	0	0	0	−
	Growmor[3]	0	0	+	0	0	−
	Promis[3]	+	0	0	0	0	−

[1]Full, [2]partial and [3]no NPK fertilization.

From the the 162 cases, at V9 10 and at R1 6 had significantly lower P concentrations in maize biomass than the NPK controls. The number of cases per site were 2 at V9 and 3 at R1 for Bothaville, 2 at V9 and 1 at R1 for Ottosdal, and 6 at V9 and 3 at R1 for Potchefstroom.

Table 6. Organic ameliorants that resulted in significant lower (−), no significant different (0) and significant higher (+) phosphorus concentrations in maize biomass at ninth leaf (V9) and silking (R1) growth stages than the NPK control.

Site	Ameliorant	V9			R1		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Bothaville	Biozone[1]	0	0	+	+	+	−
	Gliogrow[1]	0	0	+	0	0	0
	Growmax[1]	0	0	+	0	+	−
	K-humate[1]	−	0	+	+	0	0
	Lanbac[1]	0	0	0	+	0	+
	Crop care[2]	0	0	0	+	0	−
	Montys[2]	0	0	+	0	0	0
	Growmor[3]	−	0	0	0	0	−
	Promis[3]	0	0	+	0	0	0
Ottosdal	Biozone[1]	−	0	0	0	0	0
	Gliogrow[1]	0	0	0	0	+	+
	Growmax[1]	0	0	0	0	0	+
	K-humate[1]	0	0	0	+	0	0
	Lanbac[1]	−	0	0	0	0	0
	Crop care[2]	0	0	0	0	0	0
	Montys[2]	0	0	+	0	+	0
	Growmor[3]	0	0	0	0	0	0
	Promis[3]	0	0	+	0	0	0
Potchefstroom	Biozone[1]	0	0	0	0	0	0
	Gliogrow[1]	0	0	+	0	0	0
	Growmax[1]	0	0	0	0	−	+
	K-humate[1]	0	0	−	−	0	0
	Lanbac[1]	0	0	0	0	0	0
	Crop care[2]	0	0	0	0	0	0
	Montys[2]	0	0	0	0	0	0
	Growmor[3]	+	0	0	0	0	0
	Promis[3]	0	0	0	−	0	0

[1]Full, [2]partial and [3]no NPK fertilization.

In the majority of cases (46 at V9 and 61 at R1) the ameliorants had no significant effect on P concentrations in maize biomass. Per site the number of cases were 20 at V9 and 17 at R1 for Bothaville, 21 at V9 and 22 at R1 for Ottosdal, and 19 at V9 and 23 at R1 for Potchefstroom.

The results of N and P concentrations in maize biomass did not support our hypothesis that the inconsistent and poor perforfomance of the ameliorants on grain yield, biomass yield and harvest index of maize reported by Baloyi et al. (2023) may be attributed to insufficient supply of the two nutrients. Further research is required therefore to establish the inconsistency and poor performance of the ameliorants used in the study with regard to the yield parameters. The determination of ingredient(s) in the ameliorants deemed essential to establish their contribution to the N and P concentrations in maize biomass (Pena-Mendez et al., 2005). Information of this kind could provide valuable insight into the inconsistent and poor performance noted with grain yield, biomass yield and harvest index due to applications of the ameliorants.

A matter of concern is farmers who prefer ameliorants that are applied with partial (Crop care and Montys) and no (Growmor and Promis) NPK fertilization. The particular farmers must be cautious for nutrient mining as elaborated by Oluput et al. (2020) and Tindwa et al. (2020). Application of N and P by Crop care and Montys, and especially Growmor and Promis are insufficient to replenish the removal of the two nutrients by maize, leading eventually to a decline in soil fertility. The restoration of N and P degraded soils is challenging for farmers like smalholders (Usiri & Lal, 2020). Application of the other five ameliorants that coincide with full NPK fertilization should be not resulted in nutrient mining and if any very little.

5. Conclusion

At V9 and R1, higher N and P concentrations in maize biomass were measured in the NPK controls than in the untreated controls, implicating the necessity of NPK fertilization. In the untreated and NPK controls, the N and P concentrations of maize biomass declined from V9 to R1 due to dilution. Compared to the NPK controls, application of the ameliorants with full, partial and no NPK fertilization as recommended by manufacturers resulted in significantly lower, no significant difference and significantly higher N and P concentrations in maize biomass. Based on these results the inconsistent and poor response of grain yield, biomass yield and harvest index of maize can not be attributed to the concentration of N and P that manifested in maize biomass during vegetative growth. The application of the ameliorants that coincide with either no or partial NPK fertilization is a matter of concern for sustainable maize production. Characterization of active ingredient(s) in organic ameliorants is suggested for further research to get better insight into how the growth and development of maize are impacted.

Acknowledgements

We are very thankful to the ARC-Grain Crops Institute allowing us to do this investigation. The investigation was only possible with the financial support of the Maize Trust and AgriSeta. Assistance by staff and farmers were also highly appreciated. We are also very grateful for the statistical analysis by Marie Smith and linguistic editing by Adri Moffat.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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