

EVALUATION OF SELECTED INDUSTRIALLY MANUFACTURED
BIOLOGICAL AMENDMENTS FOR MAIZE PRODUCTION

by

TLANGELANI CEDRIC BALOYI

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PROMOTER: PROF. C. C. DU PREEZ

CO-PROMOTER: DR. F. R. KUTU

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DECLARATION

I **Tlangelani Cedric Baloyi** declare that the thesis hereby submitted by me for the Philosophiae Doctor degree at the University of the Free State is my own independent investigation, and has not been previously submitted by me at another university for other qualifications. The work by other authors that served as sources of information in this thesis has been duly acknowledged by the references to the authors as indicated in the literature cited list. I further relents copyright of the thesis in favour of the University of the Free State.

Signature_____

September 30, 2012

ABSTRACT

The soaring prices of inorganic fertilisers among other reasons has persuaded companies to commence producing biological enhanced substances herein refers as industrially manufactured biological amendments (IMBAs) with claims that they could increase crop growth and yield, and also revitalize the soil. Such claims are often without substantial empirical agronomic data to proof the efficacy of these IMBAs.

A glasshouse pot trial was conducted during 2008/09 season to assess the effects of graded rates of nine IMBAs (Biozone, Gliogrow, Gromor, Promis, Growmax, Crop care, K-humate, Lanbac and Montys) on maize seedlings establishment and growth over six-weeks. These were assessed at 50, 75 and 100% of the recommended rates together with optimum inorganic NPK fertiliser and a control as check. The IMBAs exerted in many instances a deleterious effect on percent maize seedling emergences when applied at 100% rate. Application rates of 50 and 75% appeared sufficient amongst most IMBAs for encouraging better growth and phenological development of maize, although the most appropriate rate is dependent on the IMBA type.

Rainfed trials were conducted for three seasons (2006/07-2008/09) at four localities (Bethlehem, Bothaville, Ottosdal and Potchefstroom) to assess the effects of the same nine IMBAs used above on maize performance and on soil health in a randomised completely block design. The IMBAs were applied based on product manufactures and/or supplier recommendations along with optimum inorganic NPK rate and the unamended control as check. All trial sites were planted to one maize cultivar PAN 6479. Every season, observations on phenological growth traits, grain yield and yield components, nitrogen and phosphorus content, uptake, and agronomic use efficiency, soil chemical and microbial properties and on grain quality traits were measured.

The manure-based IMBAs like Gromor, Promis and Growmax generally raised pH (H₂O) to between 6.0 and 7.0 which was not always the case with the other IMBAs that coincided with inorganic NPK fertiliser. Generally, Gromor and Gliogrow recorded most cases of significant pH increases compared to the NPK treatment. The frequency of significant increases in organic C, mineral N and extractable P were only four instances and less of all 12 potential cases in relation to the NPK check. Gromor resulted in no

cases of significantly higher mineral N and extractable P than the NPK check. The IMBAs promoted higher microbial biomass-C immobilisation at 4-weeks after planting while biomass-C mineralisation was predominant at flowering and crop harvest, although it tended to decline at crop harvest. The different IMBAs exerted in many instances no significant effect on biomass-C and -P compared to the NPK check.

The IMBAs had no positive effect on maize growth and phenological traits compared with the NPK treatment. Application of Gliogrow resulted in constant reduction in plant phenological growth in the 9th leaf and silking growth stages due to poor emergence, particularly from soils with higher clay content. Gromor and Promis exerted no significant positive effect on grain yield and yield components compared to the NPK check. Despite the consistent poor stand count, Gliogrow resulted in significant increases for all the yield parameters measured than any other IMBA. Compared to the NPK check, the IMBAs resulted also in few cases of significant increases on harvest index while no positive significant effect was observed on cob length.

Treatments with Biozone, Gliogrow and Promis at 9th leaf, Gliogrow and K-humate at silking, and Biozone and K-humate at harvesting significantly increased plant N content and uptake at the respective growth stages. None of the IMBAs exerted a significant effect on the agronomic use of the applied N compared to the applied N from the NPK check, except in one case with Promis. The P content and uptake recorded at 9th leaf, silking, and harvesting increased significantly in three to four instances due to the application of Promis, Growmax and Montys. The efficiency of applied P from the IMBAs was not in one case significantly better than the applied P from the NPK check.

Application of Gliogrow, Crop care and Lanbac significantly increased thousand kernel mass in two to three cases, and milling index in two to seven cases in comparison with the NPK check. Gliogrow gave solely significantly higher percentage of >11 mm, and 10-11 mm kernels than the NPK check. Equally, Gromor gave significantly higher percentage of 8-9 mm kernels, and Growmax of 7-8 mm kernels.

Keywords: biological and chemical soil properties, grain yield and quality, growth and phenological traits, nutrient content and uptake

UITTREKSEL

Die stygende pryse van anorganiese kunsmis het maatskappye oorgehaal om te begin met die vervaardiging van biologiese verrykte stowwe waarna hier in verwys word as industrieel vervaardigde biologiese amendemente (IVBA's). Die vervaardigers beweer dat die IVBA's die vermoë het om gewasgroei en opbrengste te verbeter asook om die grond te verbeter. Die bewerings is dikwels sonder enige empiriese agronomiese bewyse wat die effektiwiteit van die IVBA's staaf.

'n Glashuis potproef is in 2008/09 gedoen om die effek van verskillende konsentrasies van nege IVBA's (Biozone, Gliogrow, Gromor, Promis, Growmax, Crop care, K-humate, Lanbac en Montys) op mieliesaaing ontwikkeling oor ses weke te bepaal. Die metings is gedoen by onderskeidelik 50, 75 en 100% van die aanbevole peile tesame met optimum anorganies NPK kunsmis en 'n kontrole. Die IVBA's het in baie gevalle 'n nadelige uitwerking op die persentasie ontkieming van mieliesaaing gehad waar die peile 100% was. Toedieningspeile van 50 en 75% was genoegsaam om goeie groei en fenologiese ontwikkeling van mielies te verseker maar die mees toepaslike peil het afgehang van die tipe IVBA.

Reënval afhanklike proewe is gedoen oor drie seisoene (2006/07-2008/09) by vier lokaliteite (Bethlehem, Bothaville, Ottosdal en Potchefstroom) om die effek van dieselfde nege IVBA's te bepaal op mielieontwikkeling en grondvrugbaarheid in 'n gerandomiseerde blok proefontwerp. Die IVBA's is toegedien volgens die vervaardiger en/of die verskaffer se aanbeveling tesame met optimum anorganiese NPK en 'n onbehandelde kontrole. Al die proewe is aangeplant met dieselfde kultivar naamlik PAN 6479. Waarnemings is elke seisoen gedoen ten opsigte van fenologiese ontwikkeling, graanopbrengs en ander opbrengskomponente, stikstof en fosfor inhoud, opname en agronomiese effektiwiteit, chemiese en mikrobiologiese eienskappe van die grond en graankwaliteit.

Die komposgebaseerde IVBA's soos Gromor, Promis en Growmax het die grond pH laat styg tot tussen 6.0 en 7.0 wat nie altyd die geval was met die ander IVBA's. In die algemeen het Gromor en Gliogrow die meeste gevalle van betekenisvolle pH toenames getoon in vergelyking met die NPK behandeling. Die frekwensie van betekenisvolle toenames in organiese C, minerale N en ekstraheerbare P het slegs in

vier van die 12 potensiële gevalle gerealiseer in vergelyking tot die NPK kontrole. Gromor het in geen geval betekenisvolle hoër minerale N en ekstraheerbare P gehad in vergelyking met die NPK kontrole. Die IVBA's behandelings veroorsaak toenemende mikrobiële C-biomassa immobilisasie vier weke na plant terwyl C-biomassa mineralisasie hoofsaaklik prominent was tydens blom en in 'n mindere mate tydens oes. Die verskillende IVBA's behandelings het in baie gevalle geen betekenisvolle effek gehad op C- en P-biomassa in vergelyking met die NPK behandeling.

Die IVBA's behandelings het ook geen positiewe effek gehad op mieliegroei en fenologiese eienskappe in vergelyking met die NPK behandeling. Toediening van Gliogrow het gelei tot 'n konstante afname in fenologiese groei in die 9de blaar en stuifmeel goeistadiums, hoofsaaklik as gevolg van swak opkoms in veral die swaarder gronde. Gromor en Promis het geen positiewe effekte op graanopbrengs en ander komponente getoon in vergelyking met die NPK kontrole. Nieteenstaande die konstante swak plantestand het Gliogrow die mees positiewe effekte gehad op alle gemete komponente in vergelyking met alle ander IVBA behandelings. In vergelyking met die NPK behandeling het die IVBA behandelings slegs in 'n paar gevalle gelei tot betekenisvolle beter oes-indekse maar daar was geen verbetering in koplengtes.

Behandelings met Biozone, Gliogrow en Promis tydens die 9de blaarstadium, Gliogrow en K-humate tydens stuifmeelstadium en Biozone en K-humate tydens oes het plant N inhoud betekenisvol by die genoemde stadiums verhoog. Geen van die IVBA's het 'n betekenisvolle effek getoon op toegediende N in vergelyking met die NPK kontrole. Die P inhoud en opname wat gemeet is tydens die 9de blaar, stuifmeel en oesstadiums toon 'n betekenisvolle toename in drie tot vier gevalle waar Promis, Growmax en Montys toegedien is. Die effek van toegediende P met die IVBA's was egter in geen geval beter as die toegediende P in die NPK kontrole.

Toediening van Gliogrow, Crop care en Lanbac het die duisendpit massa in twee tot drie gevalle betekenisvol verbeter en maalindeks in twee tot sewe gevalle in vergelyking met die NPK kontrole. Gliogrow het 'n betekenisvolle hoër persentasie pitte van >11 mm en 10-11 mm tot gevolg gehad. Soortgelyk gee Gromor 'n hoër persentasie van 8-9 mm pitte en Growmax van 7-8 mm pitte.

Sleutelwoorden: biologiese en chemiese grondeienskappe, graanopbrengs en kwaliteit, groei en fenologiese eienskappe, voedingstofinhoud en -opname.

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DEDICATION

This endeavour and the fruit of studies are dedicated to my daughters (Risuna and Nhleko), and to my siblings.

To my parents, who always inspired, encouraged and pioneered me into the institution of higher learning, to get on the privileged ideas of life.

John C. Maxwell stated that: *When you discover your place you will say, there's no place like this place anywhere near this place, so this must be the place.*

So as to learning, you do not finish until God recalls your name.

The learning process is ongoing and is a result of self-discipline and perseverance.

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LIST OF ACRONYMS

List	Description
'A'	
AE _N	Agronomic efficiency based on applied N
AE _P	Agronomic efficiency based on applied P
A-pan	Daily mean evaporation
'C'	
⁰ C	Degrees Celsius
C	Carbon
Ca	Calcium
C _{mic}	Microbial biomass carbon
conc.	Concentration
Cv	Cultivar
CV (%)	Coefficient of variation
'G'	
g	Gram
'H'	
ha ⁻¹	Per hectare
HI	Harvest index
HSD	Honestly significant difference post-hoc test
'K'	
K	Potassium
kg	Kilogram
kg ha ⁻¹	Kilogram per hectare
kg kg ⁻¹	Kilogram per kilogram
'L'	
LAI	Leaf area index
LSD _T	Tukey least significant difference
'M'	
m	Meter
m ⁻²	Per meter square
Max.	Maximum

mg	Milligram
Mg	Magnesium
mg kg ⁻¹	Milligram per kilogram
Min.	Minimum
Min.N	Mineral nitrogen
mm	Millimeter
'N'	
N	Nitrogen
Na	Sodium
NH ₄ ⁺	Ammonium
NO ₃ ⁻	Nitrate
'O'	
OM	Organic matter
'P'	
P	Phosphorus
P _{mic}	Microbial biomass phosphorus
'S'	
SEM	Standard error of the mean
'T'	
TKM	One thousand kernel mass
Tn	Daily mean minimum temperature
TOC	Total organic carbon
Tx	Daily mean maximum temperature
'W'	
WAS	Weeks after sowing

CHAPTER 1

GENERAL INTRODUCTION

1.1 Motivation

Maize ranks third in world recognition among cereals after wheat and rice. It is grown in almost all the Provinces of South Africa, but Free State, Gauteng, Mpumalanga and North West Provinces are the main areas of maize production triangle. It represents not only the most widely cultivated crop in South Africa but plays key role in many household diets and feed for animals. Its optimal production requirements include high fertiliser usage, particularly nitrogen derived from either chemical or organic constituents (Awotundum *et al.*, 1994). The major maize producing regions of South Africa are characterised by soils that are highly subjected to occasional N leaching due to their sandy nature rendering them deficient in major plant nutrients. Poor soil fertility status had forced grain producers to annually increase inorganic fertiliser rates to meet higher crop yields (Pocock, 2007).

In South Africa, approximately 35% of the total land area infrequently receives enough rain for agricultural production. Unfortunately, only 13% of this is classified as high potential arable land, many of which are marginal for crop production (Department of Agriculture, 2005). These together with the rapidly declining soil fertility and land degradation over decades (Mills & Fey, 2003; O'Farrell *et al.*, 2008) resulted in reduced productivity of this important grain crop thereby constituting a threat to global food security (Boyer, 1982; USDA, 2000). Nitrogen is considered the most important and limiting nutrient for profitable maize production in most African soils (Irshad *et al.*, 2002; Wedin, 2004). Likewise, most South African soils are widely deficient on N (Laker, 1976; Ratlabala, 2003; Mandiringana *et al.*, 2005).

Fertiliser addition to crops on agricultural lands has always been through mostly inorganic fertilisation, the importance of which had increased over the years (Teichert-Coddington & Green, 1993; Teichert-Coddington *et al.*, 1993; Yoana *et al.*, 2006). However, N fertilisation is sometimes wrought with volatility and occasional pollution of groundwater as nitrate (Khanif *et al.*, 1984; Nishio, 2001; Zhao *et al.*, 2007). Besides, inorganic fertilisers are sometimes not readily available while prices (Pitse, 2007;

Pocock, 2007) are often outside the reach of millions of resource-poor farmers. For these reasons, the latter are either most often not utilised or only applied in small quantity far below the recommended rates thereby resulting in very low crop yields.

The rising concern on the yearly hike in prices of conventional inorganic NPK fertilisers among other reasons has persuaded many South African agricultural manufacturing companies to commence producing biological enhanced amendments herein referred as industrially manufactured biological amendments (IMBAs). Manufacturers and/or suppliers of these substances claim that supposedly they could bring about increased crop growth and yield and make it not only productive but also sustainable. These materials are been registered and marketed often without substantial agronomic information of their effectiveness relating to crop performance and potential residual impact in soil. Since most of these substances appear to be supplements of conventional NPK fertiliser rather than complete replacements of NPK would mean an extra cost to producers. The magnitudes of benefits associated with IMBAs as claimed may thus have been over-estimated.

Therefore, usage of ineffective materials as crop growth and yield promoters either as soil or foliar amendments could negatively affect producers that are already under financial constraint. It is therefore an obligation of science to apply the “law of the consumer jungle”, *caveat emptor* (let the buyer beware). Some of these benefits included enhanced vigorous crop growth, the combination of live micro-organisms and micro-elements as single product with inoculants keep plants greener for longer period and also increase crop yield potential etc. Equally, suppliers that sell effective substances backed by validated scientific information and empirical data will have larger business opportunities. Besides, this will lead to a win-win situation for both suppliers and consumers. The integrated use of inorganic and organic plant nutrient sources may not only recycle organic wastes that could potentially cause environmental pollution, but could also conserve a rich pool of nutrient resources and hence reduce the sole dependence on inorganic fertilisers (Ahmed *et al.*, 2006). This will also increase the potential of organic fertilisers and improves the efficiency of inorganic fertilisers (Heluf, 2002). On the other hand, assessing the agronomic effectiveness of the IMBAs and their possible impact on chemical and microbial properties will represent a land mark

and major documentation in the agricultural revolution of South Africa for the improvements of livelihoods of our rural poor, emerging and commercial farmers.

1.2 Objectives

- Develop an in-depth literature survey for the different groups of active ingredients of IMBAs available in the market (Chapter 2).
- Assess the effect of the graded recommendation rates of IMBAs in a glasshouse (Chapter 4).
- Assess the effect of IMBAs on chemical and microbial biomass properties of soil (Chapter 5).
- Assess the effect of IMBAs on maize phenological growth indices at various growth stages (Chapter 6).
- Assess the response of yield and yield components to application of the different IMBA treatments (Chapter 7).
- Examine the influence of IMBAs on N content and uptake at different growth stages and also the utilisation of applied nitrogen in the different IMBAs (Chapter 8).
- Examine the influence of IMBAs on P content and uptake at different growth stages and also the utilisation of applied phosphorus in the different IMBAs (Chapter 9).
- Assess the effect of IMBA treatments on physical traits of maize grain (Chapter 10).

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, agronomic practices for maize production in South Africa and the factors affecting maize growth and development are discussed. The review also comprised of the historical overview and current approach of maize fertilisation in South Africa. It further discusses the introduction of alternative fertiliser and/or supplements to conventional fertiliser and their possible effects on crop growth, yield and on soil health.

2.2 Extent of maize production in South Africa

Maize is the most important grain crop in South Africa, being both the major feed grain and the staple food of the majority of the South African populace (du Plessis, 2003). Approximately 60% of maize produced in South Africa is white and 40% is yellow. White maize is largely used for human consumption and yellow maize for animal feed (DAFF, 2011).

The contribution of maize towards the gross value of field crops for the past five seasons until 2010/11 constitute 47.2%, followed by sugar cane, wheat, sunflower and hay with gross values of 13.9, 12.2, 6.5 and 8.7%, respectively. This can be attributed largely to the conventional producers who averaged a remarkable 4.31 t ha^{-1} annually for the five years growing seasons from 2006/07 to 2010/11 (Table 2.1). Most of the maize produced in South Africa is consumed locally and as a result the domestic market is very important to the industry (DAFF, 2011).

Table 2.1: Production and area planted to commercial maize from 2006/07 to 2010/11 in South Africa (Adapted from DAFF, 2011)

Season	2006/07	2007/08	2008/09	2009/10	2010/11
Plantings (ha)	2 551 800	2 799 000	2 427 500	2 742 400	2 372 300
Production (t)	7 125 000	12 700 000	12 050 000	13 043 000	10 697 400
Yield (t ha^{-1})	2.79	4.54	4.96	4.76	4.50

Since the deregulation of the South African agricultural market in 1996, the maize market has essentially been an open one in which a number of basic factors play a role in determining prices and these include *inter alia* international maize prices, exchange rates, local production and consumption, production levels in the Southern African Development Community region and stock levels (both domestic and international). Based on domestic stock levels, the domestic prices of maize (Table 2.2) fluctuate within a broad-band that is determined by world prices, the exchange rate and local maize production (DAFF, 2011). This huge fluctuation in the domestic price of maize contributes to the economic vulnerability of producers. They can reduce their economic vulnerability through ensuring optimum maize productivity. In this regard proper fertilisation is essential to provide in the nutritional requirements of maize.

Table 2.2: Mean trend in producer prices (Rand) of maize from 2006/07 to 2010/11 in South Africa (Adapted from DAFF, 2011)

Season	2006/07	2007/08	2008/09	2009/10	2010/11
	R t ⁻¹				
Producer price	1 450.20	1 665.61	1 305.10	1 004.87	1321.25

2.3 Suitable conditions for maize growth and development

Maize is a tropical grass that is well adapted to a wide range of climates (Belfield & Brown, 2008). The optimum air temperature for maize growth and development is 18 to 32°C, with temperatures of 35°C and above considered inhibitory. Optimum soil temperatures for germination and early seedling growth are 12°C or greater and 21 to 30°C at tasselling. The crop can grow and yield with as little as 300 mm rainfall (40 to 60% yield decline compared to optimal conditions), but prefers 500 to 1200 mm as the optimal range. Maize has reasonable tolerance of waterlogging, however, this tolerance is lowest at the tasselling stage (Belfield & Brown, 2008) and higher when the growing point is below the ground, especially when combined with high temperatures. The crop is relatively well adapted to a wide range of soils with pH (H₂O) 5.5 to 7.8 and outside this range, availability of nutrients to maize plants can be strongly affected causing a reduction in plant growth (Lafitte, 1994). For example, moderately acidic soils would be likely to reduce P and Mo availability and possibly may also affect K and Mg availability

(English & Cahill 2005). Maize is moderately sensitive to salinity which reduces uptake of nutrients and decreases total dry matter production (Ayad *et al.*, 2010).

Locally maize is planted during late spring/early summer with optimal planting times between November and December and harvested from late May up to the end of August, though planting can start as early as October and extend to January in some areas. In a particular season, the rainfall pattern and other weather conditions determine the planting period as well as the length of the production season (Girardin, 1998). Each maize hybrid has an optimum planting date and the greater the deviation from this optimum (early or late planting), the greater the yield loss (Liu *et al.*, 2006).

Plant densities vary considerably around the world depending on cultivar and climate variability. In the more arid areas, densities as low as 15 000 plants ha⁻¹ can be used and 25 000 plants ha⁻¹ are common, but in humid or irrigated areas populations in excess of 99 000 plants ha⁻¹ are common (Hodson *et al.*, 2002). The evapotranspiration rates varies with plant density, crop age, available soil water, atmospheric conditions, etc. from an estimated 0.20-0.25 cm day⁻¹ for young plants to 0.48 cm day⁻¹ for plants in the reproductive phase (Soer, 1980). Approximately a month after silking, the plant reached maximum dry weight referred to as physiological maturity. Harvesting will normally commence when grain moisture is below 14.5% for delivery to either storage or market facilities (Belfield & Brown, 2008).

2.4 Factors affecting maize growth and development

Growth is described as the progressive development of an organism and usually expressed in terms of weight, height, length, diameter etc. (Tisdale *et al.*, 1990). Sustainable crop growth and development in agro-ecosystems derive from the proper balance of crops, soils, nutrients, radiant energy, water and coexisting organisms (Hopmans, 2007). Therefore, the agro-ecosystem is productive and healthy when this balance of rich growing conditions prevail, and when crop plants remain resilient to tolerate stress and adversity. Such factors that affect plant growth and development can be classified as genetic or environmental.

2.4.1 Genetic parameters

Maize exhibits great genetic diversity, and there is a naturally occurring germplasm (Tittonell *et al.*, 2005). The main part of the 'Green Revolution' in Asia was brought about by the combination of improved crop varieties and improved methods of fertiliser application. Therefore, inorganic fertilisers are indispensable for realising the genetic yield potential of crops (Xie *et al.*, 1998). The yield potential of crops is determined by genes of the plant and a large part of the increase in yield over the years has been due to hybrids and improved varieties (Hefny, 2010). Other characteristics such as quality, disease resistance and drought hardiness are determined by the genetic makeup of crops. Maize hybrids are an example of a dramatic yield increase resulting from genetics (Tisdale *et al.*, 1990). The environmental and agronomic responses of maize hybrids determine their adaptability and influence improvements in maize production through agronomy and breeding (Pešev, 1970). Basbag *et al.* (2007) hinted that combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits.

High crop yields produced with modern hybrids, varieties and lines will require more plant nutrients than was necessary for lower yields of the past (Tisdale *et al.*, 1990). Under low fertility conditions, a new high yielding variety cannot develop to its full yield potential (Rabaut *et al.*, 2008). Conversely, in fertile soils the same new variety will deplete the soil more rapidly and eventually yields will decline if supplemental nutrients are not applied. The selection of hybrids that are genetically capable of producing high crop yields and use supplied plants nutrients efficiently is primarily the first step in a successful crop enterprise (Tisdale *et al.*, 1990).

The genetic constitution of a given plant species limit the extent to which that plant may develop regardless of any environmental condition, no matter how favourable can these limits be extended (Tisdale *et al.*, 1990). Variety and plant nutrient needs are increasing from time to time. For example, hybrid maize producing 9 000 kg ha⁻¹ requires twice the amount of plant nutrients than a hybrid producing 4 500 kg ha⁻¹. As potential crop yields are increased, the plant nutrients requirements increase (Rabaut *et al.*, 2008). Current research is concerned with developing maize hybrids by introducing new genomes that will use N efficiently and produce more grain per kg of N fertiliser (Hodson *et al.*, 2002).

2.4.2 Environmental parameters

The phenological growth of maize is affected by external environmental factors *inter alia* temperature, radiant energy, water supply, composition of the atmosphere, soil aeration, soil structure, soil reaction, biotic factors, supply of mineral nutrients and absence of growth-restricting substances (Tisdale *et al.*, 1990). However, only few will be discussed in detail since many of these factors do not act independently. Either directly or indirectly, in many instances poor growth and development of plants are caused by environmental stress (Bello & Olaoye, 2009). It is necessary to comprehend how these factors affect plant growth and development (Tisdale *et al.*, 1990). With a basic understanding of these factors, one may be able to manipulate plants to meet their needs, whether for increased leaf area, flowering or fruit production. Moreover, by recognising the roles of these factors, one could also be able to diagnose poor growth and development of plants caused by environmental stress (Tisdale *et al.*, 1990).

2.4.2.1 Temperature

Temperature is described as a measure of the intensity of heat and plant growth occurs in a fairly narrow range of 15 to 38°C (Tisdale *et al.*, 1990). It directly affects photosynthesis, respiration and transpiration of a crop, and also the absorption of water and nutrients. The rate of these processes increases with an increase in temperature and responses are different within different crops (Liu *et al.*, 2006; Akbar *et al.*, 2008). Low temperature inhibits soil organisms such as nitrifying bacteria, whereas soil pH may decrease in summer due to activities of microorganisms (Tisdale *et al.*, 1990). Maize is a warm weather crop and do best when temperatures in the warm months range from 21 to 27°C and does not do well when mean summer temperature drop below 19°C (Liu *et al.*, 2006). At 21 to 27°C, photosynthetic rate is more rapid than respiration which results in plant growth enhancement.

Maize growth is affected adversely when temperature decreases to 5°C or increases beyond 32°C (Akbar *et al.*, 2008). Higher temperature (+30°C) increases the anthesis-silking interval and result in poor synchronization of flowering (Grant *et al.*, 1989; Bänzinger *et al.*, 2000). Further increase in temperature reduces the pollen viability and silk receptivity resulting in poor seed set and yield reduction (Samuel *et al.*, 1986). Plants produce maximum growth when exposed to a day temperature that is about 5.5 to 8°C higher than the night temperature. This allows the plant to photosynthesize and

respire during an optimum daytime temperature and to curtail the rate of respiration during a cooler night (Bello & Olaoye, 2009). For growth to occur, photosynthesis must be greater than respiration. The photosynthetic process slows at low temperatures and this slowed growth and subsequent reduce crop yields (Bello & Olaoye, 2009). Moreover, high temperatures which can exceed 38°C in January and February may be limiting during crop growth and development when the plant is most sensitive to heat stress (Belfield & Brown, 2008).

2.4.2.2 Radiant energy

Plant growth may be influenced through the quantity, quality and duration of sunlight it intercept (Tisdale *et al.*, 1990). Maize plants that receive more sunlight have a better capacity to photosynthesize and the quantity of sunlight is directly proportional to the photosynthetic process. Sunlight can be broken up by a prism into respective colors of red, orange, yellow, green, blue, indigo, and violet. Red and blue light have the greatest effect on plant growth. Blue light is primarily responsible for vegetative growth, whereas red light when combined with blue light encourages flowering in plants (Bello & Olaoye, 2009).

2.4.2.3 Water supply

The growth of plants is restricted by low and high levels of soil water. However, between these levels the growth of plants is proportional to the amount of water present. Therefore, adequate soil water improves nutrient uptake (Tisdale *et al.*, 1990; Mtambanengwe *et al.*, 2009). Excellent root growth showed to develop well when the soil is well supplied with soil water. Inadequate available soil water affects various plant physiological processes such as leaf elongation (Tisdale *et al.*, 1990). Low levels of plant available water in the root zone limit nutrient availability by retarding processes involved in nutrient uptake such as diffusion, mass flow, root interception and contact exchange. Flooding of soil pores by excessive amounts of water is detrimental since the resultant lack of oxygen restricts respiration and ion absorption (Tisdale *et al.*, 1990). Extreme low and high soil water levels also inhibit the activity of microorganisms responsible for the transformation of nutrients into plant available forms.

2.5 Nutritional requirements of maize

2.5.1 Essential nutrients for plant growth

Soil nutrients are essential for plant growth and if a plant is deprived of any one of the essential elements it would cease to exist (Tucker, 1999). A German scientist in the mid-19th century, Baron Justus von Liebig authored the term "law of the minimum, which states that plants will use essential elements only in proportion to each other, and the element that is in shortest supply in proportion to the rest will determine how well the plant uses the other nutrient elements". Million tonnages of essential plant nutrients are added annually to world soils (Buol, 1995). Hence, current plant and animal production levels are highly dependent on these additions (Russels, 1977). Knowing the nutrients required to grow plants is only one aspect of successful crop production. Optimum yield also requires the application of an appropriate nutrient source at a meaningful rate, the method and time. However, proper knowledge on how the applied elements are influenced by soil and climatic conditions is also of essence (Tucker, 1999). There are 16 nutrient elements required to grow crops and of the 16, three essential elements are taken up as carbon dioxide from the atmospheric and water from the soil and they are C, H and O. The other 13 nutrient elements are taken up from the soil and they are classified as primary nutrients (N, P and K), secondary nutrients (Ca, Mg and S) and micronutrients (Cu, Fe, Mn, Zn, B, Mo and Cl) (Tucker, 1999; Hani *et al.*, 2006).

Often the primary and secondary nutrients are referred to as the macronutrients since plants required them in greater quantities for proper growth and development. Nonetheless, producers focus usually on only three of the six macronutrients namely, N, P and K as these nutrients give the largest response (Hani *et al.*, 2006). Accordingly, van Averbek and Yoganathan (2003) asserted that in most South African soils, P is the most deficient nutrient. This means that if you would have to choose between the application of either N, P or K, crop yields would largely increase when P is added to the soil. Nitrogen is the second most deficient nutrient and crop yields are expected to increase with the addition of N after the needs of P has been satisfied (van Averbek & Yoganathan, 2003).

In many parts of the country the amount of K stored in the soil is considerably high and K applications may not always result in higher yields. However over-time, continuous

cropping will also deplete the K reserve in the soil, making it necessary to fertilise the soil with this nutrient in order to maintain high yields. In high rainfall areas or where the soils are sandy, the quantity of K stored in the soil is usually low and fertilising may be necessary from the onset. Typically high concentrations of P and K are found in fields where heavy rates of animal and poultry litter have been applied (van Averbeke & Yoganathan, 2003).

2.5.2 Primary nutrients for plant growth

2.5.2.1 Role of N, P and K in plant growth

Nitrogen is an essential component of all enzymes and therefore necessary for plant growth and development. It constitutes about one-sixth of the mass of proteins and is a basic element of nucleic acids (Bänzinger *et al.*, 2000). This element in crops promotes rapid growth, increases leaf size and quality and accelerates crop maturity. Nitrogen plays a role in approximately all plant metabolic processes. For example, N is an integral part of chlorophyll manufactured through photosynthesis. It is also used by microbes to break down organic matter.

Normal plant growth cannot be achieved without phosphorus (Bänzinger *et al.*, 2000). It is a constituent of nucleic acids, phospholipids, the coenzymes DNA and NADP, and particularly ATP. The element is involved in many other metabolic processes required for normal growth such as photosynthesis, glycolysis, respiration and fatty acid synthesis. Phosphorus enhances seed germination and early growth, hastens maturity and provides winter hardiness to crops. Earlier studies indicated that P application enhance crops to reach 50% tasselling and to silk earlier (Chapman & Carter, 1976).

Potassium is essential for photosynthesis. The element activates enzymes to metabolise carbohydrates for the manufacturing of amino acids and proteins. It facilitates also cell division and growth by helping to move starch and sugars between plant parts. Potassium enhances stalk and stem stiffness, increases disease resistance and drought tolerance, regulate opening and closing of stomates and also regulate many other metabolic processes required for growth (Tucker, 1999; Imas & Magen, 2000).

2.5.2.2 **Deficiency and toxicity of N, P and K in plants**

It was mentioned earlier that plants require *inter alia* N, P and K to complete their life cycle and each of these nutrients has a critical function that is required in varying quantities in plant tissue (Hani *et al.*, 2006). An adequate supply of N, P and K at each growth stage is essential for optimum growth and development of maize (Cox *et al.*, 1993). A nutrient deficiency occur when the nutrient is not in sufficient quantities to meet the needs of the growing plant, while nutrient toxicity occurs when plant nutrients is excessively, but often differ among species and plant varieties (Bennett, 1993). One way to understand the differences in N, P and K deficiency and toxicity symptoms among plants is knowledge of their functions and the relative mobility of the nutrient within the plant (Table 2.3). The N, P and K nutrients differ in the form they are absorbed by a plant, and their functions and mobility in the plant. This resulted that the deficiency or toxicity symptoms a plant show are characteristic for a nutrient (Bennett, 1993). Nutrients such as N, P and K can easily be remobilised within a plant from old parts to actively growing parts such as young leaves. Therefore, the deficiency of these three mobile elements usually occurs with older leaves initially (Bennett, 1993).

Table 2.3: Relative amounts of N, P and K in plants and their visual symptoms related to excessiveness and deficiency (Adapted from Bennett, 1993)

Element	Relative % in plant	Function in plant	Type	Visual symptoms
N	100	Protein, amino acids	Excess	Dark green foliage which may be susceptible to lodging, drought, disease and insect invasion. Crops may fail to yield.
			Deficient	Light green to yellow appearance of older stunted growth, poor cob development.
P	6	Nucleic acids, ATP	Excess	May cause micronutrient deficiencies, especially iron or zinc.
			Deficient	Leaves may develop purple coloration; stunted plant growth and delay in plant development.
K	25	Catalyst, ion transport	Excess	May cause deficiencies in magnesium and possibly calcium.
			Deficient	Older leaves turn yellow initially around margins and die, irregular cob development.

2.5.2.3 Uptake of N, P and K by plants

Nutrient uptake by maize like other crops is closely related to dry matter production. This resulted that sites which are consistently high yielding, proportionately higher levels of nutrients are taken up and removed in harvested grain (Belfield & Brown, 2008). In such instances over 50% of the available N and P and approximately 80% of the available K is exhausted before the crop reaches reproductive stage. The rates of N, P and K uptake as well as the cumulative uptake of N, P and K during the growing season are indicated for maize in Figures 2.1 and 2.2, respectively.

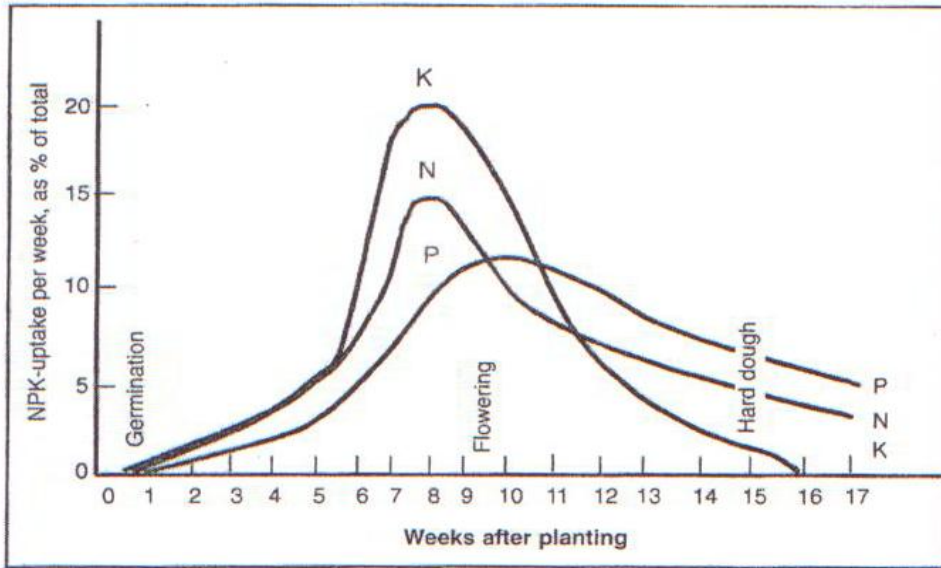


Figure 2.1: Uptake of N, P and K by maize on a weekly interval during the growing season (From Aldrich & Leng, 1965 cited by FSSA, 2003).

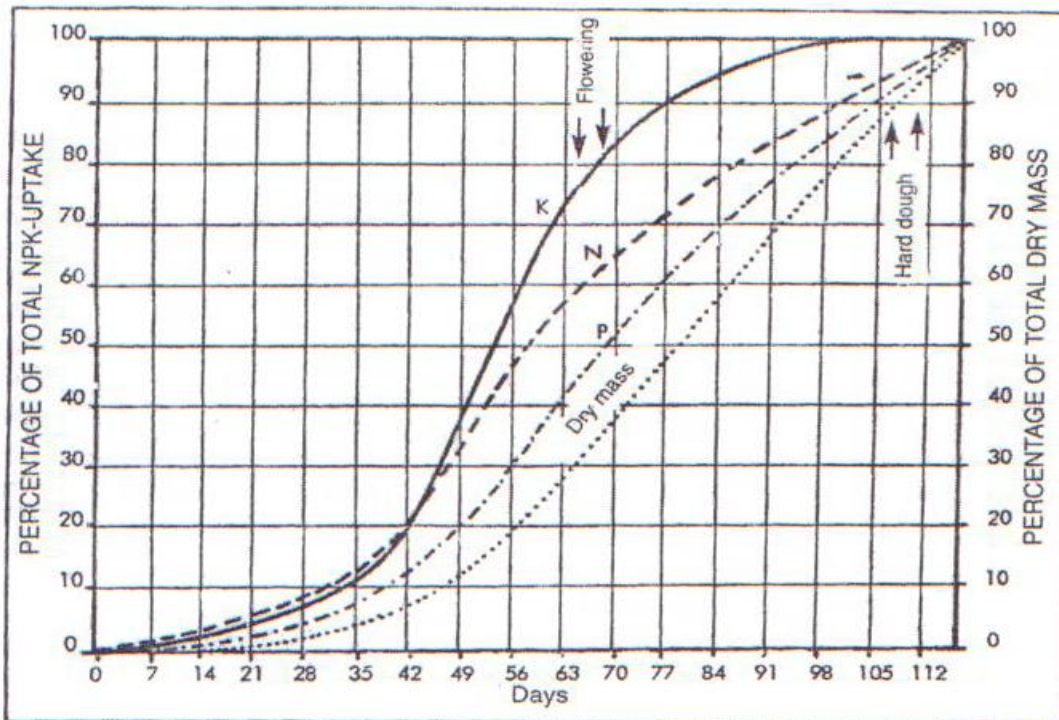


Figure 2.2: Weekly cumulative uptake of N, P and K by maize as a percentage of total uptake by the plant (From Aldrich & Leng, 1966 cited by FSSA, 2003).

Whether natural or manufactured, plant nutrient in fertilisers are generally not in a form that plants can use it directly. For example, only two forms of N are available for plant uptake (i.e. NH_4^+ and NO_3^-). Once a nutrient is added to a soil it is subject to a number of fluxes while some of the nutrient may be taken up by plants and removed in harvested products (du Preez & Claassens, 1999; Mills & Fey, 2003). The rates at which nutrients in fertiliser become available to the plant vary depending on the product (Payne & Lawrence, 2009). The uptake of nutrients and their distribution to different plant parts have been found to vary primarily with the fertility of the native soil, application of inorganic fertilisers, the growth stage of the plant and the environmental conditions (Olugunde, 1974). There is a close relationship between soil water and nutrient availability for uptake. It is generally believed that the greatest benefit from fertiliser application can be derived under irrigated conditions where water supply is least likely to limit nutrient uptake (Michael, 1981).

With adequate supply of nutrients, plants that are limited in growth due to water stress would have a higher content of nutrient elements than plants under comparable fertility, but not limited in growth by water supply (Michael, 1981). Depending on the specific climatic conditions during plant growth there is an uptake of different quantities of mineral substances from the soil (Petr *et al.*, 1988). It is indispensable to agricultural practices to study the nutritional element content in the soil and plants (Alexandrova & Donovan, 2003), as a result the biomass obtained from the plants and the uptake of the same elements by plant production are relevant for the nutritional needs of the plants.

It is important to know the fertility of the soil and ensure there are sufficient nutrients to grow crops. Demand for fertilisers can be assessed by soil and plant analyses and by visual symptoms of nutrient deficiencies (Bennett, 1993). Once the producer knows what nutrients are needed, it is then important to determine the amount of additional nutrient requirement. Producers are then able to select the best product to use and determine what rate to apply. Recovery of available N by plants is often only 35-50% and especially low in waterlogged soils. The rates of nutrients to be supplied to a crop depend on soil type, pH, climate, cultivar, targeted yield, soil water and management practices (Mtambanengwe *et al.*, 2009). The rate at which plants take up N can be influenced by the crop rooting depth, root length density and the duration of assimilation (Ayad *et al.*, 2010). A root length density of around 1 cm cm^{-3} is usually adequate for

depleting the soil of plant-available N over a cropping period and an increased root length density may increase N uptake. Ayad *et al.* (2010) stated that at the beginning of the season, mineral N supply in the soil usually exceeds the uptake capacity of maize, but during the season, maize reduces the size of the mineral N pool because uptake usually exceeds net N mineralisation. Maize can take up mineral N until about 4 to 6 weeks after flowering when available in the rooting zone (Ayad *et al.*, 2010).

Maize is also a demanding crop for P and is quite sensitive to low P availability, especially in the early growth stages (PDA, 2008). Fertiliser P should be applied at planting as most of the P is taken up early in the plant's life, particularly as it is required for healthy root development (PDA, 2008). As a result, fertiliser P should be placed where it is available to the roots quickly and the best location for this is banded below the seed at planting. Significant quantities of P can be made available if organic matter levels and rates of mineralisation are favourable. Phosphorus that is mineralised from organic matter is more beneficial than adding inorganic fertiliser since organic P is available for longer in the soil solution for plant uptake (PDA, 2008).

Maize takes up K in a relatively large amount with about 86% of total K taken up until silking and only 19% is contained in the cob and stem portion (Potash & Phosphate Institute, 2007). Therefore, most of the K absorbed remains in the stubble and is then recycled through crop residues for subsequent crop production (PDA, 2008). At late vegetative development stages (V11 to V16), maize grows rapidly with a high demand for water and nutrients (especially N, P and K), and is considered the most critical stages in the development of a maize plant (Alexandros & Donovan, 2003). Any adverse effect suffered at this stage, such as nutrient or water shortage, insect damage, or too high plant population, will significantly affect yield. At flowering stages (R1) there is a high demand for water, and the uptake of N and P is rapid, although K uptake is almost complete (Potash & Phosphate Institute, 2007). During kernel filling stages, N and P uptake continues at a rapid rate and the kernel size may be affected by unfavourable conditions (Chapman & Carter, 1976).

2.5.2.4 Removal of N, P and K in marketable product

Fertiliser application for maize is often required to correct deficiencies of essential nutrients and to replace nutrients removed in harvested crop products (Bennett, 1993; Belfield & Brown, 2008). This is especially true for the primary nutrients N, P and K. In forests and grasslands nutrients taken up by plants are returned to the soil mainly through a process of decaying litter. Dead plant material such as leaves and stems accumulate on the soil surface, where it decays or decomposes (Hati *et al.*, 2007; Belfield & Brown, 2008). On cropped land most plant material and the nutrients contained is removed from the field in the form of grain (e.g. maize and sorghum), leaves (e.g. cabbage and spinach) or other plant parts (e.g. potato and pumpkin) (Hati *et al.*, 2007). Crops differ in the amount of nutrients they remove. Some crops remove nutrients in large amounts while others do not (Potash & Phosphate Institute, 2007).

After every maize crop harvest, more than 30 kg of N, P and K per hectare could have been removed from soils each year in Sub-Saharan Africa (Table 2.4) with consequent cumulative depletion over time (OMAFRA Staff, 2003). The extent to which N, P and K are removed from soil depends on the yield realised (Belfield & Brown, 2008). For higher crop yield, N, P and K should be applied in balanced proportion so that when these nutrients are removed from soil due to cropping are adequately replenished (Potash & Phosphate Institute, 2007).

Table 2.4: Quantity of N, P and K removed by maize grain or silage (Adapted from OMAFRA Staff, 2003)

	N	P	K	Total
Grain (kg t ⁻¹)	16	3.3	4.2	23.5
Silage (kg t ⁻¹)	10	3.3	6.0	19.3

2.6 Fertilisation of maize in South Africa

2.6.1 Historical overview

Fertilisers are either inorganic or organic compounds which contain essential nutrients to promote plant growth and development. Thus based on which compounds dominate fertilisers are classified as inorganic or organic of nature (Belfield & Brown, 2008). Both

inorganic and organic fertilisers were called earlier "manures" derived from the French expression for manual tillage, but this term is now mostly restricted to organic manure (Miles & Manson, 2005). Organic fertilisers comprised mainly of animal manure and have been used to improve cropping for centuries. The introduction of inorganic fertilisers is arguably one of the great innovations resulted in the agricultural revolution of the 19th century (FSSA, 2003). The commodity nature of fertiliser combined with the high cost of shipping leads to use of locally available materials or those from the closest/cheapest source (van Averbeke & Yoganathan, 2003). Hence, a particular N source may be very popular in one part of the country while another is very popular in another geographic region only due to factors unrelated to agronomic concerns (FSSA, 2003).

Archeological studies indicated that man first started to cultivate soil about 10 000 to 12 000 years ago and it is assumed that early fertilisation practices had been lost and forgotten due to poor records keeping (FSSA, 2003). Most commonly used fertilisation products then were animal manure, bones, wool ash, wool scraps, guano, fish and limestone. Other studies revealed that as early as 1840's, a chemist Baron Justus von Liebig, developed the first theory of inorganic fertiliser production by reacting sulphuric acid with bones for the production of superphosphate, thereafter fertilisers developed more rapidly (FSSA, 2003).

In South Africa, organic fertilisers were first used in the Cape during the arrival of Jan van Riebeeck in 1652. However, John Jourdain provided the first reference to the fertility of South African soils as early as 1608 (FSSA, 2003). Subsequently, in 1666 Jan van Riebeeck successor Commander Zacharias Wagenaar imported guano from Saldanha Bay to be used as fertiliser, which became depleted over time (FSSA, 2003). The problem of poor fertility soils called for the introduction of inorganic fertiliser at about 1890. This was a small consignment of fertiliser for "maize and hay" fertiliser imported for a certain van Heerden of Malmesbury. The first local fertiliser factory was started in 1903 when SAFCO initiated phosphate production from bones in Durban (FSSA, 2003).

The key role of inorganic fertiliser in crop production steadily increased during the years in order to secure and sustain food for the growing human and animal population

(Teichert-Coddington & Green, 1993). In the 1950s and 60s, and in the early 1970s and mid-90s, the South African National Department of Agriculture executed a great deal of research on fertilisation of maize with regard to N, P and K (van Biljon, 2009a). Grant (1978) pointed out that from 1953-1978 there was a considerable increase in the area cultivated and also an increase in crop potential through improved hybrids. During the 1970s, fertiliser demand increased by more than 10% annually largely due to need to be internally self-supporting with increasingly political isolation.

The most significant result of these changes was the withdrawal of marginal land from crop production and the reduction of the hectares planted to maize (Barnard & du Preez, 2004). This has led to the decline in fertiliser consumption from 870 000 tons of NPK in 1982 to about 600 000 tons of NPK in 2000 (Figure 2.3). In review articles, van Biljon (2009a and b) indicated that maize grain yield as well as fertilisation practices have changed over the last 25 to 50 years. For example, average maize yield in South Africa increased from approximately 2.3 t ha⁻¹ in the early 1980s to 3.5 t ha⁻¹ in recent years. Maize fertilisation changed from a single application rate of products to variable rate application of fertiliser with the addition of foliar fertiliser and soil ameliorants (Kasim *et al.*, 2009).

In South Africa, a general practice over decades has been to enrich organic manures with inorganic fertilisers so as to enhance nutrient concentration in organic fertilisers (FSSA, 2003). The extent of enrichment is determined by the inorganic and organic sources used. The NPK content of enriched organic fertilisers will typically vary between 18 and 25%, while the total plant nutrients of a pure organic mixture may vary between 6 and 12% (van Averbeke & Yoganathan, 2003).

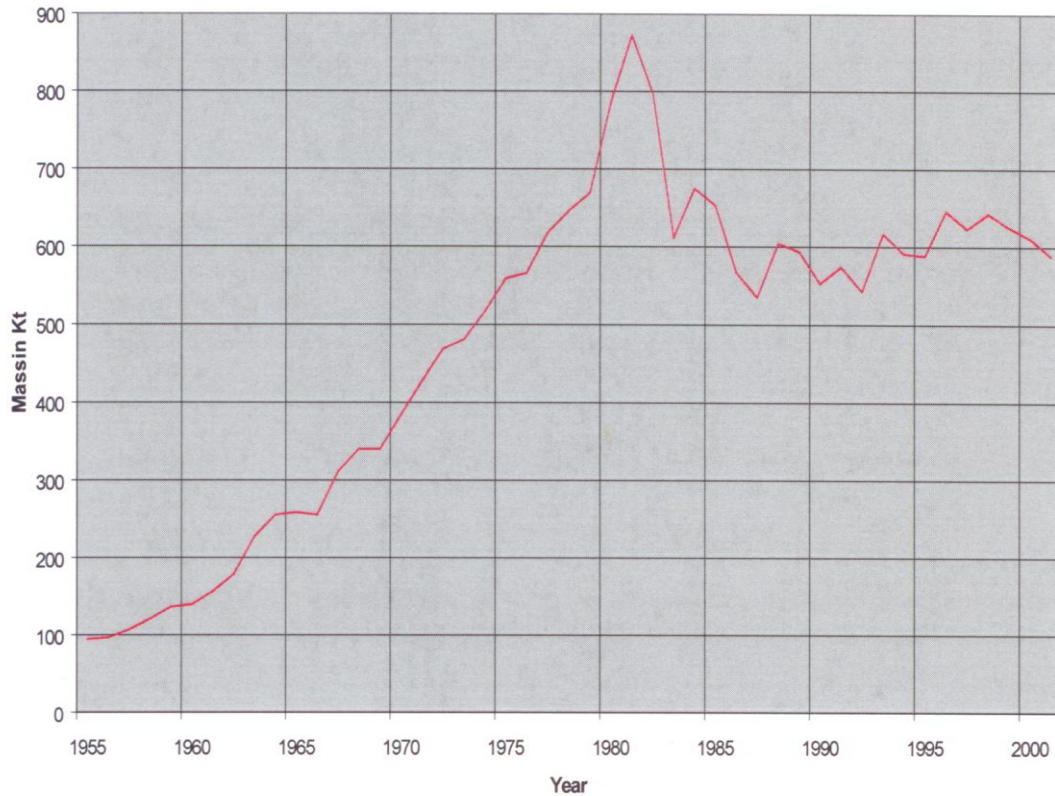


Figure 2.3: Consumption of NPK from 1955 to 2000 in South Africa (Adapted from Ratlabala, 2003).

2.6.2 Current trends in South Africa's fertiliser industry

The South African fertiliser industry of today is fully exposed to world market forces and operates in a totally deregulated environment with no import tariff measures (FAO, 2005). Presently, the industry annually supplies about 750 000 tons of NPK to the local market at a value of around R3 billion and this represents approximately 20% of the South African chemical industry. Sasol Limited supplies most of the country's ammonia, with some also coming from Mittal Steel. South Africa presently imports all its urea and LAN is manufactured locally by Sasol Nitro and Omnia, while ammonium sulphate is produced by Sasol and Mittal Steel (FSSA, 2003). Foskor supplies phosphate concentrates to local and foreign fertiliser producers (e.g. phosphoric acid and di-ammonium phosphate) and downstream products (e.g. superphosphate). All South Africa's potassium requirements are imported and South Africa through Foskor is however, a significant exporter of phosphoric acid (FAO, 2005).

In South Africa, maize is estimated to be the largest single consumer of fertiliser with almost 40% of the total fertiliser market, followed by sugar cane (15%) and wheat (10%) (van der Linde & Pitse, 2006). The other crops together represent about 35% of the total fertiliser market. The total NPK consumption in South Africa is in the order of 760 000 tons per annum and this demand is met through local production and imports (FAO, 2005). The steady growth in nitrogen consumption, albeit at a modest rate of 0.7% per annum was accompanied by a decline in phosphorus consumption, while potassium consumption remained approximately constant (FAO, 2005).

Unexpectedly, sub-Saharan Africa (SSA) which covers an area of approximately 24 times greater than that of South Africa and supports a population about 13 times more, only consumes around 1.2 million tons of NPK per year. The average NPK application rate in SSA is in the order of 9 to 12 kg ha⁻¹ while the cereal yield is on average 1 ton per hectare (van der Linde & Pitse, 2006). Africa is currently experiencing a decrease in the production of food per capita while Asia and South America are doing the opposite (FAO, 2005). Soil fertility depletion on smallholder farms has been identified throughout SSA as the fundamental biophysical cause of declining per capita food production in this region (van der Linde & Pitse, 2006). Accordingly, South Africa has much to offer in terms of helping to establish regulatory systems in SSA. South Africa with its very well established fertiliser industry that is currently operating far under its true capacity has a great challenge with helping to build-up the soil fertility in the whole region (van der Linde & Pitse, 2006).

2.6.3 Contemporary fertilisation practices

Nutrition is enormously imperative when growing a maize crop as it has a high demand for nutrients which the soil cannot always provide (Bennett, 1993; Belfield & Brown, 2008). Although many nutrients required to grow maize are abundantly in soil, some may occur in low levels (Mtambanengwe *et al.*, 2009). Low fertility levels can be natural for the soil type or can be the result of nutrient export through many years of continuous cropping on a field (Belfield & Brown, 2008). Proper fertilisation practices are therefore of utmost importance for sustainable maize production.

The use of fertiliser at planting to provide maize seedlings with the primary nutrients is a common practice in South Africa. As previously mentioned, N and P are particularly

important, and K may also need to be applied at planting if levels are below the critical threshold value of 125 mg kg^{-1} (van Biljon *et al.*, 2008). Split applications of N is recommended and 30% should be applied at planting and the remaining 70% is usually side or top dressed at knee height after eradicating weeds, while all the P and K is applied all at planting (ARC-GCI, 2010). Accordingly, fertilisers are band placed usually approximately 5 cm below and to the side of the seed and be covered with soil at planting to minimise losses due to volatilisation (N), surface run-off and erosion (P and K). The kind of band placement reduced also the risk of either seed or seedling damage by fertilisers. Applied P remains also longer in high P fixing soils with low P status (FSSA, 2003).

The amount of N required for maize crop is calculated according to yield potential. The calculation is usually based on the previous five year average. Sound judgment should prevail however with this approach. Several factors could influence the N requirement of a crop (e.g. a previous crop, especially a legume) and they must be considered when making a final recommendation. In the case of P, the required amount is based on soil P test and yield potential, whereas for K, a soil K test and clay content are taken into account (ARC-GCI, 2010). Soil tests for P and K every 3 to 4 years are recommended (Hoeft & Peck, 1991; FSSA, 2003).

In South Africa, most commercial producer plant maize with compound fertiliser and this enable the producers to apply N, P and K simultaneously. As previously mentioned, 30% of the required N and all of the P and K are applied at planting. Thus it be taken into account that more than 50% of the required N and P and 80% of the K required is taken up before the crop reaches the reproductive stage (Belfield & Brown, 2008). It is therefore imperative that an adequate supply of these primary nutrients be available to the plants early and remains available throughout the growing season. Even though only small amounts are taken up early in the season, high concentrations should be available in the root zone as the root system is small and when the soil is often cold (Bennett, 1993).

Nitrogen is susceptible to leaching or denitrification and losses of this nature can be reduced by split applications (ARC-GCI, 2010). There is much greater flexibility in the time of application of P and K since they are relatively immobile. On numerous soils,

they may be broadcast either in the fall or spring with similar results, except on sandy soils where there is a possibility that K might be leached out of the rooting zone, hence it must be then applied just at planting (FSSA, 2003).

2.7 Industrially manufactured biological amendments

A large number of biological-enriched products are registered as fertilisers in terms of the South African Fertiliser Act of 1947 (FAO, 2005). Registration commits the producer to the specified composition of the fertiliser. The Act is administered by the National Department of Agriculture, and the quality and composition of registered products are controlled by the Registrar of Fertilisers (FSSA, 2003). Of more than 700 registered biological-enriched products locally, only 17 herein refers as industrially manufactured biological amendments (IMBAs) were selected for discussion. Their selection was based primarily on composition and attributes to ensure a good representation.

2.7.1 Composition and attributes

The 17 IMBAs selected for discussion are contained in Table 2.5. Specific information on their composition and attributes are very scanty in reviewed articles. In many instances only the claims of either the product manufactures or suppliers can be rely on. The IMBAs were classified therefore into three classes namely, beneficial microorganisms (BM), manure (MN) and humic acids (HA) based products. This approach contributes to a more meaningful discussion of the IMBAs concerning their potential beneficial effect on soils and crops. All the IMBAs fit easily into one of the three classes except for Lanbac with beneficial microorganism and humic acids based (Table 2.5). Except for the manure-based IMBAs like Gromor and Promis, the other IMBAs coincide with a normal baseline inorganic NPK application. Most of the IMBAs are exclusively for either soil or foliage applications while a few are suitable for both types of applications.

Table 2.5: Synopsis of claims associated with the use of beneficial microorganism (BM), manure (MN) and humic acids (HA) based IMBAs

Class	IMBAs	Claim
BM	Biozone 12s	Decomposition of plant material in the soil as well as in compost and manure; Assist in stabilising pH levels; Increase the absorption and availability of N and other plant nutrients; Increases the immunity of plants; promotes vigorous growth and development of plants; Inhibits plant pathogenic bacteria.
BM	Gliogrow	Activates general plant growth; Nitrogen optimalisier in crops; Improve plant's natural resistance, which lead to increase general plant growth; Enhance bacteria to release inorganic N. Gives green colour to leaves and minimise the severity to rust.
BM	Hyperboost-flo	Promotes active growth of plants; Increase vegetative growth thus enhance photosynthesis.
BM	Margaret Roberts supercharger	Contains all the macro and micronutrients plus a growth stimulant; contains all the essential nutrients to obtain optimum growth of vegetables, herbs, seedlings, groundcovers, fruit bearing plants and lawns.
BM	Mitygrow TM	Attaches itself to plant roots and interacts with the exudation to promote growth and development of plant roots that enhances their ability to absorb water and nutrients; Stabilises the pH level; Increase the NPK levels; Reduces aerobic and coliform bacterial counts and inhibition of plant pathogenic bacteria and fungi; Acceleration of photosynthetic process; Makes plants stronger and more resistant to diseases, which leads to increased yields.
BM	Multi-feed classics	It is suited for optimal root development of seedlings, flower beds, shrubs, pot plants and vegetable crops; It can be applied in combination with most insecticides, systemic fungicides and all other specialized water and soluble nutrients.
BM	Triospray-flo	Prevent and/or correct micronutrient deficiencies of Mn, Cu and/or Zn; Compatible with most commonly used pesticides, but a test mix should be made prior to large scale use.
MN	Gromor Accelerator	Supply full range of plant nutrients in organic form and will not leach; Put life back into dead soil; Stimulate soil life and unlock plant nutrients; Pilot to healthier plants; improves aeration and water holding capacity.
MN	Growmax	Controls pathogens; High water removal to enable practical transportation and subsequent land application; Promotes the achievement of soil amelioration and excellent crop productivity; Controls and reduce heavy metal content in the soil.

Table 2.5: Continue

Class	IMBAs	Claim
MN	Ludwigs vigorosa	A well balanced organically enriched granular fertiliser, which contains all the essential nutrients; Enhances general healthy stem and leaf growth and flowering; Contains a high percentage of carbon in the form of humic acid.
MN	Promis	Corrects imbalances and puts life back to the soil; Stimulate soil life and unlock plant nutrients; Lead to healthier plants; improves aeration and water holding capacity.
HA	Advanced Crop care	Improves the permeability of plant membranes; Improves soil structure formation - improves aeration and water holding capacity in the soil; Promotes chelation of a number of elements into forms available for plants; Increases nutrient uptake; Improves growth of various beneficial micro-organisms; Helps reduce inorganic fertiliser requirement; Humic substances produce thicker, greener and healthier crops; Gives excellent boost to growth, colour and protein; It is an effective source of N.
HA	K-humate	The product contains humus – a major component of soil organic matter; Improves soil physical, chemical and biological properties; Increase nutrient retention ability, thereby reducing the loss of applied fertilisers from leaching and runoff; Acts as a plant growth regulator by supplying precursors of hormones; Improves uptake of nutrients and availability of nutrients results in improve quality and increased yields.
HA	Montys organics	Significantly increases cation exchange; Assists in absorption of pesticides and creates efficiencies among translocation of nutrients; Increase chlorophyll and water retention; Reduce stress tolerance from wind and drought.
HA	Nitamin	Increased yield; Improved quality; Steady growth; Reduces N loss; Low burn risks.
HA	Nucat 20/40	It is a natural activator, soil enhancer; contain macro and micro elements; It is a natural supplement.
BM + HA	Lanbac (Microbial solutions)	Stimulate root growth and germination; Improves soil structure; Helps towards achieving a favourable ratio between beneficial and pathogenic organisms; Produces natural plant growth hormones (auxins, gibberellins and cytokinins); Suppresses root diseases through competitive exclusion; Better crop vitality will help the plant handle peak stress periods.

2.7.2 Beneficial microorganism-based amendments

It is estimated that about 50% of the increase in agricultural production in the world was due to use of inorganic fertilisers (FAO, 1989). This approach is however increasingly evident to be unsustainable as it causes soil degradation and the cost of required inputs is often beyond the financial reach of small-holder producers who constitute more than 80% of the food producers in the developing nations (Tittonell *et al.*, 2005). Numerous attempts have been made to develop economically viable alternative systems more suited to the needs of small-holder producers among others is the use of “effective microorganisms” to enhance crop growth (Gomaa *et al.*, 2005). Effective microorganisms (EM) is a mixture of selected naturally occurring and cultured microorganisms that have been studied and known to significantly improve soil quality and plant growth. They are primarily photosynthetic and lactic acid bacteria, yeast, actinomycetes and fermenting fungi that can be applied as an inoculant to increase the microbial diversity of soils (Li & Ni, 1995; Woodward, 2003).

The theory of EM was developed in 1971 (Higa & Wididana, 1991). Research showed that inoculation of the soil/plant ecosystem with EM cultures improves soil quality and health as well as growth, yield and quality of crops (Higa & Parr, 1994). The use of EM is not yet widespread in South Africa, although there are reports that some commercial farmers are already using the materials and they seem to find satisfaction with its effects (Ncube *et al.*, 2008). Additions of EM could benefit the soil through the improvement of the physical, chemical and biological environments of the soil, suppression of soil-borne pathogens and pests, improvement of germination of seeds, flowering, fruiting and ripening in plants, enhancement of the photosynthetic capacity of crops and increase crop yield (Asia-Pacific Natural Agriculture Network, 1995).

Addition of EM together with organic manures is thought to be an effective technique for stimulating supply and release of plant nutrients (Gomaa *et al.*, 2005). Studies have shown that inoculating agro-ecosystems with EM can improve soil and crop quality (Higa & Parr, 1994; Hussain *et al.*, 1999). Subsequent EM application into the soil increase soil microorganisms that are beneficial for the growth of the plant and result in rapid mineralisation of organic materials (Asia-Pacific Natural Agriculture Network, 1995). Application of EM with inorganic fertiliser resulted for example in a 14% increase in yield over the inorganic fertiliser alone, demonstrating that EM is more effective when

applied with organic manures. The relatively low response of inorganic fertiliser compared to when applied with EM was due to the fact that EM is made up of different microorganisms which can respond well only in the presence of sufficient organic matter (Gomaa *et al.*, 2005).

Several comparative studies have been conducted on the effects of EM enriched Bokash with the inorganic fertilisers on plant growth and development (Fujita *et al.*, 1997; Arshad, 2006). Plants treated with inorganic fertiliser had higher dry matter yields during the early stages of growth but lower dry matter yields at the later stages compared to plants treated with EM enriched Bokash (Fujita *et al.*, 1997). Plants treated with EM enriched bokash maintained vigorous growth with greater root mass and activity and a higher rate of photosynthesis until harvest time compared to plants treated with inorganic fertiliser. Well-developed roots in plants treated with EM enriched Bokash play an important role in maintaining a higher rate of growth and photosynthetic activity (Yamanda *et al.*, 1996). Higher growth rates are due to sustained availability of nutrients mineralised from bokash by the EM (Kato *et al.*, 1997). Effective microorganisms play a cardinal role in soil fertility as a result of their involvement in the cycling of nutrients like carbon and nitrogen, which are required for plant growth. Certain soil microorganisms such as mycorrhizal fungi can also increase the availability of plant nutrients (e.g. phosphorus), whereas others can increase the amount of nutrients present in the soil (Gomaa *et al.*, 2005).

If cultures of beneficial microorganisms are to be effective after inoculation into soil, it is important that their initial populations be at a certain critical threshold level. This aid to ensure that the amount of bioactive substances they produced will be sufficient to achieve the desired positive effects on crop production and/or crop protection (Gomaa *et al.*, 2005). At present, there are no tests that can predict the probability of a particular soil-inoculated microorganism to achieve the desired result. The most reliable approach is to inoculate the beneficial microorganisms into soil as part of a mixed culture and at a sufficiently high inoculums density to maximise the probability of its adaptation to environmental and ecological conditions (Higa & Wididana, 1991; Parr *et al.*, 1994).

2.7.3 Manure-based amendments

Several organic materials have been reported as suitable soil amendments for increasing crop production (Makinde & Ayoola, 2010). Naturally occurring organic fertilisers include manure, slurry worm, worm castings, peat, seaweed, sewage and guano (Miles & Manson, 2005). The potential of cow dung, poultry droppings, refuse compost and farmyard manure as suitable soil amendments in the tropics has been reported (Makinde & Ayoola, 2010). Application of organic materials as fertilisers provides growth regulating substances and improves the physical, chemical and microbial properties of soil (van Averbeke & Yoganathan, 2003; Miles & Manson, 2005). Sole use of organic manures to sustain cropping has however been reported inadequate, as they are required in rather large quantities to meet crop nutrient requirements because of their relatively low nutrient content (Miles & Manson, 2005).

Introduction of inorganic fertilisers has largely replaced traditional practices such as recycling of organic materials and application of organic manures certainly due to their relatively low nutrient concentrations coupled with labour-intensiveness in handling (Miles & Manson, 2005). This has raised concerns about the potential long-term adverse impacts on soil productivity and environmental quality particularly in agricultural ecosystems where balanced application of N, P and K fertilisers is not practiced over a long period (Hati *et al.*, 2007).

In South Africa, manures remain an important source of plant nutrients as well as for their undisputed advantages as biological agents for improving soil health and productivity, water holding capacity and addition of organic carbon (van Averbeke & Yoganathan, 2003; Mohamed *et al.*, 2007). A survey conducted earlier by the Council for Scientific and Industrial Research (CSIR) in 1986 estimated that approximately 350 000 and 75 000 tonnes of chicken and cattle manure, respectively were generated in various forms and most of which was used as fertiliser at the time (FSSA, 2003).

Animal manure and compost have been used solely as the source of nutrients for crop and vegetable production since the earliest civilizations for improving soil properties. Poultry manure is rich organic manure since solid and liquid are excreted together resulting in no urine loss. In fresh poultry excreta, uric acid is the most abundant nitrogen compound (40-70% of total N) while urea and ammonium are present in small

amounts (Krogdahl & Dahlsgard, 1981). Farm yard manure (FYM) supply N, P and S in available forms to the plants through biological decomposition (Malathesh, 2005). Many factors affect the concentration of nutrients in manures since some manure contain more nutrients than others. For example, poultry manure generally is fairly higher in nutrients than cattle manure (Table 2.6). As a result the composition of manure depends very much on the quality of the feed that animals eat. Feeds richer in protein tend to harbour more N in the manure and the same is true for P and K (Miles & Manson, 2005).

Table 2.6: Typical N, P and K concentrations in cattle and poultry manures in South Africa (Adapted from Miles & Manson, 2005)

Type of manure	N (%)	P (%)	K (%)
Cattle	1.0	0.5	1.0
Poultry	3.6	1.2	1.3

In South Africa, most commercial farmers have the means to use inorganic fertilisers on their soils. However, in the rural areas inorganic fertilisers are not easy to come by for subsistence farmers who have to travel to town to find a supplier (van Averbek & Yoganathan, 2003; Hati *et al.*, 2007). Inorganic fertilisers are bulky and heavy and attainment of these from town to your village or farm is awkward and requires transportation (Miles & Manson, 2005). Accordingly, Hati *et al.* (2007) hinted prior to the introduction of inorganic fertilisers, farmers globally including South Africa, made use of manure to restore the fertility of their lands. Many farmers solely turned to inorganic fertilisers among other reasons that they are more concentrated than manure and easier to handle with mechanised planting equipment, insufficient quantity of manure available on large farms and the strenuous efforts of transportation (Hati *et al.*, 2007).

The concentration of nutrients in animal manure depends on a number of factors, but the most important one is soil content of the manure (Hati *et al.*, 2007). The more soil manure contains, the lower its nutrient concentration and the more one have to apply to supply the same amount of nutrients. In the central areas of the eastern Cape, kraal manure was found to contain between 20 and 80% soil by mass, causing the formula to

range between 3:1:4 (7) where the soil content was low and 3:1:2 (2) where more soil was present (Miles & Manson, 2005).

Animal manure is considered an agricultural commodity that can be utilised as a fertiliser source for crop and pasture production (Payne & Lawrence, 2009). It is recognised as an excellent source of the plant nutrients N, P and K, and subsequently returns these nutrients and other nutrients such as Ca, Mg and S to the soil through mineralisation, building soil fertility and quality (Payne & Lawrence, 2009). It comprises of quite high K content and relatively low N and P concentrations. Generally, liquid manures will contain a lower nutrient content than solid manures due to the dilution effect (Miles & Manson, 2005). The N in manure is in organic and inorganic forms and the organic form slowly mineralises providing plant-available N, while inorganic forms consist primarily of $\text{NH}_4\text{-N}$ and are immediately available to the plant (Payne & Lawrence, 2009). However, inorganic forms are also susceptible to loss through volatilisation during storage and field application as well as leaching, thus prompt incorporation of manure into the soil can reduce these N losses. The P and K in manure are mostly present in the inorganic form and are therefore readily available for plant uptake (van Averbek & Yoganathan, 2003).

Much of the N and P in manures are combined with organic substances and only becomes available to plants when these substances decompose (Miles & Manson, 2005). In chicken manure, about 90% of the total N and P are available for plant uptake in the year of application. Miles and Manson (2005) implied that in cattle manure, only about 20% of the total N and 40% of the total P becomes available in the year of application and the availability of N and P increases with increasing quality of the manure (Table 2.7). When using cattle manure at a reasonable application rate of 20 t ha^{-1} it would supply a reasonable amount of P and a lot of K, but topdressing of fertiliser N may be necessary for good yields. However, chicken litter would usually be applied at a rate of about 5 t ha^{-1} and this would supply a large amount of N and a substantial amount of P, but if the soil is low in K, more K should be applied as fertiliser (Miles & Manson, 2005).

Table 2.7: Amount of nutrients available for plant uptake in the year of manure application (calculated on the basis of manures with NPK concentrations similar to those listed in Table 2.6) (Adapted from Miles & Manson, 2005)

Type of manure	Rate (t ha ⁻¹)	Nutrients supplied (kg ha ⁻¹)		
		N	P	K
Cattle	5	10	10	50
	20	40	40	200
Poultry	5	162	54	65
	20	648	216	260

Accordingly, Payne and Lawrence (2009) argued that since manure is not a balanced fertiliser, some plant nutrient needs may be met while other nutrients may be under and/or over supplied. Any nutrient that is under-supplied by a manure application could incur a subsequent fertiliser application cost which would, in effect, lower the net value of the manure. Thus, any nutrient that is over-supplied by a manure application would not have immediate value because it was not needed by the crop (Payne & Lawrence, 2009).

Manure is well known for its value as a slow-release source of nutrients (Sullivan *et al.*, 1998). It serves as a valuable addition to a crop production system by modifying and improving soil physical properties and serving as a source of plant nutrients. Upon addition to the soil, it is initially mineralised at a faster rate until the labile components are exhausted followed by a slow mineralisation process and formation of more stable organic forms (Belay *et al.*, 2002). Ewulo (2005) indicated that poultry dung and cattle manure increased soil pH, organic C, total N, P, K, Ca, Mg, Na and CEC in clay and sandy clay loam soils, while exchangeable acidity reduced irrespective of soil type. Increases in soil C, N and P levels as a result of residual manure was reported (Sharpley & Smith, 1995). Mäder *et al.* (2002) indicated that soil pH was slightly higher in field received organic fertilisers compared to field received inorganic fertilisers. Changes in K, Ca and Mg upon application of poultry manure had been previously reported (Pool *et al.*, 2000). Boateng *et al.* (2006) showed slight pH increases from 4.3 to 4.5 and 4.6 which was attributed to the low ammonium content and the buffer

capacity of the manure. The significance of manure in improving the biological quality of soil was reported in numerous reports (McGill *et al.*, 1986; Sharpley & Smith, 1995).

Although the ability of crops to utilise essential nutrients from organic sources differs considerably, but the amount of inorganic N mobilised after decomposition of organic manure depends on several soil and environmental factors (Yamagata & Otani, 1996). Boateng *et al.* (2006) indicated that maize biomass yield was highest on plots amended with poultry manure with more biomass obtained at higher application rates. In a related study, Olaniyan *et al.* (2003) showed that maize produced 11.0%, 14.9% and 48.6% more dry matter with enriched organic fertiliser applied at 120 kg N ha⁻¹ rate than when applied at rates of 0, 40 and 80 kg N ha⁻¹.

2.7.4 Humic acids-based amendments

The term “humus” dates back to the time of the Romans, when it was frequently used to designate the soil as a whole. However, humus comprised of complex natural organic compounds that are formed in soils mainly from plant residues by a process of "humification" (Sulkowski *et al.*, 2006). They are complex aggregates of brown to dark coloured amorphous substances, which have originated during the decomposition of plant and animal residues by microorganisms under aerobic and anaerobic conditions, in soils, composts, peat bogs, and water basins (Mackowiak *et al.*, 2001). Thus not surprising there is a contradiction among producers and agricultural scientists today that crop residue and organic matter are the same as humus. Organic matter is crop residue that is in various stages of decomposition, while humus is decomposed organic matter (Chen & Aviad, 1990).

Previous studies with fractioning on humus distinguished between fulvic acid (soluble in acid and alkali) and humic acid (insoluble in acid but soluble in alkali). However, at present the two acids are regarded as a continuous series of compounds and therefore humic acid serves as the commercial term regardless the ratio of one to the other (du Preez, 2003; Mayhew, 2004).

There is a recognised and increasing use of humic acids for their beneficial impact on the growth and cultivation of crops and particularly in organically deficient soils (Mayhew, 2004). Humic acid is not a fertiliser as it does not directly provide nutrients to plants, but is a complement to inorganic or organic fertiliser. Consistent use of humic

acid will reduce the need for fertilisation due to the soil's and plant's ability to make better use of the applied nutrients. To some extent, fertilisation can be eliminated entirely if sufficient organic material is present and the soil can become self-sustaining through microbial processes and humus production (Charest *et al.*, 2004).

There are many forms of humic acids available on the market today (Mayhew, 2004). Most of the humic acids on the market are passive humic acids. They are mined from mineral deposits of lignite, a low grade coal deposit, found in many areas throughout the world. Passive humic acids comprise a small percentage of humic acid, most of which is not in a form that the plant can use. However, there are active forms of humic acid that might establish humus in the soil immediately, and in a form that is readily available for the plants use (Mayhew, 2004).

Humus absorbs the highly active non-nutrient hydrogen sources present in the soil and makes them immediately available as a food source for assimilation and usage by the plant (Charest *et al.*, 2004). The humus colloid will absorb and hold three times more organic compounds, nutrient cations and water in the soil that are in a readily usable form for the plant to utilise and this guarantee enhance crop growth and production (Filip & Bielek, 2002). Humus colloids also protect the microbial and plant systems against excessive sodium, magnesium, potassium and also other positive charged elements as the humus colloid carries a negative charged ion (Lobartini *et al.*, 1997). Furthermore, humus acts as a buffer and enhances carbon, nitrogen, phosphorous and sulfur in their nutritional service system to soils and become nutrients for soil microorganisms and plants (Charest *et al.*, 2004; Campitelli *et al.*, 2008).

When applied to clay soils, humic acid can help break up compacted soils, allowing for enhanced water penetration and better root zone growth and development (Filip & Bielek, 2002). Yet in sandy soils, humic acid supplements essential organic material necessary for water retention thus improving root growth and enhance the ability of sandy soils to retain essential plant nutrients against leaching (Tucker, 1999). Humus forms the largest fraction of organic matter and remains thus the major portion after added plant and animal residues have decomposed (Charest *et al.*, 2004). This decomposed fraction comprise of non-humic and humic substances with the latter substances regarded as the most active. Humus, especially through its humic

substances influences many properties of soils disproportioned to the quantities present (du Preez, 2003).

Humic acid stimulates microbial activity by providing the indigenous microbes with a carbon source for food that encourage their growth and activity (Charest *et al.*, 2004). Soil microbes are responsible for solubilizing vital nutrients such as P that can then be adsorbed by the humic acid and in turn made available to the plant. Microbes are responsible for the continued development of humus in the soil as it continues to break down not fully decomposed organic matter (Charest *et al.*, 2004). When humic acids are applied to a selected media, it increases the growth of a wide range of taxonomic and functional groups of soil bacteria (Vallini *et al.*, 1993 reviewed in van Tonder *et al.*, 2008). A report from a study conducted by Filip and Bielek (2002) showed there was an increase in the number of bacteria and also superior yields of microbial biomass in cultures that had humic acids added to the full strength nutrient broth. Humus as a concentrate of carbon and energy compounds aid bacteria to survive extreme environmental conditions (Charest *et al.*, 2004) and also enable them to carry out antibiotic effects in the soil and their interrelations with plant roots.

Humic acid is especially beneficial in improving the availability of nutrients to the soil for plant uptake (Ayuso *et al.*, 1996). For instance, if phosphorus is fixed by aluminum in acid soil, humic acid enhances the release of P into the soil solution for absorption by plant roots. Application of humic substances to soils with low contents of clay and organic matter resulted in significant plant growth (Lulakis & Petsas, 1995). It is claimed that humic substances play a favorable role in regulating the plant root metabolism by inducing or repressing the mechanism of protein synthesis, enzyme activation or inhibition resulting in morpho-functional changes in plant root tissues (Cacco *et al.*, 2000; Nardi *et al.*, 2002). Humic acid was used also as growth regulators to improve plant growth and enhance stress tolerance (Delfine *et al.*, 2005).

Humic substances influence the availability, uptake and transportation of nutrients. When nutrients are absorbed by an active metabolic process, humic substances could inhibit absorption since they tend to complex the ions, but if the same ions are absorbed by means of a passive mechanism like diffusion through plant tissues, humic substances do not intervene entirely in the absorption (Ayuso *et al.*, 1996). Cooper *et*

al. (1998) stated that whether nutrient uptake increased, decreased or remained constant in response to humic substances depends to a large extent on plant species and the humic materials evaluated. The stimulatory effect of humic substances have been directly correlated with enhance uptake of macronutrients such as N, P, K and S (Cacco *et al.*, 2000; Delfine *et al.*, 2005). An enhanced uptake of micronutrients such as Fe, Zn, Cu and Mn was also observed (Adani *et al.*, 1998). Certainly, humic acids increased P availability and uptake by inhibiting calcium phosphate precipitation rates, forming phosphor-humates that are competing for adsorption sites or it decreases the number of adsorption sites by promoting dissolution of metal solid phases through chelation (Delfine *et al.*, 2005).

2.8 Conclusions

Maize is the cardinal grain crop and staple food for majority of South Africa human and animal populace and also the leading contributor towards the gross value of field crops contributed largely by commercial producers. Maize producers are often placed at economical risks due to the fluctuation in the local maize prices, but this could be reduced by ensuring optimum maize productivity. Maize is estimated to be the largest single consumer of fertiliser constituting nearly 40% of the total fertiliser market. Maize fertilisation is necessary to replace nutrients removed in harvested crop products, although the extent to which nutrients are removed from soil depends on the yield realised. Balanced fertilisation programme in maize production through appropriate fertilisation practices are therefore paramount for sustainable maize production so as to alleviate problems of nutrient deficiency and toxicity. The use of fertiliser at planting to provide maize seedlings with the primary nutrients is a common practice in South Africa. Locally, most commercial farmers plant maize with compound fertiliser to reduce N losses from leaching, but when straight fertiliser are used, this is often reduced by split applications.

Sole use of organic manures as an old tradition to sustain cropping has however been reported inadequate as they are required in rather larger amounts to meet crop nutrient requirement due to their relatively low nutrient content. The world's skyrocketing animal and human populace has made it challenging to produce adequate food through this mode of crop fertilisation. The problem of poor soil fertility called for the introduction of conventional inorganic NPK fertiliser on agricultural land at about 1890. Thereafter,

fertiliser addition to crops on agricultural land has always been through inorganic fertilisation and has increased over the years. However, inorganic fertiliser prices were often outside the budget of millions of smallholder farmers coupled with their high nitrate volatility and occasional leaching to groundwater. Smallholder farmers continued to produce crops without adequate nutrient replenishment which had rendered some land marginal for crop production. Marginal lands were withdrawn due to huge quantities of nutrients required and this has caused a decline in fertiliser consumption in South Africa by 45% between the years 1982 to 2000.

Certainly that conventional NPK fertiliser is produced from non-renewable natural sources and that South Africa's less developed agricultural sector either cannot afford conventional NPK fertiliser or apply at sub-optimal rates when obtained necessitated an alternative approach. Many South Africa's agricultural companies commenced the production of industrially manufactured biological amendments designated IMBAs as either completely replacements or growth boosters to conventional inorganic NPK fertiliser. A large number of IMBAs were registered and the registration commits the producer to the specified composition of the fertiliser, but often lack detailed information on their effectiveness. The integrated use of conventional inorganic NPK fertiliser with IMBAs warranted therefore a proper evaluation of the different IMBAs. Most of the IMBAs in South African market are essentially beneficial microorganism, manure and humic acids-based products and can be used in any of the three combinations. Most of these IMBAs are exclusively for either soil or foliage applications while a few are suitable for both types of applications.

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CHAPTER 3

MATERIALS AND METHODS

Glasshouse and field studies were carried out using nine industrially manufactured biological amendments (IMBAs) to assess their effectiveness as nutrient sources for maize production. During the glasshouse study, topsoil from one of the field trial sites was used. The geographical positions, climatic characteristics and soil properties of the field trial sites are first presented followed by information on the selected IMBAs. The methodology for the glasshouse and field studies is also discussed.

3.1 Field trial sites

3.1.1 Geographical positions

Field trials were carried-out for three consecutive production seasons (2006/07-2008/09) under rainfed conditions at four localities with different soil and climatic characteristics (Figure 3.1). The localities are the ARC-Small Grain Institute's Research Station at Bethlehem, Grain South Africa's commercial field plot at Bothaville, a commercial farmer's field at Ottosdal and the ARC-Grain Crops Institute's Research Station at Potchefstroom. The latitudes, longitudes and altitudes of the localities are as given in Table 3.1.

Table 3.1: Geographical information on the field trial sites

Geographical information	Bethlehem	Bothaville	Ottosdal	Potchefstroom
Latitude	28°23'	26°62'	26°08'	27°09'
Longitude	-28°23'	-27°38'	-26°81'	-27°7'
Altitude (m)	1850	1317	1587	1355

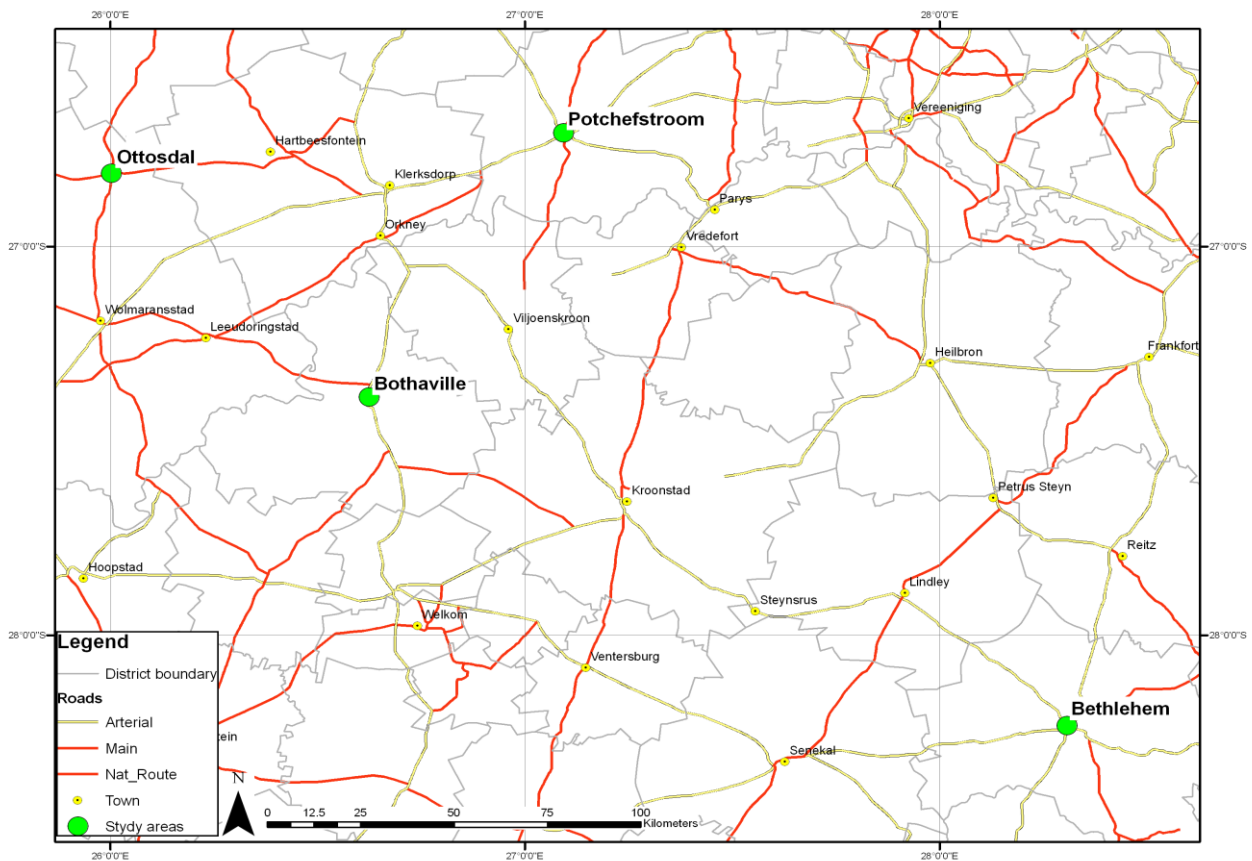


Figure 3.1: Positions of field trial sites at Bethlehem, Bothaville, Ottosdal and Potchefstroom (Source: ARC-ISCW, 2009).

3.1.2 Climatic characteristics

The long-term mean annual rainfall varies from 502 mm at Bothaville to 718 mm at Bethlehem (Table 3.2). However, annual rainfall at the four localities was in many instances very variable. For example during the study period, annual rainfall from July to June ranged from 321 to 1132 mm at Bethlehem, 490 to 580 mm at Bothaville, 333 to 486 mm at Ottosdal and 547 to 643 mm at Potchefstroom. The pre-season (July to October) and in-season (November to June) rainfall totals also varied greatly from one season to another.

The long-term daily minimum temperature ranges from 8°C at Bethlehem to 11°C at Potchefstroom (Table 3.2). The Bethlehem site has the lowest long-term daily mean maximum temperature of 24°C. The long-term mean daily maximum temperature at the other three localities was around 27°C. During the study period, the daily mean minimum and maximum temperatures were almost similar to the long-term averages.

Thus, the mean daily evaporation recorded during the trial period at the four localities corresponds well with the long-term daily averages. The prevailing climatic condition during the three year study period at each trial locality was generally representative of their long-term climate averages, except for rainfall.

Table 3.2: Selected climatic data for the three production seasons and on the long-term at the four localities (ARC-ISCW, 2009)

Localities	Month	Rain			Tn			Tx			A-pan		
		2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09
Bethlehem	Jul	0.0	0.0	0.6	-0.6	-2.9	-2.1	18.7	17.3	17.0	2.9	2.7	2.8
	Aug	58.3	0.0	0.0	1.4	-0.7	1.1	17.0	20.4	21.0	3.0	3.6	3.7
	Sep	4.0	37.8	0.0	4.4	6.8	2.5	22.6	26.1	23.5	4.5	4.1	4.9
	Oct	32.8	158.7	14.6	10.1	9.5	8.7	24.8	20.5	27.1	4.4	3.2	5.8
	Nov	25.7	96.7	149.9	11.3	10.6	12.2	24.8	23.8	26.0	5.2	4.6	4.5
	Dec	42.5	86.3	70.4	13.0	12.2	14.0	26.9	24.6	27.8	5.4	5.1	5.3
	Jan	25.2	90.1	83.1	13.0	13.4	14.6	28.3	25.5	27.0	5.9	4.8	4.5
	Feb	25.1	72.1	532.2	12.7	13.5	14.1	29.3	26.3	24.5	6.2	5.2	6.6
	Mar	33.9	78.6	157.7	10.6	11.1	11.8	27.2	23.3	24.7	4.9	4.3	13.1
	Apr	44.5	7.8	14.5	7.8	4.9	6.5	23.7	21.4	22.8	3.7	3.8	5.6
	May	1.5	41.3	32.0	0.1	3.6	3.1	20.8	19.7	18.8	3.3	2.9	3.3
	Jun	27.6	24.5	77.0	-1.3	-0.3	1.2	16.5	17.2	15.3	2.3	2.6	2.9
	In-season	226.0	497.4	1116.6	8.4	8.6	9.7	24.7	22.7	23.4	4.6	4.1	5.7
	Pre-season	95.1	196.5	15.2	5.9	5.3	4.6	22.1	20.9	23.8	3.9	3.3	4.8
Long-term	718	718	718	8.4	8.4	8.4	24.0	24.0	24.0	4.4	4.4	4.4	
Bothaville	Jul	0.3	20.8	0.0	1.0	-2.2	-1.3	22.1	18.8	20.2	3.7	3.5	3.6
	Aug	40.4	2.7	0.0	2.1	0.6	1.5	20.4	22.6	24.2	3.7	4.7	4.8
	Sep	1.3	65.2	0.0	4.6	8.4	3.1	26.3	29.0	26.9	5.8	6.0	6.5
	Oct	47.2	103.2	42.6	9.7	11.3	11.2	29.5	24.9	30.8	6.1	4.7	6.7
	Nov	102.2	121.3	136.4	2.2	12.4	13.7	31.6	28.1	30.2	5.4	6.2	5.3
	Dec	176.1	74.4	42.9	15.7	14.0	15.5	30.4	28.2	31.6	6.3	6.3	6.2
	Jan	34.8	59.0	208.8	14.8	14.6	15.7	31.7	29.1	31.1	7.1	5.5	4.6
	Feb	25.4	36.2	45.7	13.2	14.1	15.7	32.5	30.8	27.9	7.2	5.9	4.1
	Mar	37.3	28.1	39.4	11.8	13.8	11.9	29.8	30.0	27.8	5.9	4.8	4.1
	Apr	22.5	0.0	10.4	8.9	3.9	7.4	25.7	26.7	26.9	4.3	3.4	3.7
	May	2.3	39.6	18.5	1.4	5.5	4.6	22.7	22.8	22.6	4.0	3.5	2.7
	Jun	0.0	10.5	35.3	0.0	1.0	4.4	18.4	19.6	18.8	3.0	3.1	2.1
	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
Long-term	502	502	502	9.9	9.9	9.9	27.4	27.4	27.4	5.4	5.4	5.4	

Table 3.2: Continue

Localities	Month	Rain			Tn			Tx			A-pan		
		2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09
Ottosdal	Jul	0.0	0.0	4.3	0.0	0.0	4.3	0.0	0.0	4.3	0.0	0.0	4.3
	Aug	30.7	0.3	0.3	4.6	2.3	1.0	18.8	22.1	23.2	3.9	4.8	4.6
	Sep	0.0	1.1	0.0	7.8	4.2	7.4	24.2	29.9	25.9	5.9	5.8	6.0
	Oct	34.8	30.5	39.0	11.5	11.6	12.2	29.1	33.4	29.7	6.0	3.0	6.4
	Nov	19.8	29.7	89.7	12.4	13.8	13.7	29.8	24.2	30.5	6.2	0.7	5.0
	Dec	95.8	74.0	36.8	15.4	16.0	14.8	31.1	27.8	31.2	6.4	5.6	5.6
	Jan	14.9	48.1	175.6	15.3	17.3	14.8	32.5	29.7	29.1	6.8	4.7	3.6
	Feb	27.6	63.6	40.6	13.4	16.1	15.9	32.6	29.9	26.8	7.2	5.4	0.1
	Mar	57.8	160.1	30.5	11.8	11.2	12.3	29.9	25.3	27.6	6.0	3.8	1.8
	Apr	30.1	6.8	17.5	9.1	8.2	5.0	25.5	23.2	25.7	4.1	4.5	2.1
	May	0.0	39.4	14.7	1.2	5.2	5.2	22.6	23.4	22.0	4.2	3.3	1.8
	Jun	21.1	6.8	36.8	0.3	4.6	0.9	18.2	19.9	18.4	3.1	3.1	1.6
	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
Long-term	593	593	593	10.3	10.3	10.3	27.1	27.1	27.1	5.5	5.5	5.5	
Potchefstroom	Jul	0.5	0.0	0.0	2.9	1.5	0.0	21.8	19.5	19.9	3.7	3.4	3.4
	Aug	21.9	0.5	0.8	4.0	4.4	3.1	20.4	22.7	24.2	3.9	4.3	4.6
	Sep	9.4	71.6	0.0	6.8	6.7	10.9	25.8	29.1	27.1	5.6	5.3	5.7
	Oct	67.5	102.7	49.9	12.8	13.5	12.2	28.7	25.2	30.3	5.8	4.8	6.3
	Nov	79.5	82.6	89.4	14.2	15.5	13.6	28.4	27.8	29.1	6.0	6.1	4.8
	Dec	206.2	57.1	73.9	16.5	17.4	15.2	29.7	26.2	31.2	6.2	5.0	5.6
	Jan	45.1	34.2	109.5	16.0	17.7	16.4	30.8	27.5	29.7	7.1	4.9	5.0
	Feb	73.4	108.7	20.8	15.2	16.2	15.8	31.2	29.3	27.4	7.0	5.6	1.4
	Mar	50.3	138.9	73.9	13.4	13.5	13.4	29.5	25.2	26.8	5.7	4.2	3.7
	Apr	64.5	14.6	41.9	10.6	10.0	7.7	25.5	24.7	26.1	4.4	4.6	3.6
	May	0.0	29.0	58.2	2.6	6.6	6.9	22.8	22.5	21.9	4.0	3.4	1.1
	Jun	25.1	11.2	29.0	1.2	4.7	2.2	19.4	19.9	19.2	3.1	3.1	2.1
	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
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).

3.1.3 Soil properties

A soil profile pit was dug at each trial site for detailed characterisation, description and classification of the soil on the fields. Samples were taken from each diagnostic horizon in each profile (Figure 3.2) for detailed physico-chemical and mineralogical analyses. A concise description of the soils is given also in Table 3.3. The soils were identified as Avalon, Hutton and Westleigh forms according to the South African Taxonomic Soil Classification System (Soil Classification Working Group, 1991).

Table 3.3: Concise description of the soils at the field trial sites

Soil characteristics	Bethlehem	Bothaville	Ottosdal	Potchefstroom
Land type	Ca6	Ca6	Bd10	Bc25
Topography	Gentle: Convex linear	Flat: Linear concave	Flat: Linear concave	Flat: Linear linear
Soil form	Avalon	Avalon	Hutton	Westleigh
Soil family	Mafikeng	Mafikeng	Lillieburn	Mareetsane
Horizon transition	Clear	Clear	Gradual	Clear
Soil depth (m)	1.6	1.8	2.0	1.8
Effective rooting depth (cm)	70	80	120	60
Mechanical root resistance	Slight	Slight	None	Moderate

The soil samples of the diagnostic horizons were analysed by the ARC-Institute for Soil, Climate and Water, Pretoria. Standard analyses procedures (The Non-affiliated Soil Analyses Work Committee, 1990) were used to determine particle size distribution (Hydrometer), pH (H₂O), mineral N (0.1 N K₂SO₄), extractable P (Bray 1), exchangeable Ca, Mg and K (1 N NH₄OAc) and organic C (Walkley-Black). Mineralogical composition of each soil sample was determined using random powder and X-ray diffraction analyses as described by Hughes and Bohor (1970). The analytical data of the diagnostic horizons is displayed in Table 3.4.

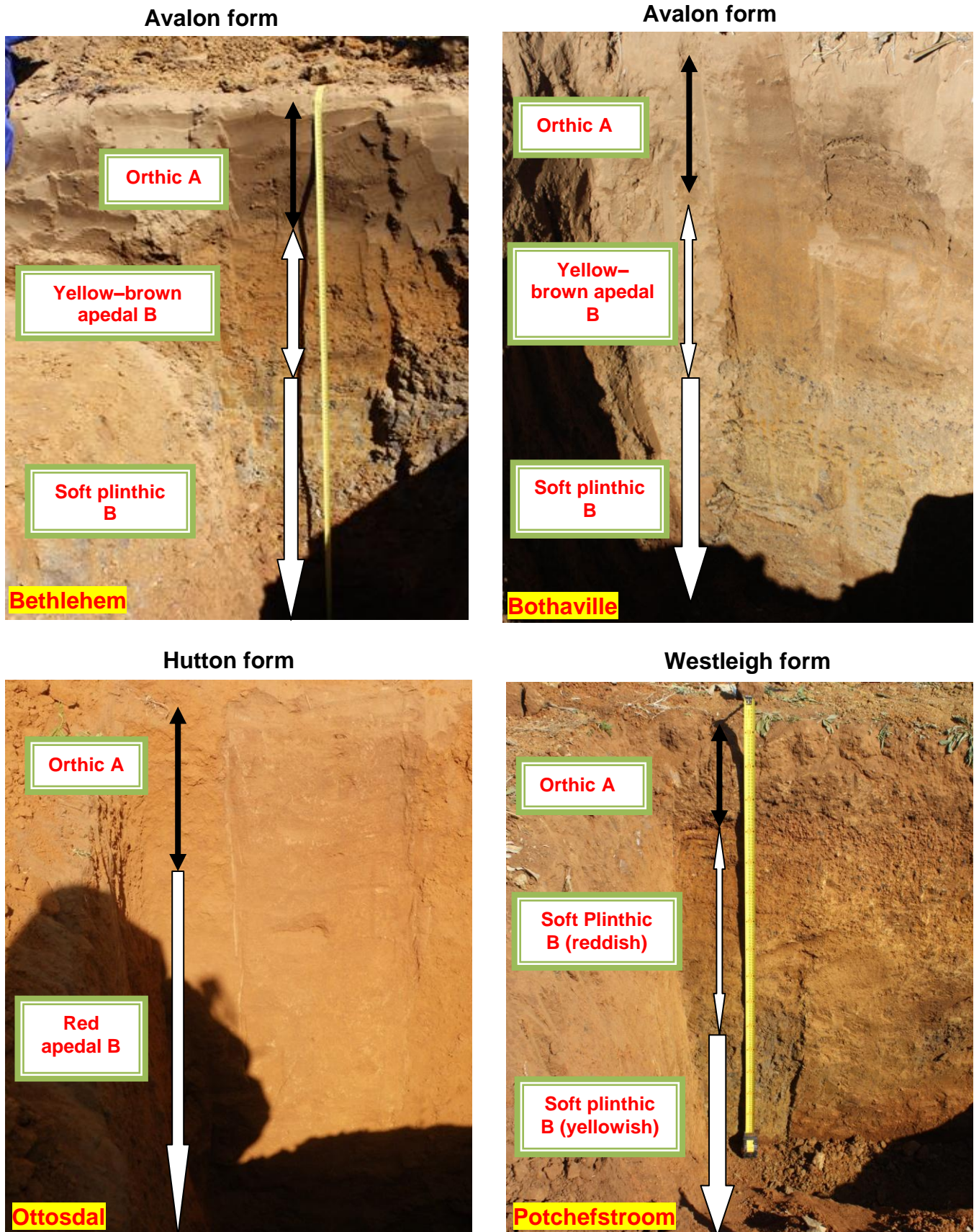


Figure 3.2: Profiles of the soil forms at the field trial sites showing their diagnostic horizons.

Table 3. 4: Some analytical data of the diagnostic horizons identified in soil profiles at the field trial sites

Locality	Diagnostic horizon	Depth (cm)	Mineralogical composition (%)	pH (H ₂ O)	Textural class	Bulk density (g cm ⁻³)	Mineral N P K Ca Mg Na Organic C						
							mg kg ⁻¹						(%)
Bethlehem	Orthic A	0-30	Qz (99); Fs (1)	6.6	Sandy clay loam	1.45	14	4.9	71	582	135	13	0.34
	Yellow-brown apedal B (B1)	30-60	Qz(79); Fs(3); Kt(1); Mi(17)	6.4	Sandy loam	1.53	14	2.5	75	1419	429	6	0.35
	Soft plinthic B (B2)	>60	Qz(85); Fs(13); Kt(1); St(1)	7.6	Sandy loam	1.49	19	1.1	139	2790	1592	102	0.05
Bothaville	Orthic A	0-40	Qz(97); Fs(1); Go(1); Dt(1)	6.0	Sandy clay loam	1.44	12	7.5	90	495	154	5	0.21
	Yellow-brown apedal B (B1)	40-80	Qz(93); Fs(2); Go(3); Kt(2)	5.1	Sandy clay loam	1.45	11	7.1	93	1510	503	6	0.35
	Soft plinthic B (B2)	>80	Qz(94); Fs(1); Go(1); Kt(1); St(3)	7.5	Sandy clay loam	1.44	23	4.3	100	3988	2500	54	0.22
Ottosdal	Orthic A	0-40	Qz(93); Fs(2); Go(1); Mi(4)	5.4	sandy clay loam	1.42	12	8.8	119	496	139	4	0.33
	Red apedal B	>40	Qz(97); Fs(1); Go(1); Kt(1)	6.5	sandy clay loam	1.43	18	6.6	59	874	261	30	0.17
Potchefstroom	Orthic A	0-30	Qz(90); Fs(4); Go(3); Kt(1); Mi(2)	7.0	Sandy clay	1.34	9	11.8	176	1979	842	21	0.76
	Soft plinthic B (B2)	30-70	Qz (84); Fs(2); Go(2); Kt(3); Mi(9)	6.9	Clay	1.27	11	10.3	113	2306	777	26	0.73

Qz = Quartz; Fs = Feldspar; Go = Goethite; Kt = Kaolinite; Mi = Mica; Dt = Dolomite; St = Smectite;

The orthic A horizons across localities comprised essentially of quartz and feldspar, particularly at Bethlehem (Table 3.4). Other minerals found in varying proportion in these surface horizons are goethite, dolomite, mica and smectite. Similar mineralogical compositions were recorded in the diagnostic B horizon of all localities, except Potchefstroom where there was a considerable reduction of quartz in favour of mica and kaolinite. Nonetheless, the soils have similar textural classes except for the higher clay content in the B horizon at Potchefstroom. This locality has also the highest organic C content.

Furthermore, the pH of diagnostic horizons ranged from slightly acidic to slightly alkaline, except it was acidic in few cases (Table 3.4). The mineral N content of the A horizons were fairly high and comparable. However, a substantial increase in mineral N at the B horizon was recorded particularly at Bethlehem, Bothaville and Ottosdal suggesting occasional N leaching. Compared to the suggested threshold of 20 mg kg⁻¹ (van Biljon *et al.*, 2008), the levels of extractable P in the A horizons across the localities were considerable lower. In the same horizon, exchangeable K levels at Bethlehem and Bothaville were lower than the 125 mg kg⁻¹ threshold (van Biljon *et al.*, 2008). However, the extractable K levels were higher than this threshold at Ottosdal and Potchefstroom. The Ca and Mg levels were however remarkably high at all localities.

3.2 Industrially manufactured biological amendments

Only nine of the 17 listed and discussed IMBAs in Chapter 2 were selected for assessment in this study as contained in Table 3.5. The selection of the nine IMBAs was based primarily on their composition so as to ensure that they are representative of the wide range of products available in the market. For example, Biozone and Gliogrow are grouped as beneficial microorganism-based IMBAs; Gromor, Promis and Growmax are manure-based IMBAs while Crop care, K-humate, Lanbac and Montys are humic acids-based IMBAs. Other factors considered were *inter alia* their availability to and affordability by farmers. The concise recommendations of either the manufacturers or suppliers regarding the usage of the IMBAs are given in Table 3.5.

Table 3.5: IMBAs selected for evaluation at four localities

IMBAs	Application method	Recommendations
Biozone	Soil application	Optimum fertiliser rate (OFR) + 10 L ha ⁻¹ at planting
Gliogrow	Seed dressing + foliar application	OFR + 0.2 L ha ⁻¹ of Maxiflo + 0.2 L ha ⁻¹ of Trykocide at planting. Seed dressing of 0.1 L ha ⁻¹ Teprosyn Zn/P per 25 kg seeds; 0.4 L ha ⁻¹ of Maxiflo + 0.4 L ha ⁻¹ of Trykocide at four weeks after emergence
Gromor	Soil application	2000 kg ha ⁻¹ at planting; Complete replacement of NPK
Promis	Soil application	1000 kg ha ⁻¹ at planting; Complete replacement of NPK
Growmax	Soil application	Equal to the OFR at the sites; Applied to meet the requirement of P and contains 3 kg P ha ⁻¹
Crop care	Soil + foliar application	400 kg ha ⁻¹ Growmax and 70% OFR + 5 L ha ⁻¹ Agri-balance at planting; 2.5 L ha ⁻¹ Agri-boost and 2.5 L Agri-Zinc at 4 weeks after planting; 2 L ha ⁻¹ Agri-fulbor at tasseling
K-humate	Soil application	OFR + 20 kg K-humate ha ⁻¹ a week prior to planting
Lanbac	Soil application	OFR + 10 L ha ⁻¹ MS Humate + 2 kg ha ⁻¹ Microboost + 2 L ha ⁻¹ Microbial inoculants at planting
Montys	Soil application	50% of the OFR + 3 L ha ⁻¹ at planting

Prior to application, the IMBAs were subjected to detailed chemical analyses at the ARC-Institute for Industrial Crops in Rustenburg for the purpose of ascertaining the nutrient composition and comparison with the conventional inorganic fertilisers. The results of the analyses are given in Table 3.6. The organic C content varied from 0.43% with Gliogrow to more than 60% with K-humate. Similarly, the IMBAs have a wide pH (H₂O) range namely, between 3.1 with Biozone to 9.6 with K-humate. In comparison with fertiliser compounds, the various IMBAs have very low N, P and K contents. Thus it is not surprising that manufacturers or suppliers claimed that the sole application of Crop care and Montys could constitute up to a 30 and 50% level of replacement for complete fertiliser, respectively while the application of Gromor and Promis application could completely (100%) replace optimum NPK fertilisation (Table 3.5).

Table 3.6: Chemical composition of the selected IMBAs

IMBAs	pH	N	P	K	Ca	Mg	Na	Organic C (%)
	(H ₂ O)							
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
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
Growmax	6.8	3.00	3.00	3.00	1.38	0.88	1.75	28.3
Crop care	8.1	0.96	1.17	4.13	0.63	0.38	7.00	2.66
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
Montys	9.5	0.45	1.17	0.13	1.75	0.50	5.00	3.33

3.3 Glasshouse study

3.3.1 Experimental procedure and treatments evaluated

A glasshouse pot trial was conducted during 2008-summer growing season at the ARC-Grain Crops Institute, Potchefstroom to assess the effects of IMBAs on the seedlings establishment and phenological growth of maize. Treatments consisted of the nine IMBAs applied at 50, 75 and 100% of the recommended rates given by either manufacturers or suppliers (Table 3.6). The optimum recommended inorganic NPK rate and unamended control treatments were included as standard check. Thus a total of 11 treatments were evaluated in 4-kg soil filled plastic pots with each treatment replicated four times. Inorganic N and P fertilisers were applied at the blanket rates of 80 kg N ha⁻¹ and 43.5 kg P ha⁻¹ using limestone ammonium nitrate and superphosphate respectively. Soil laboratory analyses results gave 192 mg K kg⁻¹, which indicated a sufficiency level and was thus excluded in the fertilisation programme. .

Air-dried sieved (<2 mm) surface soil (0-20 cm depth) used for the study was a Westleigh form collected from Potchefstroom trial site. Except for the foliar applied materials, each treatment including inorganic fertiliser was thoroughly mixed with soil and transferred into pots (20 cm high x 17 cm in diameter). All pots containing treatments were carefully arranged in the glasshouse in a completely randomised design. Two uniformly sized

maize seeds (Cv. PAN 6479) were sown in each pot at a depth of 5 cm. The temperature of the glasshouse was maintained at between 18 and 27°C throughout the six week study period using an electrical fan and wet wall cooling system. Prior to seed sowing, each pot was watered to approximately 80% field capacity using deionised water, and allowed to equilibrate for 24 hr. Thereafter, plants were supplied with 400 ml of deionised water at three days interval while weed control was achieved manually when necessary.

3.3.2 Trial monitoring and data capturing

Percent plant emergence was measured at three weeks after seed sowing (WAS), while phenological growth traits such as plant height and the number of leaves per plant were measured at three and six WAS. Additional phenological parameters such as leaf area were measured at six WAS prior to plant harvesting and biomass yield was determined upon termination of the trial. Plant height was measured using a steel tape from above the soil surface until the longest extended mature leaf (Alexander *et al.*, 2004) whereas leaf numbers per plant were manually counted. Leaf area (LA) was determined by measuring the length and breadth of a fully expanded intact leaf and multiplying the product by a factor of 0.75 (Saxena & Singh, 1965). Biomass yield was determined by cutting and weighing the whole plant above soil surface in each pot using a sharp knife. The samples were oven-dried at 65°C until a constant weight for each treatment was attained and dried weight recorded.

3.4 Field study

3.4.1 Experimental procedure and treatments evaluated

Field trials were conducted for three consecutive production seasons (2006/07-2008/09) at Bethlehem, Bothaville, Ottosdal and Potchefstroom to evaluate the effects of IMBAs on the phenological growth and performance of maize. The geographical positions (Section 3.1.1), climatic characteristics (Section 3.1.2) and soil properties (Section 3.1.3) of the trial sites were discussed earlier. Treatments comprised of the same nine selected IMBAs used in the glasshouse study applied at the recommendation rates by either manufacturers or suppliers (Table 3.5). Optimum recommended inorganic NPK fertiliser rate for each site (Table 3.7) and unamended control treatments were included as standard check. The optimum NPK application rates were based on analyses of topsoil prior to commencement of trials. Limestone

ammonium nitrate, superphosphate and potassium chloride were used as N, P and K sources, respectively. All treatments were replicated four times and arranged as a randomised complete block design. Each treatment was applied on a 10 m x 6 m plot with the trial occupying a total of 2640 m² at each site. All the soil-applied IMBAs were broadcast uniformly as recommended over the relevant plots and lightly worked into the soil with a hand hoe while the foliar applied IMBAs were sprayed to the relevant plots using a CP15 knapsack sprayer. The P and K (if appropriate) fertiliser were applied at planting with 30% of the N fertiliser. The remaining 70% of the N fertiliser was band placed when the plants were knee high.

Table 3.7: Optimum NPK fertilisation rates applied at four field trial sites

Fertiliser rate (kg ha ⁻¹)	Field trial sites			
	Bethlehem	Bothaville	Ottosdal	Potchefstroom
N	40	100	70	80
P	69.5	73.7	73.7	43.5
K	55	55	0	0

3.4.2 Crop husbandry

The preceding crops were wheat at Bethlehem, sunflower at Bothaville and cowpea respectively at Ottosdal and Potchefstroom ecotopes. Seedbed across trial sites was prepared by mouldboard ploughing, disking and harrowing. Primary tillage commenced two months prior to planting with the secondary tillage carried out just before planting. All trials were manually planted in November (Table 3.8) using hand planters (Figure 3.3) designed to sow seeds at an intra-row spacing of 0.3 m. The row width was throughout 1.5 m, implicated an aimed plant population of 22 222 plants ha⁻¹ as recommended by Mucheru *et al.* (2007). Two uniform seeds of the maize cultivar PAN 6479 were planted per hole to cater for a low seedling survival rate. The stands that had no plants at two to three weeks after planting were replanted. Maize plants were subsequently thinned to one per stand from four weeks. After each harvesting time (Table 3.8), maize stubble was ploughed in with a rotavator and the trial sites left bare until the next planting.

Table 3.8: Planting and harvesting dates of field trials at the four localities

Seasons	Bethlehem		Bothaville		Ottosdal		Potchefstroom	
	Planting	Harvest	Planting	Harvest	Planting	Harvest	Planting	Harvest
2006/07	08 Nov	14 Jun	24 Nov	03 Jul	29 Nov	04 Jun	16 Nov	29 Jun
2007/08	08 Nov	10 Jul	21 Nov	02 Jul	12 Nov	30 Jun	20 Nov	13 Jul
2008/09	24 Nov	26 Jun	20 Nov	07 Jul	12 Nov	29 Jun	16 Nov	05 Jul



Figure 3.3: Hand planters used to plant maize at the four field trial sites.

Just after planting, experimental plots were sprayed with 2 L Dual (S-metolachlor) ha⁻¹ to destroy volunteer and upcoming weeds. During the planting season, trials were kept weed free through mechanical weeding when necessary. At eight weeks after planting, all trials were treated with a Combat pesticide applied at 4 kg ha⁻¹ for the control of maize stalk borer which prevailed at these trial sites. The incidence of stalk borer attack was most prevalent at Bethlehem where severe damage was noticed in some plots during the first planting season. However, during the preceding planting seasons, greater attention was paid to this site so as to effectively manage the problem. Furthermore, the trial at Bethlehem was invaded by porcupines at the milk dough stage throughout the study period but exerted no significant economic damage to the trial.

3.4.3 Data collection

3.4.3.1 Soil chemical and microbial biomass properties

3.4.3.1.1 Chemical properties

Prior to trial establishment, 10 soil cores were randomly collected from the 0-20 cm soil depths using a soil auger with 2.5 cm diameter. Sub-samples were bulked and mixed thoroughly to obtain a composite sample for each trial site. The soil analyses results are as shown in Table 3.9. Post-harvest soil sampling was conducted also at the same soil depth from all plots at every trial site. In 2006/07, using the above-mentioned soil auger, three soil cores were randomly taken from within the rows and also from between rows (ARC-MIG, 2006). The samples within rows and from between the rows were bulked separately to form composites. However, in the two subsequent seasons, soil samples were collected in a similar manner from within the rows only.

Table 3.9: Some analytical data of the surface 0-20 cm soil at the four localities prior to field trial establishment in 2006/07 growing season

Soil properties	Bethlehem	Bothaville	Ottosdal	Potchefstroom
Sand } (%)	74.6	91.1	80.9	48.7
Silt }	11.4	0.9	7.1	17.3
Clay }	14	8	12	34
Textural class	Sandy loam	Sand	Loamy sand	Sandy clay loam
% Organic C	0.43	0.20	0.38	0.82
% Total N	0.029	0.009	0.028	0.057
pH (H ₂ O)	5.47	7.02	5.83	6.61
P } (mg kg ⁻¹)	19	22	16	56
K }	112	74	135	192
Ca }	298	348	317	840
Mg }	77	97	102	360
Na }	11	15	13	32
CEC cmol (+) kg ⁻¹	12.7	6.18	22.5	14.7
R (ohms)	2300	3630	1520	860

Each composite sample was air dried, sieved and stored for analyses at the ARC-Institute for Industrial Crops in Rustenburg. Standard analyses procedures (The Non-affiliated Soil Analyses Work Committee, 1990) were used to determine particle size distribution (Hydrometer), pH (H₂O), organic C (Walkley-Black), mineral N (0.1 N K₂SO₄), extractable P (Bray 1) and exchangeable Ca, Mg, K and Na (1 N NH₄OAc).

3.4.3.1.2 **Microbial biomass indicators**

Microbial biomass carbon (C_{mic}) and phosphorus (P_{mic}) were determined as indicators of microbial activity in the soil. Soil sampling for microbial determination was carried out first at four weeks after planting and subsequently at flowering and at crop harvest. At all four trial sites an area of 4 m² within each plot was sampled. A core sampler with 10 mm diameter was used to sample three soil cores at randomly selected positions in the designated area. The three soil core samples from each plot were pooled and thoroughly mixed to obtain a composite. All composites were sieved through a 2 mm stainless steel sieve and later stored at 4°C for C_{mic} and P_{mic} determinations.

Microbial biomass-C was determined following the chloroform fumigation extraction procedure described by Vance *et al.* (1987). This involved the extraction of dissolved organic C (Walkley, 1947) from fumigated and non-fumigated soil samples with 0.5 M K₂SO₄. The dissolved organic C in the extractions was quantified with Fe (NH₄)₂SO₄ titration after oxidation with a hot mixture of 0.0667 M K₂Cr₂O₇ and H₂SO₄ (Nelson & Sommers, 1996). In the estimation of C_{mic} the difference of dissolved organic C measured in a non-fumigated and fumigated sample was multiplied with a factor of 2.64 as suggested by Vance *et al.* (1987).

The chloroform fumigation extraction procedure of Vance *et al.* (1987) was used also for P_{mic} determination. This involved extraction of P from fumigated and non-fumigated soil samples using Bray-1 P solution (Olsen & Sommers, 1982). The extracted P was quantified colorimetrically as described by Murphy and Riley (1962). In the estimation of P_{mic}, a factor of 0.4 was used to correct for the incomplete release of P from microbial cells during fumigation (Brookes *et al.*, 1982).

The estimated values of C_{mic} were reported on an oven-dried basis based on the gravimetric water content of each field moist soil sample.

3.4.3.2 Phenological traits

Phenological growth parameters such as plant height, biomass yield and leaf area index were determined at the 9th leaf (V9) and the silking (R1) growth stages. At both growth stages, five randomly selected tagged plants from the two central rows in each plot (Figure 3.4) were used for plant height and leaf area measurements. A tape measure was used to measure plant height from ground level to the tip of longest extended mature leaf at the 9th leaf stage (Alexander *et al.*, 2004) and to the top of the tassel at silking stage (Ibeawuchi *et al.*, 2007). The length and breadth of a fully expanded intact leaf was measured at the V9 stage while at the R1 stage, the flag leaf was chosen for the leaf area measurement. The product of these two measurements was multiplied by a factor of 0.75 to estimate leaf area (LA) as described by Saxena and Singh (1965). Thereafter, leaf area index (LAI) was calculated by dividing the LA with the unit ground surface area (Breda, 2003).

Biomass production was determined through destructive sampling of all plants within a 1 m² area at the four rows in each plot as shown in Figure 3.4. At each sampling, plants were cut just above ground level with a sharp cutting edge slash. These plants were weighed on the field and later oven-dried at 65°C to a constant weight.

3.5.3.3 Grain yield and yield components

The maize of the two inner rows in each plot (21 m² as shown in Figure 3.4.) was harvested manually at physiological maturity growth stage as outlined by Beardsell (1977). During harvesting, the cobs were removed from the plants and the stover slashed, and field weighed. Thereafter sub-samples of the stover were oven-dried at 65°C to a constant weight for the determination of stover yield. The cobs were weighed and then shelled whereafter the grain was weighed also to estimate cob mass by difference. Grain mass was adjusted to a standard moisture content of 12.5%. The total above ground biomass was calculated as the sum of grain and stover yields. This biomass was needed to estimate harvest index (HI) as shown in Equation 3.1.

$$HI = \text{Grain yield} / \text{total biomass yield} \dots\dots\dots 3.1$$

The length of five randomly selected maize cobs from each plot was measured from the base to the tip of the cob.

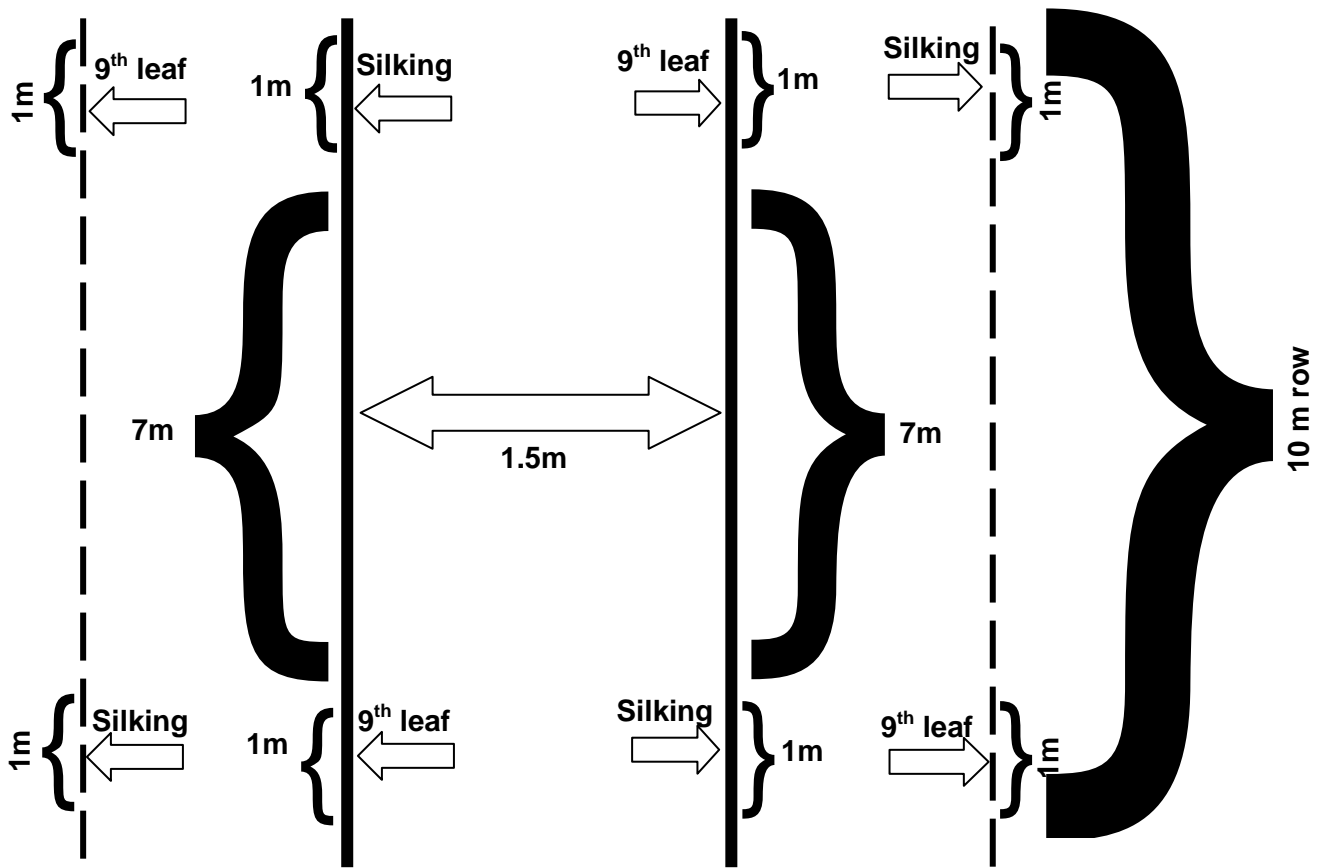


Figure 3.4: A schematic diagram showing the areas sampled for determination of biomass production at 9th leaf and silking growth stages, and of stover and grain yields at harvesting.

The agronomic efficiency (AE) of each IMBA and the NP fertiliser applied was calculated based on the amount of either N (Equation 3.2) or P (Equation 3.3) applied as suggested by Mulvaney *et al.* (2001).

$$AE_N = (GY_{+N} - GY_{-N}) / N \text{ applied} \dots \dots \dots 3.2$$

$$AE_P = (GY_{+P} - GY_{-P}) / P \text{ applied} \dots \dots \dots 3.3$$

where: GY is grain yield with (+) and without (-) either N or P application.

3.4.3.4 Nutrient contents in plant components

Sub samples of the biomass, grain and stover were washed with 0.3% (w/v) detergent solution, thoroughly rinsed with distilled water and oven-dried at 65°C to a constant weight, 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 Okalebo *et al.* (2001). Tissue N determination was accomplished with steam distillation and titration after the samples were digested with H₂SO₄ using a Micro-Kjeldahl procedure. For tissue P analyses, samples were digested in a mixture of HNO₃, H₂SO₄ and HClO₄, whereafter the P in solution was determined colorimetrically. These were done for the purpose of determining nutrient uptake in plant biomass (Equation 3.4), grain and stover (Equation 3.5) using the equations indicated beneath.

$$\text{Biomass N or P uptake} = \{(\text{N or P conc. (\%)/100})\} \times \text{biomass yield (kg ha}^{-1}\text{)} \dots\dots\dots 3.4$$

$$\text{Grain or stover uptake} = \{(\text{N or P conc. (\%)/100})\} \times \text{grain or stover yield (kg ha}^{-1}\text{)} \dots 3.5$$

3.5.3.5 Grain quality parameters

Three grain quality traits were determined, namely one thousand kernel mass, milling index and kernel size fraction. These determinations were done at the ARC-Grain Crops Institute, Potchefstroom following procedures of the Southern African Grain Laboratories (SAGL, 2005). A thousand whole kernels were counted with a seed counter after removal of the broken kernels and foreign material. Thereafter the mass of one thousand whole kernels was determined on an electronic balance. Milling index was determined on 500 g kernels that were subsequently immersed in distilled water and conditioned for 24 hours. Thereafter their milling performance was established in a ROFF 8085585 mill. The floatation tests for kernel hardness and horny/floury endosperm determinations were done as described by Oikeh *et al.* (1998). Kernel size fraction was established by sieving 100 g whole kernels for 10 minutes in a set of six grading sieves. The grading sieves had round holes ranging from 6.35 to 11 mm in diameter.

3.5 **Statistical analyses**

The chemical and microbial properties of soil, phenological growth traits, grain yield and yield components, nitrogen and phosphorus content, uptake and agronomic use efficiency and on physical grain quality traits data obtained from either the glasshouse or field studies were subjected to analyses of variance using GenStat Release 14. Differences in treatment means were separated using Tukey honestly significant difference post-hoc test (HSD) test at 5% probability level. Tables revealing the grand mean across the treatments and seasons, standard error of the mean (SEM), coefficient of variation (CV %) and the Tukey least significance difference (LSD_T) were used to indicate results obtain in the various experiments.

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CHAPTER 4

ASSESSMENT OF VARIABLE APPLICATION RATES OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS ON ESTABLISHMENT AND GROWTH CHARACTERISTICS OF MAIZE PLANTS UNDER GLASSHOUSE CONDITIONS

4.1 Introduction

The desire of every grain producer is to obtain high yields at reduced production costs so as to optimise net returns on investments. Crop establishment and plant vigour represent key factors that influence the success of grain crop production (Hammermeister *et al.*, 2008). Therefore, ensuring optimal crop establishment is not only a cost saving measure, but could also contribute to increased productivity and reduced seeding rates. Obtaining good plant emergence and establishment on maize fields is however dependent on the growth strength of the root coleoptiles and crust condition, particularly in soils with high clay content (Souty *et al.*, 1992). Seedling emergence could critically be impeded by soil compaction typically caused by the use of heavy farm machineries which often lead to increased soil strength and bulk density (Hartge, 1988), and subsequently impedes plant roots, especially at low moisture levels (Hartge, 1988; Lithourgidis *et al.*, 2005).

Regardless of the inherent soil conditions, the use of soil amendments either as pre- or post-seed sowing inputs could also impact on seedling emergence (Baloyi *et al.*, 2009). In many parts of the world, organic wastes that are often used as fertiliser materials exist in prodigious amount due to the increasing human and animal population. Such wastes include farm wastes, sewage sludge, poultry litter and industrial wastes (food, sugar, cotton and rice industry etc.). The steady accumulation of such wastes often constitutes potential sources of land, water and air pollution (Tahir *et al.*, 2006), with their use as nutrient sources greatly restricted, thereby leading to the subsequent introduction of chemical fertilisers (Tahir *et al.*, 2006). While few of the organic wastes are utilised to a limited extent for crop production, most are either burnt or remained unutilised, especially in developing countries (Shah & Anwar, 2003). These practices have not only posed serious threat to the environment, but had also resulted in the loss

of useful nutrients-pool, which otherwise could be made available to plants (Ikerra *et al.*, 1999; Kang & Shanon, 2001; Akinnifesi *et al.*, 2007).

The direct application of organic wastes on farmlands has many drawbacks since un-composted organic materials have wider carbon/nitrogen (C/N) ratio than the composted organic materials (Zia *et al.*, 2003). Consequently, they are often not suitable for soil health (Tahir *et al.*, 2006) due to the possible immobilisation of applied N, making it unavailable to plants (Ahmed *et al.*, 2006). On the other hand, organic wastes are being used either as composted or non-composted materials in large quantities in conventional practice for increased crop productivity (Neuens & Reheul, 2003; Wolkowski, 2003; Terrance *et al.*, 2004). Composting is one of the major recycling processes in which biodegradable organic materials are converted into formless humus-like substances that can be easily and more friendly handled, stored and applied to land without negative environmental impacts (Gallardo-Larva & Nogades, 1987; Tahir *et al.*, 2006). Dried cured composts are generally superior to un-composted materials having more concentrated nutrients, narrower C/N ratios and also being effectively free from pathogens, weed seeds and other potential contaminants that could cause pollution (Ahmed *et al.*, 2006).

The integrated use of inorganic and organic plant nutrient sources may not only recycle organic wastes that could potentially cause environmental pollution, but could also conserve a rich pool of nutrients resource and hence reduce the sole dependence on inorganic fertilisers (Ahmed *et al.*, 2006; Tahir *et al.*, 2006). The complementary use of conventional inorganic fertilisers with organic materials increases the potential of organic fertilisers, improves the efficiency of inorganic fertilisers (Heluf, 2002), and also reduces nutrients losses (Guar & Geeta, 1993; Makumba *et al.*, 2007). A study on N-enriched compost supplemented with 57 kg N ha⁻¹ using urea, gave comparable effectiveness to a full urea dose applied at 114 kg ha⁻¹ (Tahir *et al.*, 2006). Similarly, the application of inoculated organic fertiliser (bio-fertiliser) supplemented with 57 kg N ha⁻¹ significantly increased the growth and yield of tomato when compared to a full dose of N-fertiliser (Tahir *et al.*, 2006). Thus, the recent industrial conversion of composted organic materials into value-added single product as plant growth promoter through a novel approach of enrichment or blending of bio-fertilisers with inorganic fertilisers or

plant growth promoting rhizobacteria (Tahir *et al.*, 2006), constitute an alternative strategy for increased use of organic fertilisers.

The use of such biological growth promoter has been reported to considerably increase grain yield (Ndakidemi *et al.*, 2006; Kutu & Asiwe, 2010). In South Africa, various organic-based fertiliser materials are being manufactured in industries and promoted for use as growth enhancement substances. Recommendation on the use of these organic-enriched amendments herein refers to as industrially manufactured biological amendments (IMBAs), sometimes involve partial and/or total replacement of NPK. These products are rigorously promoted and marketed for farmers' use without sufficient agronomic information on their efficiency. This study was therefore carried out to evaluate the possible effects following the use of IMBAs which possess growth enhancement stimulus potential on the establishment and selected phenological traits of maize seedlings. It also compared the performance of the different rates of application of the IMBAs with the conventional inorganic fertilisers applied at optimum rate.

4.2 Experimental procedure

The description of the experiment and layout of the trial and also the monitoring of the trial and data collection is shown in detail in Chapter 3 under section 3.3. A glasshouse pot trial was also conducted in the 2008/09-summer cropping season over a six weeks period at Potchefstroom. A completely randomised experimental design was used and each treatment was replicated four times. Treatments consisted of the nine IMBAs assessed at 50, 75 and 100% of the recommended rates given by either the manufacturers or suppliers (Table 4.1). Recommended rates for conventional NPK fertiliser and control, which received no fertiliser or one of the products, were included as check. The N and P fertiliser were applied using limestone ammonium nitrate and superphosphate respectively, while the soil analyses results indicated a sufficiency level of K (192 mg K kg^{-1}).

Soil used for the study was a Westleigh form collected from surface 0-20 cm depth next to the Potchefstroom field trial site, air dried and sieved through a <2 mm stainless steel sieve. Except for the foliar applied materials, each treatment including conventional inorganic NPK fertiliser was thoroughly mixed with 4-kg soil and transferred into plastic pots. Two uniformly sized maize seeds (Cv. PAN 6479) were sown in each pot at a depth of 5 cm. The temperature of the glasshouse was maintained between 18 and 27°C

throughout the six-weeks using an electrical fan and wet wall cooling system. Measurements made were of percent plant emergence at 3 weeks after sowing (WAS). Plant height and number of leaves per plant were measured at 3 and 6 WAS, respectively. Additional phenological growth traits of leaf area and biomass yield were measured at six WAS prior to plant harvesting and termination of the trial. The data obtained was subjected to analyses of variance using GenStat Release 14 and differences in treatment means were separated using Tukey HSD test at 5% probability level.

Table 4.1: IMBAs selected for evaluation at the glasshouse pot trial

IMBAs	Application technique	Recommendations
Biozone	Soil application	Optimum fertiliser rate (OFR) + 10 L ha ⁻¹ at sowing
Gliogrow	Seed dressing + foliar application	OFR + 0.2 L ha ⁻¹ of Maxiflo + 0.2 L ha ⁻¹ of Trykocide at planting. Seed dressing of 0.1 L ha ⁻¹ Teprosyn Zn/P per 25 kg seeds; 0.4 L ha ⁻¹ of Maxiflo + 0.4 L ha ⁻¹ of Trykocide at four weeks after emergence
Gromor	Soil application	2000 kg ha ⁻¹ at sowing
Promis	Soil application	1000 kg ha ⁻¹ at sowing
Growmax	Soil application	Blended to meet the OFR; comprise of 3 kg N and P ha ⁻¹
Crop care	Soil + foliar application	400 kg ha ⁻¹ Growmax and 70% OFR + 5 L ha ⁻¹ Agri-balance at sowing; 2.5 L ha ⁻¹ Agri-boost and 2.5 L Agri-Zinc at 4 weeks after sowing
K-humate	Soil application	OFR + 20 kg·ha ⁻¹ a week prior to sowing
Lanbac	Soil application	OFR + 10 L ha ⁻¹ MS Humate + 2 kg ha ⁻¹ Microboost + 2 L ha ⁻¹ Microbial inoculants at sowing
Montys	Soil application	50% of the OFR + 3 L ha ⁻¹ at sowing
NPK	Soil application	80 kg N ha ⁻¹ and 43.5 kg P ha ⁻¹ ; no application of K
Control		No application of either NPK fertiliser or IMBAs

4.3 Results and discussion

There was significant treatment x rates interaction effects on plant height at 3 WAS and also on mean number of leaves per plant at 6 WAS (Table 4.2). The main effect of rate and treatment was significant for all parameters in both sampling intervals, except for

the percent plant emergence. The interaction effect of rate x treatment was significant for plant height at 3 WAS and for the number of leaves, leaf area and biomass yield at 6 WAS.

Table 4.2: Variance ratio of testing differences for seedling emergence and selected phenological growth characteristics of maize

Parameter tested	3 WAS			6 WAS			
	Percent emergence	Plant height	Number of leaves	Plant height	Number of leaves	Leaf area	Biomass yield
IMBA rates (R)	120.3ns	159.7***	6.19***	41.9***	17.0***	8.14***	29.8***
Treatments (T)	96.0ns	39.3***	1.40ns	21.7***	12.5***	3.10***	8.95***
R x T interaction	42.2ns	21.3**	1.10ns	32.6ns	4.19*	1.07***	20.5**

ns, not significant; *, **, *** significant at 5, 1 and 0.1% probability level, respectively

4.3.1 Seedling emergence

Table 4.3 indicates the effect of IMBAs x rates on maize seedling emergence. Application of the IMBAs at different graded rates differed not significantly from one another and also between them and either the NPK or control treatments. While some of the IMBA treatments exerted in many instances less percentage plant emergence compared to the two standard checks. The variable rates of Growmax and Biozone gave inconsequential effect. However, the 50% application rate of Crop Care gave equally more percent plant emergence as the two standard checks.

The application of 75% recommended rate in Montys, Gliogrow and K-humate treated pots also gave 100% plant emergence as obtained with the two standard treatments. Equally, 100% plant emergence was obtained in both 50 and 75% application rates in Gromor and Lanbac pots. The application of 50% recommended rate in Crop Care, Gromor and Lanbac therefore promoted excellent and comparable percent plant emergence as the standards, while the 75% rate guaranteed similar results in Montys, Gliogrow and K-humate. Generally, the use of the IMBAs at 100% rate had a depressive effect on plant emergence when compared to NPK fertiliser and unamended control treatments.

Table 4.3: Effect of the IMBA application rates on emergence and phenological growth characteristics of maize at different sampling periods

IMBAs	Application rate*!	% plant emergence	Plant height (cm)		Number of leaves		Leaf area (cm ²)	Biomass yield (g/pot)
			3	6	3	6		
Biozone	50	87.5	41.5ab	80.9ab	5ab	9ab	234.0abcdef	13.0abcd
	75	87.5	23.5abc	61.8abc	4ab	6abc	181.1bcdefgh	8.0bcdefgh
	100	87.5	37.4abc	67.2abc	5ab	8abc	243.0abcdef	8.2abcdefgh
Gliogrow	50	87.5	45.4ab	79.6ab	5ab	7abc	330.7a	15.7a
	75	100	35.0abc	82.5ab	5ab	9ab	237.5abcdef	11.2abcde
	100	62.5	14.0c	38.2bc	3b	4bc	188.2abcdefgh	3.5fgh
Gromor	50	100	44.1ab	60.8abc	5ab	7abc	143.4defgh	5.2efgh
	75	100	45.2ab	65.6abc	6a	7abc	132.6defgh	5.6defgh
	100	87.5	35.5abc	55.1abc	5ab	6abc	142.6defgh	5.1efgh
Promis	50	62.5	32.0abc	55.9abc	5ab	6abc	255.7abcde	8.9abcdefg
	75	75.0	27.8abc	43.3abc	5ab	6abc	95.7fgh	2.9gh
	100	75.0	15.1c	21.0c	4ab	5bc	46.4h	1.1h
Growmax	50	100	41.0ab	89.5a	5ab	9ab	257.6abcde	12.9abcd
	75	100	30.0abc	90.8a	5ab	9ab	258.0abcde	11.4abcde
	100	100	24.6abc	69.2abc	4ab	8abc	130.3defgh	6.1cdefgh
Crop care	50	100	49.9a	78.9ab	6a	10a	292.6abc	14.1ab
	75	87.5	34.7abc	82.7ab	5ab	9ab	233.8abcdef	10.5abcdefg
	100	87.5	28.8abc	52.0abc	5ab	6abc	149.2cdefgh	6.1cdefgh
K-humate	50	75.0	35.1abc	68.5abc	5ab	7abc	192.7abcdefgh	10.4abcdefg
	75	100	35.1abc	72.0ab	5ab	8abc	237.9abcdef	10.9abcdef
	100	75.0	19.6bc	57.1abc	4ab	6abc	157.5bcdefgh	4.5efgh
Lanbac	50	100	35.0abc	90.0a	5ab	9ab	302.1ab	13.5abc
	75	100	43.0ab	87.4a	5ab	10a	263.5abcd	11.0abcde
	100	87.5	28.5abc	71.2abc	5ab	8abc	195.9abcdefg	7.8bcdefgh
Montys	50	62.5	41.7ab	37.9abc	4ab	5bc	129.6defgh	3.2gh
	75	100	43.4ab	40.7abc	4ab	7abc	80.0gh	6.6bcdefgh
	100	87.5	42.7ab	47.5abc	5ab	6abc	112.6efgh	3.1gh
NPK Control	Optimum	100	39.8ab	54.6abc	5ab	6abc	104.7efgh	4.0efgh
	0	100	29.8ab	52.7abc	4ab	7abc	95.3fgh	3.3gh
Mean		88.8	34.5	64.0	5	7	193.5	7.7
SEM		20.8	4.19	9.51	1.82	0.90	38.4	1.50
CV (%)		24.7	28.8	26.9	19.0	20.4	28.1	34.1
LSD _{T(0.05)}		58.8	26.5	48.2	2.43	4.11	147.4	7.57

Means with the same letters within a column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences; SEM = standard error of the mean; CV (%) = percentage coefficient of variation; LSD_T = Turkey least significant difference; *!, percentage of the optimum recommended rate

4.3.2 Plant height and number of leaves per plant

The effect of IMBAs and application rates on plant height recorded at 3 and 6 WAS and number of leaves per plant at 6 WAS are as shown in Table 4.3. There was a significant treatment x rate interaction effect on plant height at 3 WAS, while significant differences were observed only for the main effects (rate and IMBAs) at 6 WAS. Plants from pots in which Crop Care and Gliogrow were applied at 50% of the recommended

rate were approximately 25 and 14%, respectively taller compared to the NPK pots at 3 WAS. However, plant height measured at 6 WAS in pots with 75% recommended application rates from Crop Care and Gliogrow was 50% taller than the NPK standard. Similarly, plant height from Growmax and Lanbac amended pots were comparable but generally taller than in Gromor, Montys and Promis as well as the NPK check.

There was significant treatment x rates interaction effects on mean number of leaves per plant at 6 WAS. Significantly higher mean number of leaves per plant was recorded at 6 WAS in virtually all the MBAs at 50 and 75% recommended rates than the NPK treatment, except for Gliogrow, Montys and Promis. Generally, the application of 100% of the recommended rate for all the IMBAs though resulted in significantly decreased mean number of leaves per plant but had values comparable to those in the NPK pots.

4.3.3 Leaf area and plant biomass production

The effect of IMBAs and application rates on leaf area and plant biomass yield at 6 WAS is given in Table 4.3. There was significant interaction between IMBAs and application rates on maize leaf area and biomass production recorded at 6 WAS. Plants from pots treated with Crop Care, Gliogrow, Lanbac and Promis at 50% recommended rate gave significantly higher leaf area than either the higher application rates or the NPK standard. There was a generally higher leaf area and hence canopy cover observed with the 50 and 75% application rates in virtually all the IMBAs, except for Promis, which indicates evidence of good photosynthates assimilation and resulted in higher vegetative growth (Ibeawuchi *et al.*, 2008).

Plants in pots that received Gliogrow and Crop care application at 50% rate had considerable higher biomass yield. Considerably superior biomass yields from these treatments at 50% application rate could be attributed to better plant growth coupled with greater canopy architecture during the growing period. Generally, biomass yield accumulated from plants treated at 50% recommended rate was significantly higher by approximately 24 and 112% relatively to values manifested at 75 and 100% rates.

4.4 Correlation matrix (Pearson)

The effect of percent plant emergence on plant height and the number of leaves per plant recorded at 3 WAS were modest, but was significantly greater at 6 WAS (Table

4.4). Nonetheless, the influence was impartially on the biomass yield recorded at 6 WAS, whilst the percent plant emergence of seedlings did not exert a significant influence of the leaf area measured.

Table 4.4: Some correlation matrix of percent seedling emergence at 3 WAS with the selected phenological traits at 3 and 6 WAS in the glasshouse

Parameter tested	3 WAS		6 WAS			
	Plant height	Number of leaves	Plant height	Number of leaves	Leaf area	Biomass yield
Percent emergence	0.51***	0.55***	0.70***	0.73***	0.18***	0.46***

*** significant at 0.1% probability level, respectively

4.5 Summary and conclusions

The study on emergence and phenological growth of maize was conducted with three graded rates of IMBAs, resulting in three response cases per IMBA treatment. The performance of each IMBA for these three cases was compared with the relevant NPK treatment to obtain the frequency of significant increases as presented in Table 4.5.

Application of virtually all the IMBAs resulted in no significant increase on percentage plant emergence at 3 WAS, and plant height and the number of leaves at both sampling periods compared to the NPK check. Similarly, none of the IMBAs resulted in significant increases for all parameters determined when applied at 100% recommended rate, while only Lanbac at 75% of the recommended rate recorded significantly greater leaf area than those in the NPK standard. However, treatments with Gliogrow, Crop care and Lanbac at 50% of the recommended rate exerted significantly greater leaf area than the recommended NPK check. The same is true with Biozone, Gliogrow, Growmax, Crop care and Lanbac on biomass yield when applied at 50% of the recommended rate. Application of Gromor, Promis and Montys resulted in any of the three rates in no significant influence for all parameters determined compared to the NPK standard.

Table 4.5: Frequency of occurrence of significant increases on plant emergence and selected phenological growth of maize following application of the graded rates of IMBAs in a glasshouse

50% of the recommended rate							
	% plant emergence	Plant height		Number of leaves		Leaf area	Dry biomass yield
		3	6	3	6		
Biozone	0	0	0	0	0	0	1
Gliogrow	0	0	0	0	0	1	1
Gromor	0	0	0	0	0	0	0
Promis	0	0	0	0	0	0	0
Growmax	0	0	0	0	0	0	1
Crop care	0	0	0	0	0	1	1
K-humate	0	0	0	0	0	0	0
Lanbac	0	0	0	0	0	1	1
Montys	0	0	0	0	0	0	0

75% of the recommended rate							
	% plant emergence	Plant height		Number of leaves		Leaf area	Dry biomass yield
		3	6	3	6		
Biozone	0	0	0	0	0	0	0
Gliogrow	0	0	0	0	0	0	0
Gromor	0	0	0	0	0	0	0
Promis	0	0	0	0	0	0	0
Growmax	0	0	0	0	0	0	0
Crop care	0	0	0	0	0	0	0
K-humate	0	0	0	0	0	0	0
Lanbac	0	0	0	0	0	1	0
Montys	0	0	0	0	0	0	0

100% recommended rate							
	% plant emergence	Plant height		Number of leaves		Leaf area	Dry biomass yield
		3	6	3	6		
Biozone	0	0	0	0	0	0	0
Gliogrow	0	0	0	0	0	0	0
Gromor	0	0	0	0	0	0	0
Promis	0	0	0	0	0	0	0
Growmax	0	0	0	0	0	0	0
Crop care	0	0	0	0	0	0	0
K-humate	0	0	0	0	0	0	0
Lanbac	0	0	0	0	0	0	0
Montys	0	0	0	0	0	0	0

The percentage seedlings establishment following application of Promis at 100% recommended rate was consistently less than any of the other IMBA treatments. This could be ascribed to the production of excessive organic acids during the decomposition of the organic constituents of the IMBAs (Shiga, 1997). The taller plants measured following application of Gliogrow at 50% rate than the NPK check pots may be related to beneficial effects associated with the use of these products, which may have resulted in higher N release and uptake (Chen, 2006). The inconsistent effects of the IMBAs may be attributed to the variable N release characteristics of the different products which might be dependent on the quality of the materials used for the production of the IMBA treatments. Even under uniform soil and environmental conditions, manures from the same animal species can display a wide range of N mineralisation rates (Pettygrove *et al.*, 2009). Generally, plants in pots treated with Gliogrow and Promis applied at 100% recommended rate had stunted growth with plants in Gliogrow pots either showing spindled leaves and/or did not emerged entirely and some died with visual necrotic effects on their growing tips.

High quality organic materials decompose very fast thus releasing N for possible immediate plant use (Mafongoya *et al.*, 1998) and thus promote faster plant growth. Low quality organic materials on the other hand possess slow decomposition and N release characteristics that could possibly result in poor synchrony of mineralised N with plant uptake (Mafongoya *et al.*, 1998) and ultimately lead to the reduced plant growth and negative effects associated with some of the IMBAs treated pots. Similar findings were reported by Materechera and Morutse (2009) following application of chicken manure in maize trial. However, plants from Gliogrow and Promis treatments applied at 100% recommended rate had stunted growth. These observations differed from similar study reported by Ahmed *et al.* (2006) possibly because of differences in the quality of the organic material constituents utilised for this study.

The slow development of maize canopies may limit light interception and potential productivity (Westgate *et al.*, 1997). Plants from pots that received Gliogrow and Crop Care application, respectively at 50% recommended rate gave considerably higher biomass yield than any other treatment. This could possibly be attributed to better plant growth, greater canopy architecture and leaf area expansion that possibly influenced

favourable biomass accumulation and partitioning to the leaves during the early stage of plant development (Tollenaar & Wu, 1999).

Biomass accumulation from Gliogrow (15.7g/pot) and Crop care (14.1 g/pot) treated pots represented approximately 293 and 253% higher biomass yield, respectively than the value obtained from NPK treated pots. The significantly higher biomass yields of Gliogrow and Crop Care treated plants than all other treatments may be attributed to the presence of zinc (Zn) which constituted vital micro-nutrient in these IMBAs. Proper zinc nutrition increases biomass production (Khan *et al.*, 2004). Favourable phosphorus (P)/Zn ratio and possibly the synergistic effect under low soil phosphorus condition typical of the soil used in this study could have promoted balanced nutrition which ultimately favoured root development, better nutrient uptake and vigorous plant growth (Gutierrez-Boem & Thomas 1999; Zhu *et al.*, 2001; Rajaie *et al.*, 2009).

Root/shoot ratio can influence rate of dry matter accumulation during early development, because leaf area expansion is directly related to amount of dry matter partitioned to the leaves (Tollenaar & Wu, 1999). Similarly, plant biomass accumulated from plants in pots treated with Gromor, Promis, Montys, NPK and unamended control was significantly reduced. These results are in disagreement with findings that inorganic N fertiliser significantly increased maize biomass yield up to the highest application rate comparable to plants in pots with organic materials (Makumba *et al.*, 2007). Consequently, application of 2.5 and 5-g maize stover residues reduced average biomass yield of maize by approximately 9 and 17% at 42 days after sowing (DAS) and 7 and 16% at 49 DAS.

The different application rates of IMBAs had profound positive effect on plant establishment and phenological growth characteristics of maize than the conventional NPK fertilised and unfertilised pots. Plant emergences were significantly reduced in pots treated with Gliogrow and Promis at 100% recommended rate. Application of virtually all the IMBAs beyond 75% of the recommended rate exerted a deleterious effect on plant emergence and selected growth indices. While the 50 and 75% rates appeared sufficient for most of the IMBAs, though the most appropriate rate is however dependent on the IMBAs type utilised. Pots from treatment with Biozone, Gliogrow, Growmax, Crop care, K-humate and Lanbac at 50 and 75% of the recommended rate

exerted significant higher biomass yield comparing to application of Gromor and Montys at all graded rates including the 100% recommended rate of any IMBA treatment, except for Biozone. These results validate the significance of thoroughly agronomic assessment and proper documentation of these materials and other biological soil/foliar amendments prior to recommendation for use by farmers. The percent seedling emergence has a significant positive correlation with some of the phenological traits tested while no effect was observed with the leaf area.

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CHAPTER 5

RESPONSE OF SOIL CHEMICAL AND MICROBIAL BIOMASS PROPERTIES TO APPLICATION OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS UNDER DIFFERENT ECOTOPES

5.1 Introduction

Soil is a cardinal part of the biosphere that is vital for continued existence of life on earth. Despite of the role that soil and its communities played in protecting our natural ecosystems, the imperative functions they perform are still poorly understood (Boniao *et al.*, 2006). In general, African soils show nutrient deficiency problems after only a short period of cultivation due to their nature and the prevailing environmental conditions (Ayoola, 2006). Likewise, most South African soils have very low fertility status (Laker, 1976) that often coincide with restricted factors such as low infiltration rate, compaction, acidity, and low organic carbon stocks (Mnkeni & Mkile, 2006).

At present, crop production is practiced on biologically inactive and physically deteriorated soils that results in crops responding less to the use of chemical inputs (Primavesi, 1990). Soil fertility is the capacity of soil to support plant growth on a sustained basis under given climatic conditions and soil properties. However, good soil fertility could be maximised by ensuring that essential nutrients are present in the soil in significant quantities through application of sufficient amounts at optimal pH and high CEC to hold nutrients in place (Lalfakzuala *et al.*, 2008). Inorganic fertilisers do not only promote plant growth and microbes, but also have detrimental effects on the soil and its life, especially when concentrated and water soluble products are applied (Senwo & Tabatabai, 1998). Soil acidification may be very harmful to microbes (Kinraide, 2003). In agricultural soils, microorganisms exert a profound influence on plant nutrient availability and organic matter (OM) transformation (Li *et al.*, 2008; Onwonga *et al.*, 2010).

Microbial biomass and activity are directly correlated with OM that is positively influenced by organic materials such as post-harvest crop residues and manure (Belay *et al.*, 2002). Microbial biomass responds quickly to change in soil conditions, particularly a decrease or increase in plant or animal residues (El-Ghamry *et al.*, 2001).

Applications of organic amendments in the soil do not only increase total organic C (TOC) content but also has a series of effects on the microbial proliferation and activity (Tejada *et al.*, 2006; Hu & Cao, 2007). However, organic amendments alone increase soil microbial biomass carbon, and either had no effect or an increase with inorganic NPK fertilisers (Goshal & Singh, 1995). The use of inorganic NPK fertilisers alone increases the rate of OM mineralisation leading to a decrease in easily decomposable OM, which is correlated to a decrease in microbial biomass (Černý *et al.*, 2003). This also often associated with soil acidity and nutrient imbalance (Hojati & Nourbakhsh, 2006; Gilani & Bahmanyar, 2008). Due to occasional leaching of nutrients from soil after application of inorganic NPK fertiliser, even at recommended rates the desired long-term nutrient levels may not be achieved (Buresh *et al.*, 1997). Bunch (2002) affirmed that practically the entire N, much of K and even small amounts of P applied as inorganic fertiliser today will not be there twenty years later even if plants not utilising them.

The needs to reduce costs of fertilising crops are important grounds for advocating increased use of organic amendments. Benefits arising from the use of organic materials have not been fully exploited partly due to huge quantities required in order to satisfy the nutritional needs of crops (Hossain & 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 & Mwangi, 1996). In order to maintain high levels of agricultural productivity, it is critical that the relationship between nutrients in the soil and crop productivity is properly understood, especially if such productivity is to be achieved cost-effectively (Bunch, 2002). Locally, numerous organic-based fertilisers are being manufactured and marketed for farmers' use often without substantial agronomic information of their effectiveness and in relation to soil health. Recommendations regarding their utilisation sometimes involve partial and/or total replacement of conventional NPK fertiliser. This study was therefore conducted to assess the effects of the use of the industrially manufactured biological amendments (IMBAs) on soil chemical and microbial biomass properties under different ecotopes.

5.2 Experimental procedure

The detail description on methods and materials used for this study were duly given in Chapter 3. However, a concise description is herein provided. The study evaluated

nine IMBAs at rates recommended either by the product manufacturers or suppliers. Optimum rates of conventional inorganic NPK fertiliser at each site and unamended control treatments were included as check. All treatments were replicated four times and fitted in a randomised complete block design. Soil samples for chemical analysis were collected once prior to trial establishment and in each season (2006/07-2008/09) at harvest from 0-20 cm soil depth using a soil auger. The constituents determined of these samples included pH, organic C, mineral N and extractable P. Soil samples were also taken from 0-10 cm depth from an area of 4 m² within each plot using a core sampler, first at four weeks after planting, and subsequently at flowering and crop harvest for the determination of microbial biomass-C (C_{mic}) and -P (P_{mic}). Data obtained were subjected to analyses of variance using GenStat Release 14th edition.

5.3 Results and discussion

5.3.1 Chemical properties

5.3.1.1 pH

The effect of IMBA treatments on post-harvest pH across the seasons at four sites is given in Table 5.1.

5.3.1.1.1 Bethlehem

The pH values ranged from 5.82 with Lanbac to 6.02 with Gromor in 2006/07, 4.91 with Crop care to 5.14 with Gliogrow in 2007/08, and 5.17 with Biozone to 6.29 with Gromor in 2008/09. Significant differences in pH between few of the IMBA treatments were observed in 2007/08 and 2008/09, but not in 2006/07. This could be ascribed to the differences in rainfall amount which was only 226 mm in 2006/07 compared to 497 and 1116 mm in 2007/08 and 2008/09 respectively. With reference to the NPK treatment, significantly higher pH values manifested with some of the IMBA treatments, viz. in 2006/07 with Gromor, Promis and Growmax, in 2007/08 with Gliogrow, and in 2008/09 with Gliogrow and Gromor. The lower pH in the NPK treated plots could be attributed to the acidifying effect of inorganic fertiliser. It is important to notice that during decomposition the various IMBA treatments release organic acids that could possibly lower pH also. However, in many instances, post-harvest pH following application of the IMBA treatments increased compared to the values in the unfertilised plots, but differed significantly only in 2007/08 and 2008/09.

Table 5.1: Effect of IMBAs on pH at harvest during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	5.94abc	4.91c	5.17d	5.34	5.94a	6.22bc	6.44bc	6.20
Gliogrow	5.91abc	5.14a	5.99ab	5.68	5.87ab	6.72a	6.77ab	6.45
Gromor	6.02a	5.05ab	6.29a	5.79	5.90ab	6.67ab	6.65bc	6.41
Promis	6.00ab	4.94bc	5.35bcd	5.43	5.81abc	6.34bc	6.56bc	6.24
Growmax	6.02a	4.94bc	5.71bc	5.56	5.66bcd	6.45b	6.63bc	6.24
Crop care	5.85abc	4.91c	5.30bcd	5.35	5.69bcd	6.07cd	6.87a	6.21
K-humate	5.94abc	5.03b	5.25cd	5.40	5.91ab	6.27bc	6.64abc	6.27
Lanbac	5.82bc	5.02b	5.26cd	5.37	5.80abc	6.13bcd	6.71ab	6.21
Montys	5.90abc	5.03b	5.44bcd	5.45	5.73abcd	6.26bc	6.71ab	6.23
NPK	5.77c	4.97b	5.43c	5.44	5.62c	6.21bc	6.13c	5.99
Control	5.91abc	4.89c	5.52bcd	5.44	5.51d	5.98d	6.37c	5.95
Mean	5.92	4.98	5.52	5.47	5.77	6.30	6.59	6.22
SEM	0.089	0.050	0.231		0.115	0.106	0.146	
CV (%)	2.1	1.4	5.9		2.8	2.4	3.1	
LSD _{T(0.05)}	0.181	0.101	0.472		0.235	0.217	0.298	
	Ottosdal				Potchefstroom			
Biozone	5.17ab	5.30abc	6.19ab	5.55	5.70d	5.34bc	6.27b	5.77
Gliogrow	5.21ab	5.28abc	6.21ab	5.57	6.17b	5.47ab	6.39ab	6.01
Gromor	5.33a	5.00c	6.56a	5.63	6.35a	5.54a	6.48a	6.12
Promis	5.18ab	5.57a	6.25ab	5.67	6.06bc	5.40abc	6.29b	5.92
Growmax	5.26ab	5.42ab	5.77c	5.48	6.22b	5.32bc	6.38ab	5.97
Crop care	5.12bc	4.99c	5.75c	5.29	5.85cd	5.36bc	6.25b	5.82
K-humate	5.18ab	5.58a	5.65c	5.47	5.99c	5.40abc	6.27b	5.88
Lanbac	5.17ab	5.12bc	5.55c	5.28	6.04bc	5.27c	6.27b	5.86
Montys	5.20ab	5.29abc	5.91bc	5.46	5.93cd	5.40abc	6.04c	5.79
NPK	5.19ab	5.38abc	6.23ab	5.60	5.84d	5.27c	6.39ab	5.83
Control	4.98c	5.13bc	5.75c	5.29	5.92cd	5.47ab	6.27b	5.89
Mean	5.18	5.28	5.98	5.48	6.00	5.39	6.30	5.90
SEM	0.090	0.188	0.197		0.046	0.077	0.075	
CV (%)	2.5	5.0	4.7		1.1	2.0	1.7	
LSD _{T(0.05)}	0.184	0.384	0.402		0.095	0.157	0.154	

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

5.3.1.1.2 Bothaville

In consideration of the post-harvest pH, the lowest and highest values resulted with Growmax (5.66) and Biozone (5.94) in 2006/07, Crop care (6.07) and Gliogrow (6.72) in 2007/08, and Biozone (6.44) and Crop care (6.87) in 2008/09. Some significant differences amongst the IMBAs were observed in each season. This is also true for the differences between the IMBAs and either the NPK or control treatments. For example, in 2006/07 Biozone, Gromor and K-humate, in 2007/08 Gliogrow and in 2008/09 Gliogrow, Crop care, Lanbac and Montys resulted in significantly higher pH than the NPK check probably on account of the acidifying effect of inorganic fertilisers.

Comparing to the control, the IMBAs gave in many instances higher pH with significant differences observed between them in all three seasons.

5.3.1.1.3 **Ottosdal**

The pH values ranged from 5.12 with Crop care to 5.33 with Gromor in 2006/07, 4.99 with Crop care to 5.58 with K-humate in 2007/08, and 5.55 with Lanbac to 6.56 with Gromor in 2008/09. In each season, significant differences amongst some IMBA treatments were recorded. In comparison with the NPK check, none of the IMBAs gave either significantly lower or higher pH values. In fact the IMBAs resulted often with lower values of pH, e.g. Biozone, Crop care and Lanbac in every season. Of all the IMBA treatments, Gromor in 2006/07 and 2008/09, and Promis and K-humate in 2007/08 gave significantly higher soil pH values than in the unfertilised plots.

5.3.1.1.4 **Potchefstroom**

Concerning post-harvest pH, the values varied between 6.04 with Montys and 6.22 with Growmax in 2006/07, 5.27 with Lanbac and 5.54 with Gromor in 2007/08, and 6.25 with Crop care and 6.48 with Gromor in 2008/09. Every season pH values differed significantly amongst some of the IMBAs. This was also applicable for differences between some of the IMBAs and either the NPK (2006/07 and 2007/08) or control treatments (2006/07 and 2008/09). Generally, Gromor (2006/07 and 2008/09) and Growmax (2006/07) gave substantial higher pH values than the other IMBAs and the NPK check. Comparing to the control, pH values decreased in many instances with some of the IMBAs in 2006/07 and 2008/09. This was not the case in 2007/08. In this particular season, higher pH values resulted in the unfertilised plots probably due to lower N uptake.

5.3.1.2 **Organic C**

The percentage organic C in the IMBA treatments across the seasons and localities is given under Table 5.2.

5.3.1.2.1 **Bethlehem**

Organic C ranged from 0.50% with Growmax to 0.56% with Lanbac in 2006/07, 0.45% with Gromor to 0.50% with Lanbac in 2007/08, and 0.43% with Lanbac to 0.52% with K-humate in 2008/09. The differences amongst some of the IMBAs were significant in

each of the three seasons. None of the IMBAs gave higher organic C values than the NPK check in 2006/07 and 2007/08. In fact in 2006/07, NPK treatment gave significantly higher organic C than all the IMBA treatments. The only exception in this regard was treatment with Biozone and Lanbac. In 2007/08, only Biozone and Gromor had significantly lower organic C values. This was not the case in 2008/09 when organic C recorded with several of the IMBAs was significantly higher than the NPK check. Comparing to the control, the IMBA treatments coincided with higher organic C values in all the three seasons.

5.3.1.2.2 **Bothaville**

The organic C varied between 0.28% (Gromor) and 0.36% (Montys) in 2006/07, 0.25% (Biozone) and 0.33% (Gliogrow) in 2007/08, and 0.27% (Montys) and 0.35% (Biozone, Crop care and K-humate) in 2008/09. Significant differences amongst the IMBAs (in each season) and between the IMBAs and either the NPK (2006/07 and 2007/08) and control treatments (in each season) were found. Amongst the IMBAs resulted Montys (2006/07), Crop care (2007/08), and Biozone, Crop care and K-humate (2008/09) in a substantial higher content of organic C. However, comparing to the NPK check, Biozone, Gliogrow, Crop care and Montys in 2006/07 and Crop care in 2007/08 gave a substantial higher organic C. With regard to the control, lower organic C resulted from several of the IMBAs, except for Gliogrow and Crop care in 2007/08, though not significantly. Treatments with Promis and Montys gave in 2008/09 similar effects. The lower organic C in 2007/08 and 2008/09 could be related to increased organic C mineralisation due to higher nutrient uptake anticipated since higher yields realised in these seasons than in 2006/07.

5.3.1.2.3 **Ottosdal**

Amongst the IMBAs, K-humate (0.56%) in 2006/07 and Gliogrow in 2007/08 (0.53%) and 2008/09 (0.53%) gave the highest organic C content. The lowest organic C resulted from Gromor (0.52%), Biozone (0.45%) and K-humate (0.46%) in 2006/07, 2007/08 and 2008/09, respectively. Significant differences amongst some of the IMBAs were observed in 2007/08 and 2008/09. In comparison with the NPK check, Gliogrow and Crop care (2007/08) and Gliogrow and Growmax (2008/09) resulted in significantly higher organic C. In none of the three seasons was organic C in the unfertilised plots higher than in the IMBA plots. However, those of the Gliogrow and Crop care in

2007/08 and Gliogrow, Growmax and Montys in 2008/09 resulted in significantly higher organic C than the control.

Table 5.2: Effect of IMBAs on organic C (%) at harvest during three production seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	0.55abc	0.47bc	0.44c	0.49	0.33b	0.25b	0.35a	0.31
Gliogrow	0.54bc	0.46abc	0.48abc	0.49	0.33b	0.33ab	0.30ab	0.32
Gromor	0.53bc	0.45bc	0.46bc	0.48	0.28cd	0.28b	0.34ab	0.30
Promis	0.53bc	0.47abc	0.46bc	0.49	0.31bc	0.31b	0.34ab	0.32
Growmax	0.50bc	0.47abc	0.47abc	0.48	0.30bc	0.28b	0.32ab	0.30
Crop care	0.54bc	0.48abc	0.42bc	0.48	0.33b	0.39a	0.35a	0.35
K-humate	0.52bc	0.49ab	0.52a	0.51	0.30bc	0.31b	0.35a	0.32
Lanbac	0.56ab	0.50ab	0.43bc	0.50	0.30bc	0.30b	0.31ab	0.30
Montys	0.52b	0.50ab	0.49ab	0.50	0.36a	0.31b	0.27b	0.31
NPK	0.60a	0.51a	0.44c	0.52	0.29c	0.29b	0.29ab	0.29
Control	0.49c	0.42c	0.45c	0.45	0.26d	0.32b	0.31ab	0.30
Mean	0.53	0.47	0.46	0.49	0.31	0.31	0.32	0.31
SEM	0.029	0.030	0.022		0.015	0.031	0.032	
CV (%)	7.6	8.9	6.7		6.9	14.6	14.3	
LSD _{T(0.05)}	0.059	0.061	0.045		0.030	0.064	0.066	
	Ottosdal				Potchefstroom			
Biozone	0.55	0.45c	0.49ab	0.50	0.77d	0.79a	0.74c	0.77
Gliogrow	0.54	0.52a	0.53a	0.53	0.84cd	0.76abc	0.78b	0.80
Gromor	0.52	0.48bc	0.48b	0.49	0.91a	0.79a	0.77c	0.82
Promis	0.53	0.47bc	0.48b	0.49	0.82cd	0.78ab	0.84ab	0.82
Growmax	0.55	0.46bc	0.53a	0.51	0.82cd	0.78ab	0.76c	0.79
Crop care	0.53	0.50ab	0.47b	0.50	0.83cd	0.79a	0.86a	0.83
K-humate	0.56	0.46bc	0.46b	0.49	0.86bc	0.79a	0.78b	0.81
Lanbac	0.55	0.46bc	0.50ab	0.50	0.81cd	0.75abc	0.80b	0.79
Montys	0.54	0.46bc	0.53a	0.51	0.82cd	0.79a	0.79b	0.80
NPK	0.57	0.45c	0.47b	0.50	0.83cd	0.78ab	0.81b	0.81
Control	0.52	0.45c	0.46b	0.48	0.80d	0.74c	0.75c	0.76
Mean	0.54	0.47	0.49	0.50	0.83	0.78	0.79	0.80
SEM	0.027	0.016	0.019		0.021	0.019	0.015	
CV (%)	7.0	4.7	5.5		3.5	3.4	2.7	
LSD _{T(0.05)}	0.055	0.032	0.039		0.042	0.038	0.031	

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

5.3.1.2.4 Potchefstroom

Post-harvest organic C values ranged from 0.77% with Biozone to 0.91% with Gromor in 2006/07, 0.75% with Lanbac to 0.79% with Crop care in 2007/08, and 0.74% with Biozone to 0.86% with Crop care in 2008/09. These differences amongst IMBA

treatments differed significantly. Comparing to the NPK check, Gromor in 2006/07, Biozone, Gromor, Crop care, K-humate and Montys in 2007/08, and Crop care in 2008/09 resulted in significantly higher organic C content. With regard to the control, only Biozone gave lower organic C in 2008/09, though not always significant. In fact the IMBAs resulted often in significantly higher organic C, e.g. Gromor and K-humate in 2006/07, Biozone, Gromor, Crop care, K-humate and Montys in 2007/08, and Promis and Crop care in 2008/09.

5.3.1.3 **Mineral N**

Post-harvest mineral N in the IMBA treatments across the seasons and localities is presented in Table 5.3.

5.3.1.3.1 **Bethlehem**

Mineral N content ranged from 1.25 mg kg⁻¹ with Growmax to 3.48 mg kg⁻¹ with Gliogrow in 2006/07, 2.28 mg kg⁻¹ with Promis to 2.85 mg kg⁻¹ with Biozone in 2007/08, and 2.17 mg kg⁻¹ with Promis to 5.97 mg kg⁻¹ with Lanbac in 2008/09. Some significant differences manifested amongst the IMBAs e.g. Gliogrow performed better than all the other IMBAs in 2006/07. The only exception in this regard was K-humate. In 2007/08, Biozone performed better than Gliogrow, Promis, Growmax and Crop care. However, in 2008/09, Lanbac performed better than all the other IMBAs, except for Biozone, Gliogrow and Montys. Comparing to the NPK check, Gliogrow (2006/07) and Lanbac (2006/07 and 2007/08) gave significantly higher mineral N. This could be attributed to beneficial microorganisms contained in these materials that have the potential to speed-up mineralisation. However, post-harvest mineral N was in all three seasons lower with Growmax probably on account of the resistance of manure to microbial decomposition. In not any of the three seasons post-harvest mineral N in the IMBA treatments was lower than in the unfertilised plots. The differences between several of the IMBAs and the control were significant in any of the three seasons.

5.3.1.3.2 **Bothaville**

With regard to mineral N, values ranged from 2.23 mg kg⁻¹ with Growmax to 3.81 mg kg⁻¹ with Crop care in 2006/07, 1.60 mg kg⁻¹ with Gromor to 2.18 mg kg⁻¹ with K-humate in 2007/08, and 0.95 mg kg⁻¹ with Gromor to 1.78 mg kg⁻¹ with K-humate in 2008/09. Comparing to the NPK check, significantly higher mineral N was observed in 2006/07

with Gliogrow, Crop care and Lanbac and in 2007/08 with Crop care and K-humate. However in each season, mineral N was with Gromor lower, though not significantly. Comparing to the control, all the IMBAs resulted in significantly higher mineral N in 2006/07 and only with Crop care and K-humate in 2007/08.

Table 5.3: Effect of IMBAs on mineral N (mg kg^{-1}) at harvest during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	2.28b	2.85a	5.55ab	3.56	3.16abcd	1.80ab	0.95c	1.97
Gliogrow	3.48a	2.35b	4.40ab	3.41	3.31bc	1.80ab	1.15bc	2.09
Gromor	1.42bc	2.53ab	3.55bc	2.50	2.68d	1.60b	0.95c	1.74
Promis	1.43bc	2.28b	2.17c	1.96	2.30d	1.75b	1.23abc	1.76
Growmax	1.25c	2.30b	2.72c	2.09	2.23d	2.05ab	1.23abc	1.84
Crop care	1.53bc	2.40b	2.30c	2.08	3.81a	2.18a	1.55ab	2.51
K-humate	1.57bc	2.63ab	3.25c	2.48	3.35ab	2.18a	1.78a	2.43
Lanbac	2.52ab	2.53ab	5.97a	3.67	3.28bc	1.95ab	1.35abc	2.19
Montys	1.48bc	2.55ab	3.87ab	2.63	2.82cd	1.73b	1.35abc	1.97
NPK	1.17c	2.43b	3.72ab	2.44	2.80d	1.73b	1.33abc	1.95
Control	1.10c	1.65c	1.67c	1.47	1.76e	1.80ab	0.85c	1.47
Mean	1.75	2.41	3.56	2.57	2.86	1.63	1.25	1.91
SEM	0.282	0.200	1.107		0.231	0.197	0.275	
CV (%)	22.8	11.8	43.9		11.4	15.1	31.2	
LSD _{T(0.05)}	0.576	0.409	2.260		0.472	0.402	0.561	
	Ottosdal				Potchefstroom			
Biozone	1.93c	3.35ab	1.93ab	2.40	5.61bc	3.70a	1.10d	3.47
Gliogrow	3.60ab	3.40ab	1.13c	2.71	10.2a	2.33ab	1.28d	4.59
Gromor	1.34c	3.03ab	1.43bc	1.93	4.35bc	1.20b	1.20d	2.25
Promis	2.96abc	2.65b	1.05c	2.22	2.97cd	1.02b	1.60bc	1.86
Growmax	1.72c	3.15ab	2.30a	2.39	4.36bc	2.10ab	1.25d	2.57
Crop care	2.68abc	3.95a	1.40bc	2.68	7.97ab	1.27b	2.15b	3.80
K-humate	4.23a	2.85b	2.10ab	3.06	5.87b	1.97b	1.40cd	3.08
Lanbac	2.28bc	2.90b	1.25bc	2.14	4.43bc	2.23ab	1.93bc	2.86
Montys	1.82c	2.58b	1.75ab	2.05	5.06bc	1.20b	4.55a	3.60
NPK	2.09bc	2.95b	1.05c	2.03	5.32b	1.52b	1.90bc	2.91
Control	1.34c	2.53b	0.73c	1.53	1.11d	1.20b	1.08d	1.13
Mean	2.36	3.03	1.46	2.28	5.20	1.80	1.77	2.92
SEM	0.785	0.459	0.389		1.310	0.837	0.282	
CV (%)	47.0	21.4	37.6		35.6	65.9	22.6	
LSD _{T(0.05)}	1.602	0.937	0.795		2.676	1.709	0.576	

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

5.3.1.3.3 Ottosdal

Post-harvest mineral N ranged from 1.34 mg kg^{-1} with Gromor to 4.23 mg kg^{-1} with K-humate in 2006/07, 2.58 mg kg^{-1} with Montys to 3.95 mg kg^{-1} with Crop care in 2007/08,

and 1.05 mg kg⁻¹ with Promis to 2.30 mg kg⁻¹ with Growmax in 2008/09. Some of these differences amongst the IMBAs were significant. The IMBAs differed significantly in some instances from either the NPK or control treatments. Generally, mineral N values in the IMBA plots were higher than in either the NPK check or unfertilised plots.

5.3.1.3.4 **Potchefstroom**

Some significant differences amongst the IMBAs manifested in all three seasons with regard to mineral N. Generally, in 2006/07 Gliogrow performed better than the other IMBAs, except for Crop care. In 2007/08, all the IMBAs performed poorer than Biozone, except for Gliogrow, Growmax and Lanbac. However in 2008/09, mineral N content from Montys was substantially higher than the other IMBAs. With regard to the NPK check, Gromor and Promis (in each season) and Growmax (2006/07 and 2008/09) resulted in lower mineral N. These differences were significant in 2006/07 and 2008/09. Comparing to the control, Gromor, Promis and Montys gave in 2007/08 lower mineral N, though not significantly.

5.3.1.4 **Extractable P**

The effect of the IMBA treatments on post-harvest extractable P across the seasons and localities is shown in Table 5.4.

5.3.1.4.1 **Bethlehem**

Post-harvest extractable P content ranged from 29.5 mg kg⁻¹ with Promis to 42.5 mg kg⁻¹ with Lanbac in 2006/07, 24.2 mg kg⁻¹ with K-humate to 45.8 mg kg⁻¹ with Crop care in 2007/08, and 30.3 mg kg⁻¹ with K-humate to 34.8 mg kg⁻¹ with Gromor in 2008/09. Some significant differences amongst the IMBAs were observed in 2006/07 when Lanbac resulted in higher extractable P than Gromor and Promis and in 2007/08 when Crop care resulted in higher soil P than Promis, K-humate and Montys. In comparison with the NPK check, the only significant effect was observed in 2007/08 with Crop care that resulted in higher extractable P. Despite K-humate contain the highest P (17.6 mg kg⁻¹) than the other IMBAs, post-harvest extractable P with this treatment was in each season lower than the NPK treatment. This could be attributed to the fact that this P from K-humate is in organic form and has yet to undergo mineralisation. In not any of the three seasons extractable P content in the control higher than in the IMBA plots. However, significantly higher extractable P was recorded with Crop care and Lanbac in 2006/07, Biozone,

Gliogrow, Gromor, Promis, Growmax, Crop care and Lanbac in 2007/08, and Gromor, Crop care and Lanbac in 2008/09.

Table 5.4: Effect of IMBAs on extractable P (mg kg^{-1}) at harvest during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	35.5abc	38.2ab	30.3ab	34.7	29.0ab	25.8ab	21.3c	25.3
Gliogrow	36.2abc	41.2ab	31.3ab	36.2	29.5ab	28.3a	26.8ab	28.2
Gromor	31.2bc	38.8ab	34.8a	34.9	28.5ab	22.3bc	25.8abc	25.5
Promis	29.5bc	35.2b	30.8ab	31.8	28.8ab	19.8c	28.8a	25.8
Growmax	33.8abc	40.8ab	31.3ab	35.3	29.0ab	27.8ab	24.3abc	27.0
Crop care	38.2ab	45.8a	33.3a	39.1	31.8a	26.8ab	25.3abc	27.9
K-humate	33.8abc	24.2c	30.3ab	29.4	28.3ab	26.8ab	20.8c	25.3
Lanbac	42.5a	42.2ab	32.8a	39.2	27.0b	19.3c	28.8a	25.0
Montys	37.2abc	24.8c	30.8ab	30.9	28.0ab	28.3a	25.8abc	27.3
NPK	41.2ab	32.8b	30.3ab	34.8	28.3ab	24.3ab	23.8bc	25.4
Control	27.2c	20.2c	27.3b	24.9	25.8b	16.8c	22.8bc	21.8
Mean	35.2	34.9	31.2	33.8	28.5	24.2	24.9	25.9
SEM	5.12	5.15	2.438		2.129	2.585	2.43	
CV (%)	20.6	20.8	11.1		10.6	15.1	13.8	
LSD _{T(0.05)}	10.46	10.51	4.98		4.35	5.28	4.96	
IMBAs	Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	36.8abc	35.2abc	32.2bc	34.7	74.8ab	51.8	51.3b	59.3
Gliogrow	33.0abcd	34.2abc	29.2bc	32.1	77.0a	53.8	48.8b	59.8
Gromor	29.8cd	32.8abc	33.2bc	31.9	73.5b	57.3	50.8b	60.5
Promis	32.2bcd	20.8c	28.8bc	27.3	77.0a	56.8	53.8ab	62.5
Growmax	34.2abcd	42.2a	30.2bc	35.5	69.8c	53.3	45.8bc	56.3
Crop care	39.8ab	34.2abc	35.8b	36.6	76.5ab	56.8	60.3a	64.5
K-humate	36.2abcd	28.8bcd	49.8a	38.3	72.5bc	54.8	45.3bc	57.5
Lanbac	42.5a	32.2abc	37.2b	37.3	70.8c	54.3	40.3c	55.1
Montys	37.0abc	26.2bcd	31.2bc	31.5	73.5b	60.3	52.8b	62.2
NPK	40.8ab	33.8ab	50.2a	41.6	73.8b	61.8	52.3b	62.6
Control	26.8d	22.8c	21.8c	23.8	69.5c	52.8	38.8c	53.7
Mean	35.4	31.2	34.5	33.7	73.5	55.8	49.1	59.4
SEM	4.80	6.25	5.97		1.28	4.43	3.59	
CV (%)	19.2	28.3	24.5		2.5	11.2	10.4	
LSD _{T(0.05)}	9.81	12.77	12.20		2.61	9.05	7.34	

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

5.3.1.4.2 Bothaville

Extractable P ranged from 27.0 mg kg^{-1} with Lanbac to 31.8 mg kg^{-1} with Crop care in 2006/07, 19.3 mg kg^{-1} with Lanbac to 28.3 mg kg^{-1} with either Gliogrow or Montys in 2007/08, and 20.8 mg kg^{-1} with K-humate and 28.8 mg kg^{-1} with Promis in 2008/09.

Some of these differences amongst the IMBAs were significant. This also applies for differences between some of the IMBAs and the control. With reference to the NPK treatment, the only significant effects were observed in 2008/09 with Promis and Lanbac that resulted in higher extractable P contents.

5.3.1.4.3 **Ottosdal**

The lowest and highest extractable P values coincided with Gromor (29.8 mg kg⁻¹) and Lanbac (42.5 mg kg⁻¹) in 2006/07, Promis (20.8 mg kg⁻¹) and Growmax (42.3 mg kg⁻¹) in 2007/08, and Promis (28.8 mg kg⁻¹) and K-humate (49.8 mg kg⁻¹) in 2008/09. These differences amongst the IMBAs were significant in some instances. For each of the three seasons, some of the IMBAs gave significantly higher extractable P values than the NPK check, e.g. Gromor and Promis in 2006/07, Promis in 2007/08, and all the IMBAs, except for K-humate in 2008/09. In comparison with the control, extractable P content from the IMBA treatments was in many instances significantly higher.

5.3.1.4.4 **Potchefstroom**

Extractable P varied between 69.8 mg kg⁻¹ (Growmax) and 77.0 mg kg⁻¹ (Gliogrow and Promis) in 2006/07, 51.8 mg kg⁻¹ (Biozone) and 60.3 mg kg⁻¹ (Montys) in 2007/08, and 40.3 mg kg⁻¹ (Lanbac) and 60.3 mg kg⁻¹ in 2008/09. These differences amongst the IMBAs were significant in 2006/07 and 2008/09, but not in 2007/08. With respect to the NPK check, Promis (2006/07) and Crop care (2008/09) resulted in significantly higher extractable P content. On the other hand, Growmax (2006/07) and Lanbac (2006/07 and 2008/09) had significantly lower extractable P content. Regardless that Montys (1.2 mg kg⁻¹) contained less P than Gromor (16 mg kg⁻¹) and K-humate (17.6 mg kg⁻¹), this IMBA resulted in 2006/07 with substantially higher extractable P than afore-mentioned IMBAs. However, Crop care in 2008/09 gave similar significant increases than Growmax, K-humate and Lanbac. In the same season, Lanbac resulted in significantly lower extractable P than Promis and Montys. Comparing to the control, several of the IMBAs augmented post-harvest extractable P in all the three seasons. However, significant differences between some of the IMBAs and control realised only in 2006/07 and 2008/09.

5.3.2 Microbial biomass properties

5.3.2.1 Microbial biomass-C

The effect of IMBA treatments on C_{mic} at three samplings across the seasons and localities is presented Table 5.5.

5.3.2.1.1 Bethlehem

At 4-weeks after planting, C_{mic} ranged from $-173.0 \mu\text{g C g}^{-1}$ (Crop care) to $-872.2 \mu\text{g C g}^{-1}$ (Growmax) in 2006/07, $-1437.5 \mu\text{g C g}^{-1}$ (Lanbac) to $543.7 \mu\text{g C g}^{-1}$ (Gliogrow) in 2007/08, and $-99.5 \mu\text{g C g}^{-1}$ (Gromor) to $-39.0 \mu\text{g C g}^{-1}$ (Growmax) in 2008/09. Some of the IMBA treatments differed significantly from one another in 2007/08 and 2008/09. The C_{mic} values recorded with Gromor (both seasons) and Lanbac (one season) were significantly lower due to higher degree of immobilisation. In any of the three seasons, none of the IMBA treatments gave either significantly lower or higher C_{mic} values compared to the NPK and control treatments. Regardless of this insignificance, Biozone and Crop care showed reduced values of immobilisation than the NPK check in two out of the three seasons. In comparison to the control, only Growmax resulted in lower immobilisation probably due to low C input from root residue in the unfertilised plots. The higher immobilisation from several of the IMBA treatments could be attributed to the resistance of organic based amendments to microbial decomposition.

At flowering, values of C_{mic} varied between $99.9 \mu\text{g C g}^{-1}$ (K-humate) and $179.4 \mu\text{g C g}^{-1}$ (Gromor) in 2006/07, $185.6 \mu\text{g C g}^{-1}$ (Gliogrow) and $311.8 \mu\text{g C g}^{-1}$ (K-humate) in 2007/08, and $167.4 \mu\text{g C g}^{-1}$ (Gromor) and $254.1 \mu\text{g C g}^{-1}$ (Lanbac) in 2008/09. In this regard, significant differences amongst the IMBAs were observed in 2006/07 when Gromor performed better than K-humate. The C_{mic} values between the IMBAs and from either the NPK or control treatments did not differ significantly in all three seasons. In fact C_{mic} mineralisation was predominant in the NPK plots than in several of the IMBA plots. However, compared to the control, the IMBAs showed higher C_{mic} mineralisation in any of the three seasons.

Table 5.5: Effect of IMBAs on microbial biomass-C ($\mu\text{g C g}^{-1}$) at three samplings during three production seasons at four sites

IMBAs	Bethlehem			Bothaville			Ottosdal			Potchefstroom		
	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09
4 weeks after planting												
Biozone	-244.2	-112.5abc	-55.1ab	-84.8ab	75.7	-470.3	23.6	-298.3	-41.5b	6.9	-328.4	-85.1abc
Gliogrow	-695.2	543.7a	-68.7ab	-118.0ab	-32.4	-938.6	-24.4	-601.3	-15.0a	17.4	-935.8	-123.5abc
Gromor	-595.6	-838.1bc	-99.5b	-102.1ab	-44.2	-956.7	-18.0	-737.2	-30.1ab	-77.6	-775.3	-224.1bc
Promis	-213.3	-450.2ab	-77.2ab	58.3a	-75.7	-402.5	31.0	-182.9	-30.4ab	36.9	-344.7	-38.7a
Growmax	-872.2	-19.1ab	-39.0a	-66.8ab	-0.7	-159.5	-18.1	-404.1	-30.5ab	38.0	-1166.5	-15.4a
Crop care	-173.0	-48.1ab	-84.8ab	-66.5ab	-43.1	-381.2	37.4	-201.1	-26.5ab	-69.3	-289.7	-100.3abc
K-humate	-184.4	-343.8abc	-54.8ab	32.7ab	-75.4	-503.5	6.0	-143.1	-29.7ab	-94.1	-240.3	-281.1c
Lanbac	-729.2	-1437.5c	-39.1a	-213.1b	-32.1	-1053.9	-44.3	-442.4	-26.7ab	-52.9	-934.2	-177.6abc
Montys	-493.2	-615.3abc	-77.8ab	-111.3ab	-43.0	-822.1	2.9	-278.8	-26.2ab	-52.9	-1083.6	-177.6abc
NPK	-281.1	-261.0abc	-38.2ab	-97.1ab	-43.4	-454.3	33.3	-109.7	-19.0ab	-21.7	-359.6	-209.2b
Control	-143.6	-304.3abc	-46.5ab	-152.2ab	-0.1	-405.6	-27.3	-140.7-	-33.9ab	82.9	-259.3	30.9a
Mean	-420.5	-353.3	-61.9	-83.7	-28.6	-595.3	0.2	-309.0	-28.1	-16.9	-610.7	-127.4
SEM	369.6	475.9	16.1	89.2	36.9	365.3	36.8	289.7	7.1	58.0	491.0	54.0
LSD _{T(0.05)}	1067.5	1374.4	46.6	257.7	106.5	1055.1	106.3	836.7	20.5	118.5	1418.2	155.9
Flowering stage												
Biozone	168.7ab	228.3	217.5	97.3b	251.7ab	177.7ab	125.4	274.7ab	194.7ab	266.3ab	339.6	202.3ab
Gliogrow	118.0ab	185.6	274.8	288.8ab	307.5a	202.7a	82.0	317.9ab	313.3a	394.5a	376.1	255.8ab
Gromor	179.4a	244.1	243.3	309.0ab	181.8b	165.6ab	-13.7	284.0ab	183.5b	214.6ab	393.0	276.2a
Promis	128.8ab	272.0	226.1	381.1ab	240.5abc	108.4ab	46.1	307.8ab	200.1ab	235.4ab	390.2	196.5ab
Growmax	143.9ab	234.3	200.2	378.6ab	176.8b	143.4ab	195.0	310.2ab	159.8b	214.1ab	352.0	187.3ab
Crop care	153.1ab	210.6	201.3	200.5ab	246.6ab	158.1ab	99.1	345.3a	192.9b	144.7b	394.8	265.1ab
K-humate	99.9b	311.8	236.4	226.8ab	145.3b	197.7ab	49.6	314.5ab	190.0b	99.6b	360.3	177.2ab
Lanbac	147.5ab	288.4	254.1	208.8ab	223.1abc	120.2ab	136.0	290.2ab	281.4ab	308.3a	402.5	236.6ab
Montys	142.5ab	251.3	197.9	413.4a	227.4abc	215.4a	-89.9	273.4ab	272.2ab	222.0ab	372.0	202.5ab
NPK	152.9ab	300.5	227.0	102.6b	151.1bc	169.4ab	63.3	328.8ab	200.5ab	240.6ab	349.7	145.3ab
Control	152.6ab	177.8	167.4	98.4b	124.2c	99.8b	19.5	246.1b	135.4b	168.7b	322.7	134.8b
Mean	144.3	245.9	222.4	245.9	206.9	159.8	64.8	299.3	211.3	228.1	368.4	207.2
SEM	22.9	47.9	44.7	106.6	41.5	31.9	68.8	26.5	41.2	70.3	41.2	46.8
LSD _{T(0.05)}	66.2	138.4	129.2	307.9	119.9	92.2	198.9	76.64	119.0	203.0	118.9	135.3

Table 5.5: Continue

IMBAs	Bethlehem			Bothaville			Ottosdal			Potchefstroom		
	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09
	Crop harvest											
Biozone	137.0a	234.4	183.9ab	39.8	33.4abc	36.9	93.4ab	-4.3ab	76.1	-9.7	-84.1ab	-33.8
Gliogrow	88.4ab	99.6	142.6ab	95.1	-11.8bc	87.2	66.9ab	30.3ab	31.7	42.4	73.1ab	127.0
Gromor	70.4ab	130.7	116.5ab	1.6	61.6ab	77.2	141.4a	-4.4ab	217.7	37.8	-28.4ab	137.9
Promis	80.0ab	111.2	129.7ab	84.0	2.1abc	84.3	106.4ab	30.3ab	114.8	16.7	105.1a	57.5
Growmax	110.4a	89.5	179.3a	27.9	65.2a	29.3	81.3ab	22.9ab	15.6	9.5	-41.7b	34.7
Crop care	44.4ab	79.1	96.2ab	41.0	22.3abc	-6.8	72.1ab	-24.0ab	6.1	12.5	45.1ab	33.7
K-humate	37.4ab	98.1	53.0ab	18.3	50.2ab	52.9	57.9ab	52.2a	58.9	19.3	39.1ab	47.4
Lanbac	59.5ab	100.1	95.4ab	27.9	56.7ab	103.7	115.7ab	-20.8ab	114.3	36.3	60.2ab	105.6
Montys	53.4ab	97.6	123.1ab	14.6	-9.1bc	-1.7	70.8ab	57.0a	22.3	69.3	66.0ab	230.0
NPK	70.9a	58.0	91.8ab	11.6	38.0abc	11.3	75.7ab	-30.9b	39.8	23.8	27.9ab	76.6
Control	-19.7b	26.4	35.1b	-3.4	-26.1c	-7.4	3.2b	-25.0b	-17.1	10.4	-2.6ab	37.5
Mean	66.6	102.3	113.3	32.6	25.7	42.5	80.4	7.6	61.8	24.4	23.6	77.6
SEM	43.2	51.2	49.9	48.6	22.7	43.2	39.5	23.7	84.7	25.0	46.1	76.7
LSD _{T(0.05)}	124.9	147.8	144.0	106.3	65.7	124.7	114.1	68.5	244.6	72.1	133.2	221.6

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

Amongst the IMBA treatments at crop harvest, there was C_{mic} mineralisation, although values tended to be lower than at flowering. The lowest and highest C_{mic} values coincided with K-humate ($37.4 \mu\text{g C g}^{-1}$) and Biozone ($137.0 \mu\text{g C g}^{-1}$) in 2006/07, Crop care ($79.1 \mu\text{g C g}^{-1}$) and Biozone ($234.4 \mu\text{g C g}^{-1}$) in 2007/08, and K-humate ($53.0 \mu\text{g C g}^{-1}$) and Biozone ($183.9 \mu\text{g C g}^{-1}$) in 2008/09. These differences were not significantly in any of the three seasons. This insignificance applies also for differences between the IMBAs and NPK check. Regardless of the lack of significant differences in the latter, C_{mic} mineralisation was predominant in 2007/08 and 2008/09 (amongst all the IMBAs) and in 2006/07 (Biozone, Gliogrow and Growmax). In not any of the three seasons C_{mic} mineralisation was in the unfertilised plots higher than in any of the IMBA plots. However, C_{mic} mineralisation from Growmax in 2006/07 and 2008/09 was significantly higher than in the unfertilised plots probably due to synergy of manure and inorganic fertiliser.

5.3.2.1.2 **Bothaville**

Like at Bethlehem, at 4-weeks after planting in this locality, C_{mic} immobilisation occurred in many instances. The lowest and highest C_{mic} values resulted with Lanbac ($-213.1 \mu\text{g C g}^{-1}$) and Promis ($58.3 \mu\text{g C g}^{-1}$) in 2006/07, Promis ($-75.7 \mu\text{g C g}^{-1}$) and Biozone ($75.7 \mu\text{g C g}^{-1}$) in 2007/08, and Lanbac ($-1053.9 \mu\text{g C g}^{-1}$) and Growmax ($-159.5 \mu\text{g C g}^{-1}$) in 2008/09. The only significant difference amongst the IMBAs was observed in 2006/07 with Lanbac and Promis. No significant differences were observed between the IMBAs and either the NPK or control treatments in each season. Despite non-significant differences between IMBAs and NPK check, Crop care tended to give lower immobilisation values. In comparison with the control, only Lanbac showed exacerbated immobilisation in 2006/07. Conversely, Growmax (2007/08) and Promis, Growmax and Crop care (2008/09) tended to give lower immobilisation fluxes.

Concerning C_{mic} at flowering, similar to Bethlehem, there was mineralisation regardless of the IMBA treatment and season of application. These values were $97.3 \mu\text{g C g}^{-1}$ (Biozone) and $413.4 \mu\text{g C g}^{-1}$ (Montys) in 2006/07, $145.3 \mu\text{g C g}^{-1}$ (K-humate) and $307.5 \mu\text{g C g}^{-1}$ (Gliogrow) in 2007/08, and $108.4 \mu\text{g C g}^{-1}$ (Promis) and $215.4 \mu\text{g C g}^{-1}$ (Montys) in 2008/09. Significant differences amongst some of the IMBAs were observed in 2006/07 and 2007/08. Comparing to the NPK check, C_{mic} mineralisation was predominant from several of the IMBAs, but differed significantly only in 2006/07

(Montys) and 2007/08 (Gliogrow). With regard to the control, none of the IMBAs recorded lower values of C_{mic} mineralisation in each season. However, some of the IMBA plots gave significantly higher C_{mic} values than the unfertilised plots in every season.

With regard to C_{mic} at crop harvest, there was mineralisation regardless of the IMBA treatment, although immobilisation was depicted in few instances. The lowest C_{mic} values resulted from Gromor ($1.6 \mu\text{g C g}^{-1}$) in 2006/07, Gliogrow ($-11.8 \mu\text{g C g}^{-1}$) in 2007/08, and Crop care ($-6.8 \mu\text{g C g}^{-1}$) in 2008/09. Gliogrow ($95.1 \mu\text{g C g}^{-1}$), Growmax ($65.2 \mu\text{g C g}^{-1}$) and Lanbac ($103.7 \mu\text{g C g}^{-1}$) gave in 2006/07, 2007/08 and 2008/09, respectively the highest values. The only significant difference amongst the IMBA treatments was observed in 2007/08 when Growmax registered higher values of C_{mic} than Gliogrow and Montys. For each of the three seasons, C_{mic} values obtained with the IMBAs did not differ significantly from the NPK check. However, C_{mic} mineralisation was in many instances predominant with application of the several IMBAs. In not any of the three seasons, C_{mic} values in the IMBA plots were lower than in the unfertilised plots. The only significant difference in this regard was obtained in 2007/08 with Growmax.

5.3.2.1.3 **Ottosdal**

Concerning C_{mic} at 4-weeks after planting like at other localities, immobilisation was predominant across the treatments. However, several of the IMBAs showed C_{mic} mineralisation in 2006/07 possibly due to adequate nutrition from cowpea residues previously planted on this locality. The lowest C_{mic} values recorded was with Lanbac ($-44.3 \mu\text{g C g}^{-1}$) in 2006/07, Gromor ($-737.2 \mu\text{g C g}^{-1}$) in 2007/08, and Biozone ($-41.5 \mu\text{g C g}^{-1}$) in 2008/09. The highest C_{mic} values resulted with Crop care ($37.4 \mu\text{g C g}^{-1}$) in 2006/07, K-humate ($-143.1 \mu\text{g C g}^{-1}$) in 2007/08, and Gliogrow ($-15.0 \mu\text{g C g}^{-1}$) in 2008/09. The only significant difference manifested in 2008/09 between Biozone and Gliogrow. In not any of the three seasons, C_{mic} values between the IMBAs and either the NPK or control treatments differed significantly. However, immobilisation was more pronounced with several of the IMBA treatments than in the NPK check. Compared to the control, Gliogrow, Gromor, Promis, Growmax, Crop care, K-humate and Montys showed reduced immobilisation rate in two out of the three seasons. This was not the

case in 2008/09 where immobilisation was more pronounced from several of the IMBA treatments.

Like at Bethlehem and Bothaville, C_{mic} mineralisation occurred regardless of the IMBA treatment. The only exception was with Gromor and Montys in 2006/07. Therefore C_{mic} values ranged from $-89.9 \mu\text{g C g}^{-1}$ (Montys) to $195.0 \mu\text{g C g}^{-1}$ (Growmax) in 2006/07, $246.1 \mu\text{g C g}^{-1}$ (Crop care) to $317.1 \mu\text{g C g}^{-1}$ (Gliogrow) in 2007/08, and $159.8 \mu\text{g C g}^{-1}$ (Growmax) to $313.3 \mu\text{g C g}^{-1}$ (Gliogrow) in 2008/09. Only in the latter season some (2008/09) significant differences amongst the IMBAs were observed. In none of the three seasons, C_{mic} mineralisation recorded amongst the IMBA treatments was significantly higher than in the NPK check. In comparison to the control, C_{mic} mineralisation was predominant following application of the IMBAs in each of the three seasons. Significant differences were observed in 2007/08 and 2008/09, but they were more frequent in 2008/09.

Unlike Bethlehem and Bothaville, nearly half of the IMBAs at crop harvest depicted C_{mic} immobilisation in 2007/08. This was not the case in 2006/07 and 2008/09. The C_{mic} values ranged therefore from $57.9 \mu\text{g C g}^{-1}$ with K-humate to $141.4 \mu\text{g C g}^{-1}$ with Gromor in 2006/07, $-24.0 \mu\text{g C g}^{-1}$ with Crop care to $57.0 \mu\text{g C g}^{-1}$ with Montys in 2007/08, and $6.1 \mu\text{g C g}^{-1}$ with Crop care and $217.7 \mu\text{g C g}^{-1}$ with Gromor in 2008/09. Compared to the NPK check, the IMBA treatments coincided with higher C_{mic} mineralisation in each season, though not significantly. However, in comparison to the control, the IMBA treatments resulted in each season with higher C_{mic} values than unfertilised plots. The differences between some of the IMBAs and control were significant in 2006/07 and 2007/08.

5.3.2.1.4 Potchefstroom

With regard to C_{mic} at 4-weeks after planting, like in the other three sites, immobilisation was predominant amongst the IMBAs. However, like at Ottosdal, there were C_{mic} mineralisation in 2006/07 between some of the IMBAs probably on account of adequate nutrition from residual nutrients following a cowpea crop planted the previous season. The lowest and highest C_{mic} values resulted with K-humate ($-94.1 \mu\text{g C g}^{-1}$) and Growmax ($38.0 \mu\text{g C g}^{-1}$) in 2006/07, Growmax ($-1166.5 \mu\text{g C g}^{-1}$) and K-humate ($-240.3 \mu\text{g C g}^{-1}$) in 2007/08, and K-humate ($-281.1 \mu\text{g C g}^{-1}$) and Growmax ($-15.4 \mu\text{g C g}^{-1}$) in

2008/09. Significant differences amongst the IMBA treatments were observed only in 2008/09. Regardless of the insignificance between the IMBAs and NPK check, Biozone and Crop care gave in every season a lower rate of immobilisation. For each season, C_{mic} immobilisation was more pronounced in the IMBAs than in the unfertilised plots possibly due to low C inputs from root residue in the latter.

Like with the other three localities, C_{mic} mineralisation was predominant amongst the IMBAs at flowering. The lowest and highest values resulted with K-humate ($99.6 \mu\text{g C g}^{-1}$) and Gliogrow ($394.5 \mu\text{g C g}^{-1}$) in 2006/07, Biozone ($339.6 \mu\text{g C g}^{-1}$) and Lanbac ($402.5 \mu\text{g C g}^{-1}$) in 2007/08, and K-humate ($177.2 \mu\text{g C g}^{-1}$) and Gromor ($276.2 \mu\text{g C g}^{-1}$) in 2008/09. The only significant differences amongst IMBAs were observed in 2006/07. No significant differences were observed between the IMBAs and the NPK check in any of the three seasons. Comparing to the control, only Crop care and K-humate in 2006/07 gave lower C_{mic} mineralisation, though not significantly. The only significant positive result in this case was observed in 2008/09 with Gromor.

Concerning C_{mic} at crop harvest, like at Ottosdal amongst some of the IMBA treatments, C_{mic} immobilisation were noted. Biozone had in each season the lowest C_{mic} values, viz. with -9.7 , -84.1 and $-33.8 \mu\text{g C g}^{-1}$ in 2006/07, 2007/08 and 2008/09, respectively. The highest C_{mic} values coincided in two of the three seasons with Montys ($69.3 \mu\text{g C g}^{-1}$ in 2006/07 and $230 \mu\text{g C g}^{-1}$ in 2008/09), and Promis ($105.1 \mu\text{g C g}^{-1}$) in 2007/08. These differences were significant only in 2007/08. In not any of the three seasons C_{mic} values in the IMBA treatments differed significantly from either the NPK or control treatments. Nonetheless, several of the IMBAs resulted in lower C_{mic} values than the NPK check, but were steadily higher than the unfertilised plots.

5.3.2.2 **Microbial biomass-P**

The effect of IMBA treatments on P_{mic} at three samplings across the seasons and localities is presented in Table 5.6.

Table 5.6: Effect of IMBAs on microbial biomass-P (mg P g⁻¹) at three samplings during three production seasons at four sites

IMBAs	Bethlehem			Bothaville			Ottosdal			Potchefstroom		
	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09
4 weeks after planting												
Biozone	4.4ab	9.7abc	9.3	12.8ab	4.4ab	8.0	9.0	-4.5b	9.4	13.8ab	12.9ab	1.7ab
Gliogrow	5.7a	18.5ab	14.4	11.5ab	16.3a	14.7	4.4	38.1a	8.5	11.3abc	10.4abc	10.9a
Gromor	1.7ab	5.0abc	8.5	10.7ab	0.9ab	3.0	2.2	-0.2ab	15.4	8.7abc	7.2abc	1.0ab
Promis	4.4ab	20.0a	-3.7	13.2a	7.3ab	10.7	7.4	-9.7b	4.8	14.9a	12.9ab	2.1ab
Growmax	0.0b	-1.1c	12.3	10.3b	2.6ab	16.4	6.8	-0.8ab	-5.0	13.7ab	14.6a	10.9a
Crop care	2.0ab	9.4abc	5.0	10.5ab	8.0ab	22.5	2.2	7.3ab	12.4	3.2c	2.5c	-3.8ab
K-humate	-3.7b	-3.4c	-0.8	10.5ab	1.9ab	8.1	6.4	-11.5b	8.4	14.4a	13.8abc	5.3ab
Lanbac	2.2ab	6.8abc	2.9	12.0ab	-4.0ab	8.1	9.2	25.2ab	17.3	11.0abc	10.0abc	2.0ab
Montys	1.1ab	4.2bc	-2.2	10.6ab	1.4ab	21.7	4.6	10.2ab	13.6	7.7abc	6.7abc	2.0ab
NPK	2.7ab	13.1ab	-1.1	12.4ab	-0.5ab	23.6	15.2	13.0ab	12.3	10.0abc	9.8abc	-8.8b
Control	3.1ab	7.4ab	9.0	11.1ab	-5.0b	14.6	3.2	15.3ab	1.7	8.7abc	7.7abc	4.3ab
Mean	2.1	8.1	4.9	11.4	3.0	13.7	6.4	7.5	9.0	10.7	9.8	2.5
SEM	1.82	5.42	7.98	0.94	7.31	9.67	3.06	13.60	5.55	4.79	3.02	5.27
LSD _{T(0.05)}	5.26	15.7	23.1	2.70	21.1	27.9	8.84	39.3	16.0	9.79	8.73	15.2
Flowering stage												
Biozone	1.8	3.9	7.2ab	4.3b	8.2ab	5.7ab	8.6	10.5ab	3.7	13.2abc	18.9a	-0.9
Gliogrow	3.2	15.5	8.1ab	7.7ab	-16.8b	2.0ab	4.3	23.0ab	-6.1	6.2c	10.7abc	-10.1
Gromor	2.5	10.0	16.4a	7.1ab	-11.4ab	3.7ab	2.1	39.0a	14.9	6.0c	7.7abc	-0.2
Promis	2.4	11.5	7.4ab	7.3ab	11.7ab	1.1ab	7.1	19.5ab	2.8	17.1a	16.9ab	-1.3
Growmax	0.9	11.7	-12.7b	8.8ab	13.4ab	-8.1b	6.7	28.8ab	-7.4	16.0ab	10.3abc	-10.1
Crop care	3.4	13.6	-8.8b	6.0ab	6.5ab	5.0ab	1.8	23.1ab	9.6	6.7c	3.4c	4.6
K-humate	3.2	5.5	-9.9b	9.0ab	15.4a	11.7a	6.3	12.0ab	6.1	12.4abc	12.3abc	-4.5
Lanbac	2.8	4.6	-4.1ab	10.3a	12.8ab	10.4a	9.1	12.9ab	7.0	10.7abc	13.4abc	-1.1
Montys	2.5	1.3	-7.4ab	8.7ab	11.8ab	12.2a	4.2	29.0ab	2.8	9.1bc	7.7abc	-1.2
NPK	1.9	10.7	3.3ab	7.5ab	10.6ab	-1.1ab	14.9	11.4ab	6.4	8.6bc	10.4abc	9.6
Control	0.4	-0.6	-2.2ab	7.2ab	9.7ab	1.5ab	3.1	2.4b	2.6	10.4abc	12.9abc	-3.5
Mean	2.3	8.0	-0.2	7.6	6.5	4.0	6.2	19.2	3.8	10.6	11.3	-1.7
SEM	1.28	5.89	8.61	1.67	10.99	4.84	3.03	12.17	8.27	3.68	4.45	5.28
LSD _{T(0.05)}	3.69	17.0	24.9	4.79	31.8	14.0	8.80	35.2	23.9	7.52	12.9	15.2

Table 5.6: Continue

IMBAs	Bethlehem			Bothaville			Ottosdal			Potchefstroom		
	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09	2006/07	2007/08	2008/09
	Crop harvest											
Biozone	3.1	15.5ab	1.5ab	3.8b	9.2ab	10.2	6.4	25.8a	3.3	13.6ab	6.9abc	11.6
Gliogrow	4.5	21.6a	3.6ab	5.0ab	8.6ab	14.6	2.1	13.4abc	9.0	15.0a	4.6c	2.5
Gromor	-0.3	0.0bc	-3.5b	5.9ab	11.2ab	8.5	-0.1	20.5ab	0.7	10.4ab	6.6b	12.3
Promis	4.2	28.5a	-5.2b	3.4b	8.2ab	10.5	4.9	-8.1c	1.4	7.6abc	9.0ab	11.2
Growmax	0.6	-14.0c	16.0a	6.3ab	9.3ab	4.1	4.6	15.4abc	1.6	16.0a	18.9a	2.4
Crop care	2.4	5.2abc	7.3ab	6.1ab	14.9a	20.0	-0.4	26.1a	1.8	-1.9c	1.6c	17.1
K-humate	-0.2	-12.3c	9.7ab	6.7a	3.1b	9.9	4.2	24.5a	1.6	15.8a	15.2ab	8.0
Lanbac	2.4	9.1abc	3.8ab	4.6ab	8.3ab	15.5	7.0	16.9abc	5.6	9.5ab	6.5abc	11.4
Montys	2.0	7.1abc	3.0ab	6.0ab	10.2ab	21.7	2.0	14.9abc	7.4	8.1abc	5.6abc	11.3
NPK	2.6	15.5ab	-1.8ab	4.2ab	12.1a	25.4	12.7	-12.7c	3.4	11.1ab	9.3abc	22.1
Control	3.9	15.3ab	6.0ab	5.4ab	9.8ab	12.9	1.0	-7.1c	3.4	5.2bc	8.0abc	9.0
Mean	2.3	8.3	3.7	5.2	9.5	13.9	4.0	11.8	3.5	10.0	8.4	10.8
SEM	1.74	9.47	6.54	0.97	2.80	7.56	3.03	10.34	4.59	4.31	3.57	5.26
LSD _{T(0.05)}	5.02	27.4	18.9	2.80	8.08	21.8	8.81	29.9	13.3	8.80	10.3	15.2

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

5.3.2.2.1 **Bethlehem**

At 4-weeks, P_{mic} values ranged from -3.7 mg P g^{-1} (K-humate) to 5.7 mg P g^{-1} (Gliogrow) in 2006/07, -3.4 mg P g^{-1} (K-humate) to 20.0 mg P g^{-1} (Promis) in 2007/08, and -3.7 mg P g^{-1} (Promis) to 14.4 mg P g^{-1} (Gliogrow) in 2008/09. Some of the IMBA treatments differed significantly in 2006/07 and 2007/08. In these particular seasons, Gliogrow and Promis resulted in a substantial higher P_{mic} values than the other IMBAs. The differences between the IMBAs and either the NPK or control treatments differed not significantly in any of the three seasons. Despite this insignificance, P_{mic} immobilisation was predominant in the IMBAs compared to either NPK or control plots.

Concerning P_{mic} at flowering, mineralisation was observed irrespective of the IMBA treatment in 2006/07 and 2007/08. This was not the case in 2008/09 since P_{mic} immobilisation was predominant with several of the IMBA treatments. The values of P_{mic} ranged from 0.9 mg P g^{-1} (Growmax) to 3.4 mg P g^{-1} (Crop care) in 2006/07, 1.3 mg P g^{-1} (Montys) to 15.5 mg P g^{-1} (Gliogrow) in 2007/08, and $-12.7 \text{ mg P g}^{-1}$ (Growmax) to 16.4 mg P g^{-1} (Gromor) in 2008/09. Significant differences amongst the IMBAs were observed only in 2008/09 probably due to the higher degree of immobilisation from Growmax. Comparing to the NPK check, the IMBAs promoted higher P_{mic} mineralisation in 2006/07, but was in many instances lower in 2007/08 and 2008/09. However, the IMBA treatments realised higher P_{mic} mineralisation trends than the control in 2006/07 and 2007/08. Conversely in 2008/09, several of the IMBAs showed P_{mic} immobilisation similar to that in the unfertilised plots.

With regard to P_{mic} at crop harvest, mineralisation was recorded with several of the IMBAs in all three seasons, although P_{mic} immobilisation was depicted in few instances. The lowest and highest P_{mic} values in this regard resulted with Gromor (-0.3 mg P g^{-1}) and Gliogrow (4.5 mg P g^{-1}) in 2006/07, Growmax ($-14.0 \text{ mg P g}^{-1}$) and Promis (28.5 mg P g^{-1}) in 2007/08, and Promis (-5.2 mg P g^{-1}) and Growmax (16.0 mg P g^{-1}) in 2008/09. Significant differences amongst some of the IMBAs were observed in 2007/08 and 2008/09. However, no significant differences were found between the IMBA treatments and either the NPK or control treatments. In fact, P_{mic} in the NPK and control plots was in many cases higher than in the IMBA plots.

5.3.2.2.2 Bothaville

At 4-weeks after planting, P_{mic} mineralisation occurred across the IMBA treatments in each season. The only exception was Lanbac in 2006/07. The lowest and highest P_{mic} values resulted with Growmax (10.3 mg P g⁻¹) and Promis (13.2 mg P g⁻¹) in 2006/07, Lanbac (-4.0 mg P g⁻¹) and Gliogrow (16.3 mg P g⁻¹) in 2007/08, and Gromor (3.0 mg P g⁻¹) and Crop care (22.5 mg P g⁻¹) in 2008/09. Significant differences between some of the IMBAs were observed in 2006/07. The values of P_{mic} mineralisation in the NPK check was in many instances higher than in the IMBA plots probably due higher degree of immobilisation from some of the IMBAs. Comparing to the control, significant differences were observed with some of the IMBAs in 2007/08. Regardless of this, P_{mic} mineralisation in the control was higher than in the IMBA plots, especially in 2006/07 and 2008/09. This could be attributed to the lack of competition due to inadequacy of nutrients for soil microorganisms in the unfertilised plots.

At flowering, only Gliogrow and Gromor in 2007/08, and Growmax in 2008/09 showed P_{mic} immobilisation trends. The lowest and highest P_{mic} values coincided with Biozone (4.3 mg P g⁻¹) and Lanbac (10.3 mg P g⁻¹) in 2006/07, Gliogrow (-16.8 mg P g⁻¹) and K-humate (15.4 mg P g⁻¹) in 2007/08, and Growmax (-8.1 mg P g⁻¹) and Montys (12.2 mg P g⁻¹) in 2008/09. These differences were significant in all the three seasons. In none of the three seasons, P_{mic} values recorded in the IMBA plots were either significantly lower or higher than in the NPK or control plots. However, P_{mic} values resulted from several of the IMBAs were higher than that of the two standards, especially in 2006/07 and 2008/09.

At crop harvest, application of the IMBAs augmented P_{mic} mineralisation regardless of the season. These values ranged from 3.4 mg P g⁻¹ (Promis) to 6.7 mg P g⁻¹ (K-humate) in 2006/07, 3.1 mg P g⁻¹ (K-humate) to 14.9 mg P g⁻¹ (Crop care) in 2007/08, and 4.1 mg P g⁻¹ (Growmax) to 21.7 mg P g⁻¹ (Montys) in 2008/09. Some of the IMBAs differed significantly in 2006/07 and 2007/08. In not any of the three seasons, the P_{mic} values of the IMBA treatments differed significantly from either the NPK or control treatments. However, P_{mic} values in the NPK check was in many instances higher than in the IMBA plots, especially in 2007/08 and 2008/09 probably due to the resistance of organic based inputs to microbial decomposition. This was not the case comparing the IMBAs to the control since P_{mic} values were higher only in 2007/08.

5.3.2.2.3 **Ottosdal**

With respect to P_{mic} at 4-weeks after planting amongst the IMBAs, the lowest values resulted with Gromor (2.2 mg P g^{-1}) in 2006/07, K-humate ($-11.5 \text{ mg P g}^{-1}$) in 2007/08, and Growmax (-5.0 mg P g^{-1}) in 2008/09. However, Lanbac in 2006/07 (9.2 mg P g^{-1}) and 2008/09 (17.3 mg P g^{-1}), and Gliogrow (38.1 mg P g^{-1}) in 2007/08 coincided with the highest P_{mic} values. Significant differences were found between some of the IMBAs in 2007/08 and 2008/09. In these seasons, Gliogrow and Lanbac resulted in substantial higher P_{mic} values than the other IMBAs probably due to the beneficial microorganisms they contained as active ingredients that could have speed-up the rate of mineralisation. This was not the case with Biozone that was also used as a beneficial microorganism IMBA probably on account of differences in strains. Like with the previous two localities, P_{mic} immobilisation was more pronounced in the IMBA plots than in either the NPK or control plots, though not significantly.

At flowering, P_{mic} mineralisation was observed amongst IMBAs in all three seasons. The only exceptions were Gliogrow and Growmax in 2008/09. For each season, the lowest P_{mic} values resulted from Crop care (1.8 mg P g^{-1}) in 2006/07, Biozone (10.5 mg P g^{-1}) in 2007/08, and Growmax (-8.4 mg P g^{-1}) in 2008/09. However, Lanbac (9.1 mg P g^{-1}) in 2006/07 and Gromor in 2007/08 (39.0 mg P g^{-1}) and 2008/09 (14.9 mg P g^{-1}) had the highest P_{mic} values. No significant differences were found amongst the IMBAs and also between them and the NPK check in each season. With respect to the control, Gromor was the only IMBA that gave a significantly higher P_{mic} value viz. 2007/08. However, P_{mic} mineralisation in the IMBA plots were in many instances higher than in the control, although there was P_{mic} immobilisation trends amongst few of the IMBAs.

For each season at crop harvest, P_{mic} mineralisation was predominant amongst several of the IMBA treatments, although P_{mic} immobilisation was observed. The P_{mic} values ranged from -0.4 mg P g^{-1} (K-humate) to 7.0 mg P g^{-1} (Lanbac) in 2006/07, -8.1 mg P g^{-1} (Promis) to 26.1 mg P g^{-1} (Crop care) in 2007/08, and 0.7 mg P g^{-1} (Gromor) to 9.0 mg P g^{-1} (Gliogrow) in 2008/09. Significant differences amongst the IMBAs and between them and either the NPK or control treatments were observed only in 2007/08. However, P_{mic} values in the NPK check were in many instances higher than in the IMBA plots, especially in 2006/07 and 2008/09.

5.3.2.2.4 Potchefstroom

Mineralisation of P_{mic} was observed at 4-weeks after planting regardless of IMBA treatment in all three seasons. The highest P_{mic} values resulted with Promis (14.9 mg P g⁻¹) in 2006/07, Growmax in 2007/08 (14.6 mg P g⁻¹) and 2008/09 (10.9 mg P g⁻¹). Crop care had in each season the lowest P_{mic} values with 3.2, 2.5 and -3.8 mg P g⁻¹ in 2006/07, 2007/08 and 2008/09, respectively. The differences amongst some of the IMBAs were significant in all three seasons. Comparing to the NPK check, Gliogrow and Growmax resulted in significantly higher P_{mic} mineralisation values in 2008/09. This could be attributed to immobilisation in the NPK plots. In all three seasons, P_{mic} values in the unfertilised control were in many instances lower than in the IMBA treatments.

At flowering, P_{mic} mineralisation was predominant regardless of the IMBA treatment in 2006/07 and 2007/08. This was not the case in 2008/09 when P_{mic} immobilisation was predominant in all the IMBA plots, except for Crop care. The values varied between 6.0 mg P g⁻¹ (Gromor) to 17.1 mg P g⁻¹ (Promis) in 2006/07, 3.4 mg P g⁻¹ (Crop care) to 18.9 mg P g⁻¹ (Biozone) in 2007/08, and -10.1 mg P g⁻¹ (Growmax) to -0.2 mg P g⁻¹ (Gromor) in 2008/09. These differences were significant in 2006/07 and 2007/08. Comparing to the NPK check, only Promis gave in 2006/07 a significant higher P_{mic} . The differences between the IMBAs and control in each season were not significant.

Concerning P_{mic} at crop harvest, the values ranged from -1.9 mg P g⁻¹ (Crop care) to 15.8 mg P g⁻¹ (K-humate) in 2006/07, 1.6 mg P g⁻¹ (Crop care) to 18.9 mg P g⁻¹ (Growmax) in 2007/08, and 2.4 mg P g⁻¹ (Growmax) to 17.1 mg P g⁻¹ (Crop care) in 2008/09. These differences were significant in 2006/07 and 2007/08. In none of the three seasons P_{mic} values in the IMBA treatments differed significantly from the NPK check. In fact the NPK treatment resulted in higher P_{mic} values, especially in 2007/08 and 2008/09. This could be ascribed to the relatively low P content from several of the IMBAs to warrant availability in the soil throughout the growing season. Comparing to the control, only K-humate gave in 2006/07 a significantly higher P_{mic} fluxes.

5.4 Summary and conclusions

The study on chemical and microbial biomass properties was undertaken over three growing seasons at four localities, resulting in 12 response cases per IMBA treatment. The performance of each IMBA for these 12 cases was compared with the relevant

NPK treatment to obtain the frequency of significant increases as presented in Table 5.7.

Table 5.7: Frequency of occurrence of significant increases in soil chemical and microbial biomass properties following IMBAs application in comparison with NPK treatment over the three production seasons at four sites

IMBAs	Chemical properties				Microbial biomass properties					
	pH	Organic	Mineral	Extractable	Biomass-C			Biomass-P		
		C	N	P	4-	Flowering	Crop	4-	Flowering	Crop
					weeks		harvest	weeks		harvest
Biozone	1	1	4	0	0	0	0	0	0	1
Gliogrow	7	3	3	1	0	1	0	1	0	0
Gromor	5	1	0	0	0	0	0	0	0	0
Promis	2	0	0	2	1	0	0	0	1	0
Growmax	2	1	1	0	1	0	0	1	0	0
Crop care	1	4	3	2	0	0	0	0	0	1
K-humate	2	2	4	0	0	0	1	0	0	1
Lanbac	1	2	2	1	0	0	0	0	0	0
Montys	1	1	2	0	0	1	1	0	0	0

Generally, application of virtually all the IMBA treatments resulted in significant pH increases compared to the NPK standard. These significant increases were more frequently on the sandy soil of Bothaville ecotope and the clayey soil of Potchefstroom ecotope. In fact none of the IMBA treatments gave significantly higher pH values than the NPK check in the sandy soils of the Ottosdal ecotope. However, of all the IMBAs, Gromor and Gliogrow were the most effective as they performed significantly better than the NPK treatment in five and seven cases, for pH respectively. The frequency of significant increases amongst the different IMBAs in relation to the NPK check on organic C, mineral N and extractable P were lower with four cases of significant increases being the maximum. Concerning microbial biomass properties, the IMBAs showed only sporadic a significant increase in either biomass-C or biomass-P compared to the NPK check.

Generally, application of Gliogrow, Gromor and Growmax at Bethlehem and Potchefstroom ecotopes and also Crop care and Lanbac at Bothaville ecotype gave

consistently higher pH values (Table 5.1) than the NPK standard. The various IMBA treatments had an inconsequential effect at Ottosdal ecotype. Given that several of the IMBA treatments had an alkaline pH range, post-harvest pH values were in some instances similar to pre-plant pH values. However, in most instances a marked decrease in pH levels resulted from the IMBA treatments. This could be attributed to microbial decomposition, and thus the release of organic acids which neutralised the alkalinity of these materials (Fan *et al.*, 2007). On the other hand, the decrease in pH levels could also be ascribed to the NPK fertiliser that the IMBAs contain in various amounts. The ammonium released from either the inorganic or organic fraction of IMBAs enhances acidification when nitrified (Ismail *et al.*, 1994 cited by Belay *et al.*, 2002). Similar results were reported by Somani and Totawat (1996) on organic amendments applied in alkaline soils.

The lower pH recorded in 2007/08 than in either 2006/07 or 2008/09 may be attributed to higher rainfall in this particular season, favouring microbial activity and cation leaching. Wong *et al.* (1992) indicated that leaching of basic cations like calcium, magnesium, potassium and sodium leads to acidic soils. The pH levels also tended to decrease in fields previously planted to legumes than to other crops. 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 & van Diest, 1981). The high pH values at Bothaville therefore indicate that the soil was saturated to a larger extent with basic cations (Triantafilis *et al.*, 2003).

The decrease in organic C (Table 5.2) in 2007/08 may be attributed to the higher crop yield obtained in this particular season. As a result decomposition of organic C was enhanced to fulfil in the nutrient demand of the crop. The rate of C addition was insufficient to maintain organic C levels (Fan *et al.*, 2007). For example, Ayoola (2006) found that organic C levels decreased by 17, 44, 47 and 59% with organic fertiliser, inorganic + organic fertiliser, no fertiliser and inorganic fertiliser, respectively. This shows that incorporation of organic fertiliser into the soil could be an efficient way of maintaining a desired soil organic matter level (Fan *et al.*, 2007). Long-term addition of manure resulted in higher total organic C, total N and extractable P levels in soil. However, long-term NPK application resulted in lower levels of organic C and basic

cations that cause eventually a decrease in pH (Belay *et al.*, 2002). Other studies demonstrated that 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 & Montemurro, 2010).

The lower mineral N (Table 5.3) recorded in 2007/08 across the ecotopes could be related to the higher grain yields obtained in this season. Okwuagwu *et al.* (2003) found that application of inorganic and organic fertilisers resulted in lower mineral N due to crop uptake. Nitrogen immobilisation by microorganisms and loss through volatilisation might have also contributed to the low values (Defoer *et al.*, 2000). The higher mineral N at Potchefstroom could be on account of the site's high clay content that is able to retain significant quantities of the plant nutrient (Diepen & van der Wall, 1996). Increase of mineral N that coincided with the IMBAs used as growth boosters is possibly due to synergy (Boateng *et al.*, 2006). These results concur with previous findings that complementary application of inorganic and organic materials encourages N build-up in the soil (Murwira & Kirchmann, 1993) and increase the absorption of N, P and K in plant tissue (Bokhtiar & Sakurai, 2005).

A marked decrease in extractable P (Table 5.4) in the second and third season of IMBAs application may be attributed to their effects on pH ranges across the ecotopes (Ismail *et al.*, 1994 cited by Belay *et al.*, 2002). Phosphorus is never readily soluble in soil, but it is most plant available at a pH range of 6 to 7 (UNSW, 2007). If the pH is less than 5, availability of P is very low due to precipitation with either Fe or Al (UNSW, 2007). Post-harvest P in the various IMBA treatments was in many cases higher than either in the NPK or unfertilised plots. A report of Okwuagwu *et al.* (2003) indicated higher available P in plots treated with cattle manure and NPK + cattle manure mixture as a result of the long-term residual effect. Chen (2006) indicated that the N/P ratio of organic fertiliser usually is significantly lower than the N/P uptake ratio of crops thus, organic fertiliser application based on N supply typically results in P addition in excess of the crop's need that manifested as excessive residual P as obtained in this study.

The predominant C_{mic} immobilisation (Table 5.5) 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). Trials in this

study were planted each season in November, which is typically wet. The marked decrease in C_{mic} across seasons and localities at 4-weeks after planting could further be associated to wet soil conditions (Ponnamperuma, 1972) and/or competition for nutrients by crop roots and microorganisms (Bhattacharyya *et al.*, 2003). In comparison to other localities, the higher C_{mic} mineralisation at Potchefstroom could be attributed to the site's higher clay content that coincide with high nutrient levels (van Veen *et al.*, 1985). Hassink (1994) indicated that the proportions of both organic C and N in microbial biomass were higher in fine-textured soils than in coarse-textured soils. The increased C_{mic} mineralisation at flowering and crop harvest is attributed *inter alia* to drier soil conditions with higher temperatures. A report of Neff and Hooper (2002) asserted that C_{mic} decomposition increases with temperature in both laboratory and field settings raising the possibility of significant C release. This could stimulate mineralisation (Sakamoto & Oba, 1991; Freeman *et al.*, 1996) on drier environments. Application of organic amendments to the soil not only increases organic C but also has a series of effects on microbial proliferation and activity (Tejada *et al.*, 2006; Hu & Cao, 2007).

Application of the IMBA treatments often augmented P_{mic} (Table 5.6) mineralisation at all three samplings regardless of the treatment, although immobilisation trends resulted in few instances. However, values obtained in this study were relatively lower than ranges reported by Chen *et al.* (2004) in a black soil fertilised with a mixture of farm manure and inorganic fertiliser or sole manure. The consistently lower P_{mic} mineralisation during flowering at Bethlehem and Potchefstroom ecotopes could be on account of waterlogged conditions in 2008/09 since these sites were situated in higher summer rainfall regions. Conversely, Zhao *et al.* (2009) found that there was significant adaptation of microbial biomass-C and -P in soils subjected to waterlogging under field conditions. Similar trends were reported by Rubio *et al.* (1997).

In this study, few IMBAs gave marginal higher P_{mic} than the NPK check across the samplings, although not always significant, but consistently exerted higher values than the untreated control at flowering and crop harvest. This is in agreement with observations by Chen (2006) who reported that P_{mic} from treatments with farmyard manure + NPK and farmyard manure alone was highest at reproductive growth stage and that from treatments with NPK and control was highest at an earlier growth stage. Steward and Tiessen (1987) indicated that immobilisation, mineralisation and

redistribution of P depends on physico-chemical properties such as P sorption by colloidal surfaces, as much as it depends on microbial or plant uptake of P.

The application of IMBAs like Gliogrow and Gromor had a profound positive effect on pH across seasons and localities compared to the NPK check. All the IMBAs used as total replacement of conventional inorganic NPK fertiliser generally raised pH to between 6.0 and 7.0 which was not the case in many instances with the other IMBAs that coincided with either optimum or reduced rates of inorganic NPK fertiliser. The use of Gliogrow and Crop care compared to the other IMBAs augmented organic C while mineral N was consistently higher than the NPK check following application of Biozone, Gliogrow, Crop care and K-humate. Nonetheless, application of Promis did not have a significant effect on organic C and mineral N, and Gromor on mineral N. The IMBA treatments resulted in many cases with lower extractable P than the NPK check probably due to the lower P content of the products and the resistance of these amendments to microbial decomposition. For example, only Promis and Crop care showed two cases of significant increases across the seasons and localities.

The IMBA treatments promoted higher C_{mic} immobilisation at 4-weeks after planting, but C_{mic} mineralisation was predominant at flowering and crop harvest, although it tended to decline at crop harvest. Application of Promis and Growmax at 4-weeks after planting, Gliogrow and Montys at flowering and also K-humate and Montys at crop harvest resulted in significant higher biomass-C mineralisation compared to the NPK check in a few instances which was not the case with the other IMBAs. Application of the IMBAs coincided also with higher P_{mic} values, but tended to be lower in many instances than the NPK check at all three samplings. More so, Gromor, Lanbac and Montys applications did not have a significant influence on microbial biomass-P across the three samplings. However, immobilisation was depicted in few instances, especially in the sandy soils of Bethlehem ecotope. The IMBA treatments resulted in many instances with significantly higher pH, organic C, mineral N and extractable P contents than in the unfertilised control plots. Moreover, the IMBA treatments had consistently the highest degree of immobilisation for both C_{mic} and P_{mic} compared to the unfertilised plots probably due to lower C inputs from root residue in these plots.

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CHAPTER 6

ASSESSMENT OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS ON PHENOLOGICAL GROWTH OF MAIZE UNDER DIFFERENT ECOTOPES

6.1 Introduction

Growth analysis is one of the approaches used to examine factors that influence plant development and crop yield. It involves the measurement of plant growth in terms of net assimilation rate, leaf area and crop growth rates (Barnes & Beard, 1992; Nath & Moore, 1992). The diagnosis of growth-limiting factors and the forecasting of grain yield through growth analyses should significantly improve site-specific farming, while at the same time, the method provides vital information on features of growth at its critical times (Berzsenyi & Dang, 2007; Aliu *et al.*, 2010). Plant growth however requires that nutrients be present in the soil in adequate amount and in suitable forms for uptake (du Preez & Claassens, 1999; Mills & Fey, 2003) to ensure efficient crop production.

Maize plants respond very well to different rates of N fertiliser that could consequently improve plant growth, yield and protein contents of grains (Muhammad *et al.*, 2000). Nitrogen is the nutrient that is most important for maize production as it affects biomass production by influencing leaf area development and also the photosynthetic efficiency (Muchow, 1988). The measurement of leaf area index (LAI) is critical to understanding many aspects of crop development, growth and management, and it has been recognised as a key variable in agricultural modelling (Bakhtiar *et al.*, 2009). Nitrogen deficiency delays both vegetative and reproductive phenological development (Uhart & Andrade, 1995). Earlier report showed maize biomass production to increase linearly with N application up to 200 kg N ha⁻¹ (O'Leary & Rehm, 1990).

The quickest approach to supply soil with nutrients is through conventional inorganic fertiliser application (Tisdale *et al.*, 1990). In fact organic products like farmyard manure have been used to achieve increased crop production, although pure organic farming can rarely meet increasing demand for nutrient supply since sufficient quantity of organic fertilisers are not always available (Hussain *et al.*, 1999). Alternative nutrient supply such as the integration of effective microorganisms inoculums with inorganic and/or organic fertiliser had been reported (Shah *et al.*, 2001). The enrichment of

farmyard manure with N and P fertiliser to improve their quality has been studied (Tolessa & Friesen, 2001). Yet, there are scanty published reports on the effect of the use of enriched organic materials with beneficial microorganism and humic acids on maize growth and development.

In South Africa, different organic-based fertiliser materials are being manufactured in chemical/fertiliser industries. Recommendation on the use of the biological-enriched amendments herein refers to as industrially manufactured biological amendments (IMBAs) sometimes involve partial and/or total replacement of conventional NPK. These products have been promoted for farmers' use without sufficient scientific agronomic validation on their effectiveness on growth and development of maize (Baloyi *et al.*, 2010). Hence, this study was conducted to evaluate the effects of the use of IMBAs on phenological growth characteristics of maize.

6.2 Experimental procedure

The detailed procedure and description of this trial were duly given in Chapter 3, nevertheless, a concise description is provided herein. The trial assessed nine IMBAs at rates recommended by either the product manufacturers or suppliers during three production seasons at four sites. Recommended rates of conventional inorganic NPK fertiliser at each site and the unamended control treatments were included as standard check. The inorganic NPK fertiliser treatment was applied in the form of limestone ammonium nitrate, superphosphate and potassium chloride, respectively. A randomised complete block design was used and each treatment replicated four times. Maize phenological growth parameters determined were plant height, biomass yield and leaf area index at the 9th leaf and silking growth stages. The phenological growth data obtained were subjected to analyses of variance using GenStat Release 14. Differences in treatment means were separated using Tukey's honestly significant difference post-hoc test at 5% probability level.

6.3 Results and discussion

6.3.1 Plant height

The plant heights measured during the 9th leaf and silking growth stages in the IMBA treatments across the seasons and localities are presented in Table 6.1.

Table 6.1: Plant height (cm) as affected by IMBAs at two growth stages during three production seasons at four sites

IMBAs	Bethlehem								Bothaville							
	9 th leaf growth stage				Silking growth stage				9 th leaf growth stage				Silking growth stage			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	96.0ab	118.1ab	108.7ab	107.6	175.9	184.2a	185.7	181.9	95.9a	121.9ab	141.7a	119.8	195.0	219.8a	201.0	205.3
Gliogrow	82.7ab	110.2ab	97.3ab	96.7	178.9	183.8a	194.7	185.8	94.1ab	131.4ab	120.9c	115.5	178.8	223.8a	206.7	203.1
Gromor	96.3ab	87.2b	109.8ab	97.8	181.5	183.0a	193.6	186.0	91.6ab	97.2c	129.9bc	106.2	172.5	194.9bc	204.8	190.7
Promis	75.9b	107.1ab	116.2a	99.7	170.5	191.8a	193.4	185.2	92.7ab	117.1b	131.5ab	113.7	186.3	209.4ab	221.3	205.6
Growmax	89.9ab	108.0ab	102.3ab	100.1	173.6	199.2a	182.0	184.9	94.8a	118.0b	128.3bc	113.7	186.3	205.3abc	213.3	201.6
Crop care	100.4ab	118.1ab	102.1ab	106.9	183.3	182.3ab	183.2	182.9	93.7ab	134.4ab	137.7ab	121.9	193.8	218.1ab	216.6	209.5
K-humate	104.1a	126.1a	99.1ab	109.8	180.0	186.6a	177.4	181.3	95.0a	136.1a	134.2ab	121.7	185.0	207.5abc	207.7	200.1
Lanbac	83.9ab	121.4a	112.2ab	105.8	179.1	189.7a	198.6	189.1	97.7a	120.2ab	136.1ab	118.0	176.3	214.2ab	219.4	203.3
Montys	88.9ab	105.1ab	86.4b	93.5	182.6	201.0a	179.5	187.7	92.6ab	115.1bc	135.8ab	114.5	186.3	210.0ab	210.8	202.4
NPK	106.1a	116.6ab	106.7ab	109.8	171.8	187.0ab	186.5	181.7	92.0ab	126.6ab	134.6ab	117.7	180.0	212.1ab	207.4	199.8
Control	91.1ab	88.6b	103.8ab	94.5	167.3	163.0b	184.6	171.6	86.3b	98.6c	132.4ab	105.7	171.3	185.7c	203.5	186.8
Mean	92.3	109.7	104.1	102.0	176.8	186.5	187.2	183.5	93.3	119.7	133.0	115.3	182.8	209.2	210.2	200.7
SEM	7.30	9.11	11.1		10.3	9.64	10.8		4.06	8.82	5.48		11.7	11.5	16.1	
CV (%)	11.2	11.8	15.1		8.2	7.3	8.2		6.2	10.4	5.8		9.0	7.8	10.9	
LSD _{T(0.05)}	14.9	18.6	22.6		20.9	19.7	22.1		8.29	18.0	11.2		23.8	23.4	32.9	
	Ottosdal								Potchefstroom							
Biozone	113.1b	124.6abc	145.4a	127.7	201.3	226.5ab	236.8	221.5	115.0b	123.6ab	137.8	125.5	210.7a	238.3a	242.1	230.4
Gliogrow	152.0a	103.9d	129.2b	128.4	211.3	202.5bc	237.0	216.9	143.4ab	83.5c	132.4	119.8	187.0ab	238.6a	223.2	216.2
Gromor	155.0a	114.1bcd	143.4a	137.5	212.5	205.0bc	229.5	215.7	156.9a	104.1b	137.6	132.9	175.2bc	238.8a	231.7	215.2
Promis	128.1ab	131.2ab	146.7a	135.3	210.0	223.1ab	251.0	228.0	116.1ab	128.5a	135.5	126.7	209.3a	245.4a	231.7	228.8
Growmax	144.4ab	139.1a	149.4a	144.3	196.3	210.6bc	236.4	214.4	143.6ab	120.2ab	128.9	130.9	191.9ab	251.5a	232.4	225.2
Crop care	133.4ab	126.7abc	149.3a	136.5	205.0	231.7a	234.2	223.6	126.2ab	108.9ab	134.0	123.0	190.7abc	250.2a	222.2	221.0
K-humate	161.8a	138.3a	152.4a	150.8	213.8	225.8ab	230.4	223.3	156.1a	121.8ab	129.0	135.6	189.4abc	250.6a	220.5	220.1
Lanbac	162.5a	141.3a	146.3a	150.0	202.5	224.2ab	237.6	221.4	162.4a	130.6a	138.6	143.8	197.0ab	249.9a	234.0	226.9
Montys	138.1ab	134.5a	149.9a	140.8	215.0	222.9ab	235.2	224.4	140.6ab	132.4a	137.4	136.8	211.8a	248.2a	237.2	232.4
NPK	135.2ab	137.1a	148.9a	140.4	213.8	219.0ab	246.5	226.4	141.6ab	122.3ab	132.7	132.2	212.5a	240.8a	230.1	227.8
Control	136.1ab	108.9cd	141.4a	128.8	201.3	201.6c	229.4	210.8	114.3b	112.9ab	129.4	118.8	166.5c	222.2b	215.5	201.4
Mean	141.8	127.2	145.7	138.2	207.5	217.5	236.7	220.6	137.8	117.1	133.9	129.6	194.7	243.1	229.1	222.3
SEM	17.1	9.13	5.78		10.3	8.22	11.4		19.5	9.53	5.66		11.9	7.80	13.2	
CV (%)	17.0	10.2	5.6		7.0	5.4	6.8		20.0	11.5	6.0		8.6	4.5	8.1	
LSD _{T(0.05)}	34.9	18.7	11.8		21.0	16.8	23.4		39.9	19.5	11.6		24.3	15.9	26.9	

Means with the same letters within the column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

6.3.1.1 **Bethlehem**

At the 9th leaf stage, plant height ranged from 75.9 cm with Promis to 104.1 cm with K-humate in 2006/07, 87.2 cm with Gromor to 126.1 cm with K-humate in 2007/08, and 97.3 cm with Gliogrow to 116.2 cm with Promis in 2008/09. The differences in the mean plant height among the IMBAs differed significantly in all three seasons. Generally, K-humate gave significantly taller plants than those from Promis in 2006/07 and Gromor in 2007/08. However, in 2008/09, plants from treatment with Montys were significantly shorter than those from Promis. Despite the differences in plant height among some of the IMBAs, none of them performed significantly better than the NPK treatment. Similarly in 2006/07, NPK treatment gave significantly taller plants than Gliogrow, Promis, Growmax, Lanbac and Montys. Similar observations were only applicable to Gromor in 2007/08 and 2008/09. Plant height from plots treated with Gliogrow and Montys in 2006/07 and 2008/09 and also Promis and Lanbac in 2006/07 were shorter than those in the control plots, though not significantly. These were however significantly shorter compared to those from Growmax and Montys plots in 2007/08.

The IMBAs had inconsequential effects on plant height at the silking stage. Plant height from plots in which Crop care, Montys and Lanbac was applied gave the tallest plants though not significantly among all the other IMBAs in 2006/07, 2007/08 and 2008/09, respectively. Likewise, none of the IMBAs performed either significantly better or poorer than the NPK treatment. Nearly all the IMBAs gave taller plants relative to the control treatment in each season, but differed significantly only in 2007/08 following application with Montys and Growmax treatments.

6.3.1.2 **Bothaville**

The shortest and tallest plants during the 9th leaf stage were found respectively from plots treated with Gromor and Lanbac in 2006/07, Gromor and K-humate in 2007/08, and Gliogrow and Crop care in 2008/09. None of the IMBAs differed significantly from one another and to the NPK treatment in 2006/07, but the differences in plant height amongst some of the IMBAs were significant in 2007/08 and 2008/09. For both seasons, Biozone, Crop care, K-humate and Lanbac treatments resulted in the tallest plants with no significant differences among them. Plants of the same magnitude were observed in 2008/09 with Gliogrow, Promis and Montys. In fact plant height recorded with Gromor in 2007/08 and Gliogrow in 2008/09 was significantly shorter than the NPK

check. At this stage, only Gromor in 2006/07 and Gliogrow in 2007/08 performed poorer though not significantly than the control treatment. However, plant height from Gliogrow, K-humate and Lanbac treatments in 2006/07 and Biozone in 2007/08 was significantly taller than those in the control plots.

The ranges of plant height at the silking stage were from 172.5 cm with Gromor to 193.8 cm with Crop care in 2006/07, 194.9 cm with Gromor to 223.8 cm with Gliogrow in 2007/08, and 201.0 cm with Biozone to 221.3 with Promis in 2008/09. These differences differed significantly only in 2007/08 as shown in Table 6.1. Generally, plants from Biozone and Gliogrow treatments were either significantly shorter or taller than the NPK treatment in any of the three seasons. All the IMBAs recorded taller plants though not significantly than the height of plants in the control in every season.

6.3.1.3 **Ottosdal**

The application of IMBAs at the 9th leaf stage resulted in the tallest plants from plots in which Lanbac was applied in 2006/07 (162.5 cm) and 2007/08 (141.3 cm), and K-humate (152.4 cm) in 2008/09, while stunted plants resulted with Biozone (113.1 cm) in 2006/07, and Gliogrow in 2007/08 (103.9 cm) and 2008/09 (129.2 cm). The differences in plant height among some of the IMBAs differed significantly in all three seasons. This can be attributed to the poor performance of Biozone in 2006/07, Gliogrow and Gromor in 2007/08, and Gliogrow in 2008/09. In comparison with the NPK check, none of the IMBAs recorded significantly taller plants during the three seasons. A similar observation was obtained with Gliogrow in 2008/09. Plants recorded following application of Lanbac in 2007/08 and Growmax, Crop care, K-humate and Montys in 2008/09 were significantly taller relative to those in the unfertilised plots.

At silking stage, significant differences amongst the IMBAs manifested only in 2007/08 when Crop care resulted in significantly taller plants than Gromor. None of the IMBA treatments gave either significantly shorter or taller plants compared to those in the NPK treated plots. In fact plants obtained from virtually all the IMBAs were consistently taller though not significantly in 2008/09 than the NPK check. However, plant height varied between 196.3 cm from Growmax and 215.0 from Montys treatments in 2006/07, 202.5 cm from Gliogrow and 231.7 cm from Crop care treatments in 2007/08, and 229.5 cm from Gromor and 251.0 cm from Promis treatments in 2008/09.

6.3.1.4 **Potchefstroom**

At the 9th leaf stage, Lanbac in 2006/07, Montys in 2007/08, and Biozone in 2008/09 gave the tallest plants in every season. The shortest plants were recorded with Biozone, Gliogrow and Growmax in 2006/07, 2007/08 and 2008/09, respectively. Some significant differences amongst the IMBAs were found only in 2006/07 and 2007/08. None of the IMBAs gave plants that were either significantly taller or shorter than either the NPK or control plots in any of the three seasons. In fact plants from plots treated with Gliogrow were significantly shorter than those in the NPK treatment in 2006/07.

None of the IMBAs at silking stage performed either significantly better or poorer than the NPK treatment in any of the three seasons. From the IMBA treatments, shortest plants were recorded following application of Gromor (175.2 cm), Biozone (238.3 cm) and K-humate (220.5 cm). The tallest plants were recorded with Montys (211.8 cm), Growmax (251.5 cm) and Biozone (242.1 cm) in 2006/07, 2007/08 and 2008/09, respectively. These differences in plant height amongst some of the IMBAs were significant only in 2007/08. Similarly, plants from plots in which the IMBA treatments were applied gave consistently taller plants than those in the control treatment with significant differences obtained amongst them in 2007/08 and 2008/09.

6.3.2 **Biomass**

The biomass yields recorded during the 9th leaf and silking growth stages in the IMBA treatments across the seasons and localities are given in Table 6.2.

6.3.2.1 **Bethlehem**

Biomass yield recorded among the IMBA treatments varied greatly in any of the three seasons at the 9th leaf stage. The biomass produced in 2006/07 was reduced in the range from 3% with Biozone to 109% with Promis compared to K-humate. Similarly in 2007/08, biomass from plots treated with Gromor decreased in the range from 10% with Crop care to 243% with Promis compared to K-humate, while it was marginally reduced in the range from a percent with Growmax to 46% with Gromor compared to Lanbac in 2008/09. These differences were significant only in 2007/08. None of the IMBAs performed significantly better than the NPK treatment in any of the three seasons. However in 2007/08, biomass yield from plots in which Crop care and K-humate were applied increased substantially compared to the NPK check. As in 2006/07, Gliogrow,

Gromor and K-humate, and Promis in 2008/09 performed significantly poorer than those in the NPK treatment. Likewise, nearly all the IMBAs gave significantly higher plant biomass in 2006/07 compared to the control. These observations were only applicable to treatments with K-humate in 2007/08 and with Gliogrow and Growmax in 2008/09.

From the IMBA treatments at silking stage, the lowest and highest biomass was recorded from plots treated with K-humate (2419 kg ha⁻¹) and Lanbac (3675 kg ha⁻¹) in 2006/07, Gromor (2564 kg ha⁻¹) and K-humate (3323 kg ha⁻¹) in 2007/08, and Growmax (2629 kg ha⁻¹) and Lanbac (3822 kg ha⁻¹) in 2008/09, though not significantly. Significant differences amongst some of the IMBAs were observed in 2007/08 and 2008/09. Plant biomass from the IMBAs was neither significantly increased nor reduced than the NPK check in all three seasons. In fact biomass from plots treated with Lanbac was higher in all the three seasons relative to those in the NPK treated plots, though not significantly. Plant biomass in plots treated with nearly all the IMBA treatments increased significantly relative to those in the control plots in any of the three seasons.

6.3.2.2 Bothaville

Plant biomass yield recorded at the 9th leaf stage varied greatly among the IMBAs, particularly in the 2006/07. Biomass yield increased in the range of 53% with Promis to 137% with K-humate than Gromor. In 2007/08, plant biomass with Promis and Gromor increased by 10% and 41%, respectively compared to those from Biozone. Similarly in 2008/09, Promis showed a marginally plant biomass increase of 1.3% than Gliogrow, while it increased by 46% from Growmax plots. These differences in plant biomass amongst the IMBAs were significant only in 2006/07. Despite biomass recorded from some of the IMBAs was consistently higher in 2006/07 and 2007/08, none of them gave either significantly increased or reduced biomass than the NPK check in any of the three seasons. In fact biomass with K-humate application was higher though not significantly than those in the NPK treatment in every season. Equally, none of the IMBAs gave in each season lower biomass yield than the control plots, except for Gromor in 2007/08. Nearly all the IMBAs gave significantly higher biomass yield in 2006/07. These observations were only applicable to K-humate in 2007/08 and to Gliogrow and Growmax in 2008/09.

Table 6.2: Effect of IMBAs on maize biomass yield (kg ha⁻¹) at two growth stages during three production seasons at four sites

IMBAs	Bethlehem								Bothaville							
	9 th leaf growth stage				Silking growth stage				9 th leaf growth stage				Silking growth stage			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	720a	475abc	1099ab	765	3402ab	2635ab	3390a	3142	644ab	646ab	1468ab	919	2360ab	3806ab	3446a	3204
Gliogrow	533ab	408abc	839b	593	3393ab	2604ab	3300ab	3099	683ab	815a	1213ab	904	2407a	3625ab	3301a	3111
Gromor	477ab	193c	836b	502	3164ab	2564b	3608a	3112	343c	911a	1272ab	842	2191ab	2394bc	3249a	2611
Promis	355b	373abc	1116ab	615	3562a	3214ab	3293ab	3356	523abc	713ab	1229ab	822	1903ab	3091bc	3472a	2822
Growmax	512ab	396abc	1209ab	706	2794ab	3076ab	2629bc	2833	546abc	838a	1771a	1052	2132ab	3417bc	3677a	3075
Crop care	603ab	602ab	998ab	734	2723ab	3128ab	3300ab	3050	734ab	824a	1660ab	1072	2433a	3959ab	3411a	3268
K-humate	742a	663a	887b	764	2419ab	3323a	3506a	3083	813a	844a	1414ab	1023	2121ab	3957ab	3501a	3193
Lanbac	537ab	533ab	1217ab	762	3675a	3236ab	3822a	3578	558abc	796a	1530ab	961	2736a	3791ab	3248a	3259
Montys	532ab	470abc	1119ab	707	2906ab	2901ab	3208ab	3005	620abc	900a	1349ab	956	2031ab	3321b	3470a	2940
NPK	771a	584ab	1517a	957	3294ab	3033ab	3302ab	3210	734ab	629ab	1217ab	860	1765b	4517a	3699a	3327
Control	334b	345bc	799b	493	3260b	1583c	2437c	2126	495bc	404b	1098b	666	1599b	1766c	2269b	1878
Mean	556	458	1058	691	3063	2845	3254	3054	608	756	1384	916	2152	3422	3340	2972
SEM	161.0	131.1	294.2		564.5	356.9	361.9		139.1	179.4	324.1		297.7	531.6	218.9	
CV (%)	40.9	42.6	39.3		26.1	17.7	15.7		32.3	33.6	33.1		19.7	22.0	9.3	
LSD _{T(0.05)}	329	282	601		1153	729	739		284	366	662		608.1	1086	447	
					Ottosdal				Potchefstroom							
Biozone	1060ab	1095ab	1506ab	1220	3952a	3794ab	3604ab	3783	1012	1197ab	1668a	1292	3330a	3568a	4122ab	3673
Gliogrow	1070ab	776c	1277ab	1041	3271abc	3232ab	3529ab	3344	873	1149ab	1595a	1205	2991ab	3472ab	3613ab	3359
Gromor	1124ab	743c	1479ab	1115	2745bc	3140b	4028a	3304	787	1407ab	1149ab	1114	3078ab	2934ab	4325a	3446
Promis	1158ab	1030abc	1214ab	1134	3189abc	4053a	3258abc	3500	877	996ab	1492ab	1122	3158a	3931a	3704ab	3598
Growmax	1119ab	1177a	1618a	1305	3709a	4084a	3431bc	3741	794	1344ab	1300ab	1146	3149a	3225ab	3882ab	3419
Crop care	1101ab	1082ab	1351ab	1178	3266abc	3914ab	3705ab	3628	792	1145ab	1270ab	1069	3340a	3315ab	4060ab	3572
K-humate	1350a	1023abc	1340ab	1238	3921a	3865ab	2905bc	3564	889	1242ab	1365ab	1165	3378a	3547a	3305b	3410
Lanbac	1103ab	1197a	1166ab	1155	3674ab	4030a	3457abc	3720	931	852ab	1688a	1157	3495a	3717a	3745ab	3652
Montys	1211ab	947abc	1458ab	1205	2929bc	4045a	3602ab	3525	870	1261ab	1853a	1328	3197a	3872a	3842ab	3637
NPK	1074ab	1121ab	1126ab	1107	3301abc	4069a	3752ab	3707	750	1527a	1536a	1271	3437a	3823a	3809ab	3690
Control	876b	836bc	783b	831	2390c	2222c	2884c	2498	729	846b	971b	849	2570b	2555b	2371c	2499
Mean	1113	1002	1302	1139	3304	3677	3469	3483	846	1179	1444	1156	3193	3451	3707	3450
SEM	167.8	128.5	367.8		456.2	407.0	284.2		124.7	319.8	263.4		281.5	465.6	366.5	
CV (%)	21.3	18.1	40.0		19.5	15.7	11.6		20.9	38.4	25.8		12.5	19.1	14.0	
LSD _{T(0.05)}	343	263	751		932	831	580		255	653	538		575	951	748	

Means with the same letters within the column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

The differences in biomass yield recorded among the IMBA treatments were not significant at silking stage in the three seasons. Nonetheless, biomass yield increased by 44% from Lanbac compared to Promis in 2006/07, by 65% from Crop care compared to Gromor in 2007/08, and by 13% from Growmax than Lanbac in 2008/09. In comparison with the NPK treatment, biomass recorded with Gliogrow, Crop care and Lanbac in 2006/07 was significantly higher and was with Gromor, Promis, Growmax and Montys in 2007/08 significantly lower. Recorded biomass yield of the same magnitude was obtained with Gromor and Promis in 2008/09. Plant biomass from plots treated with virtually all the IMBAs increased significantly relative to those in the control plots in any of the three seasons.

6.3.2.3 **Ottosdal**

At 9th leaf stage, biomass recorded among some of the IMBA treatments differed significantly in 2007/08 as presented in Table 6.2. Plants from plots treated with K-humate in 2006/07, Lanbac in 2007/08, and Growmax in 2008/09 gave the highest biomass yield. The lowest biomass yield was recorded from Biozone, Gromor and Lanbac treatments in 2006/07, 2007/08 and 2008/09, respectively. In comparison with the NPK check, biomass recorded in 2006/07 and 2008/09 increased though not significantly irrespective of the IMBA treatment, except for Biozone and Gliogrow treatments in 2006/07. Equally, plant biomass from Growmax and Lanbac treatments increased though not significantly in any of the three seasons than the NPK treatment. However, the NPK treatment gave significantly higher plant biomass than Gliogrow and Gromor treatments in 2007/08. Biomass yield recorded amongst the IMBA treatments in each season was lower only from Gliogrow and Gromor in 2007/08 relative to those in the control plots, but the differences amongst them was not significant. However, K-humate in 2006/07, Growmax and Lanbac in 2007/08 and Growmax in 2008/09 gave significantly higher biomass than the control.

The differences in plant biomass produced among the IMBA treatments were significant in all three seasons at the silking stage. The lowest and highest plant biomass was recorded, respectively from Gromor (2745 kg ha⁻¹) and Biozone (3952 kg ha⁻¹) in 2006/07, Gromor (3140 kg ha⁻¹) and Growmax (4084 kg ha⁻¹) in 2007/08, and K-humate (2905 kg ha⁻¹) and Gromor (4028 kg ha⁻¹) in 2008/09. Plant biomass from Biozone, Growmax, K-humate and Lanbac treatments increased though not significantly in all the

three seasons than the NPK standard. However, plant biomass from Gliogrow and Gromor treatments in 2007/08 and also K-humate in 2008/09 decreased significantly when the NPK treatment served as reference. Differences in biomass of the same magnitude were recorded from Growmax and Gromor in 2007/08 and 2008/09, respectively. The differences in biomass among the IMBAs and the control treatment were significant in every season. Plant biomass from Biozone plots was significantly higher than those in the control plots in each season. Similar differences in biomass were recorded though less frequently with Crop care, Gliogrow, Gromor, Growmax, K-humate, Lanbac and Montys and also Promis.

6.3.2.4 **Potchefstroom**

From the IMBA treatments at 9th leaf stage, biomass increased though not significantly by 29% from Biozone compared to Gromor in 2006/07, 65% from Gromor than Lanbac in 2007/08, and by 61% from Montys compared to Gromor in 2008/09. In comparison with the NPK treatment, biomass recorded from the IMBA plots were lower in most cases during 2006/07 with significant differences obtained amongst them. However in 2007/08, the IMBAs gave consistent higher biomass than NPK check, although it was significant only from Biozone application. Likewise in 2008/09, plants from plots that received Biozone, Gliogrow, Lanbac and Montys treatments gave consistent higher biomass relative to the NPK treatment, though not significantly. Biomass yield recorded amongst the IMBA treatments was consistently higher in every season compared to those in the control treatment, but significant differences was found less frequently in 2007/08 than in 2008/09.

The increase in biomass yield at silking stage among the IMBA treatments varied between 3% from Gromor and 17% from Lanbac than Gliogrow in 2006/07, 10% from Growmax and 34% from Promis in 2007/08 compared to those in Gromor, and 9% from Gliogrow and 31% from Gromor in 2008/09 compared to those in K-humate. The differences amongst the IMBA treatments were significant only in 2008/09. None of the IMBAs gave either significantly increased or reduced plant biomass than the NPK treatment. Generally, biomass from plots treated with Biozone, Crop care, Gromor, Growmax and Montys in 2006/07, Lanbac in 2007/08, and Montys and Promis in 2008/09 was higher though not significantly in any of the three seasons compared to the NPK treatment. There were significant differences among the IMBAs and the control

plots in each season on biomass yield. In fact biomass from Biozone, K-humate, Lanbac and Montys treatments was significantly higher in any of the three seasons. Similar differences in biomass were recorded though less frequently from Crop care, Growmax and Gliogrow treatments.

6.3.3 Leaf area index

The leaf area index (LAI) recorded during the 9th leaf and silking growth stages in the IMBA treatments across the seasons and localities are displayed in Table 6.3.

5.3.3.1 Bethlehem

Plants from plots treated with Biozone and K-humate in 2006/07 and Crop care and Lanbac in 2007/08 had a significantly larger LAI than some of the IMBAs at the 9th leaf stage. The differences in LAI among some of the IMBAs were significant in 2006/07 and 2007/08. None of the IMBAs gave plants with significantly greater LAI than the NPK treatment. In fact the LAI from Gliogrow and Promis in 2006/07 was significantly lower. These observations were applicable also to Gliogrow, Gromor, Montys and Promis in 2007/08. Despite this insignificance in 2006/07 and 2008/09, none of the IMBA treatments gave lower LAI values than the control plots, except that LAI values was smaller with Gliogrow and Promis in 2006/07. A difference in LAI of the same magnitude was recorded from Gromor in 2007/08 and from Growmax and Montys in 2008/09. Equally, Biozone, Crop care, Growmax, K-humate and Lanbac gave plants with significantly greater LAI relative to those in the control treatment in 2007/08.

At the silking stage, none of the IMBAs gave plants with a lower LAI than those in the control plots. Amongst the IMBAs, plants with the lowest and highest LAI were recorded with Montys (1.49) and Promis (1.98) in 2006/07, Gliogrow (1.67) and Growmax (1.93) in 2007/08, and Growmax (1.63) and Crop care (2.14) in 2008/09. Significant differences amongst some of the IMBAs manifested in 2006/07 and 2008/09 when Growmax and Montys respectively in 2006/07 and 2008/09 resulted in significantly larger plant canopy than Promis in 2006/07 and Crop care in 2008/09. Comparing to the NPK check, the LAI values from virtually all the IMBAs decreased in 2006/07, though not significantly. However, LAI values were lower only from Crop care, Gliogrow and Gromor treatments in 2007/08 and from Growmax, Lanbac and Montys treatments in 2008/09, but the differences amongst them were not significant.

Table 6.3: Effect of IMBAs on leaf area index at two growth stages during three production seasons at four sites

IMBAs	Bethlehem								Bothaville							
	ninth leaf growth stage				Silking growth stage				ninth leaf growth stage				Silking growth stage			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	1.05a	1.14abc	1.45	1.21	1.66abc	1.80	1.75ab	1.73	1.00	1.38ab	1.17ab	1.18	2.11	2.55	2.94ab	2.53
Gliogrow	0.50bc	0.76cd	1.38	0.88	1.91ab	1.67	1.73ab	1.77	1.17	1.51a	1.22ab	1.30	2.07	2.59	2.55abc	2.40
Gromor	0.90abc	0.40d	1.32	0.87	1.85ab	1.69	1.86ab	1.80	1.12	0.61e	1.16bc	0.96	2.24	2.45	2.42bc	2.37
Promis	0.44c	0.86b	1.59	0.96	1.98a	1.70	1.93ab	1.87	1.04	1.06bcd	1.26ab	1.12	2.03	2.34	2.63abc	2.33
Growmax	0.98ab	0.99abc	1.20	1.06	1.52bc	1.93	1.63b	1.69	1.42	1.20abc	1.32a	1.31	2.13	2.39	2.67abc	2.40
Crop care	1.01ab	1.30a	1.40	1.24	1.72abc	1.69	2.14a	1.85	1.32	1.48ab	1.18abc	1.32	2.17	2.47	2.61abc	2.41
K-humate	1.11a	1.24ab	1.37	1.24	1.51bc	1.73	1.74ab	1.66	1.35	1.45ab	1.22abc	1.34	2.26	2.28	3.04a	2.53
Lanbac	0.93abc	1.30a	1.43	1.22	1.82ab	1.79	1.70ab	1.77	1.25	0.97cde	1.17abc	1.13	2.20	2.52	2.60abc	2.44
Montys	0.81abc	0.87bc	1.19	0.96	1.49c	1.84	1.64b	1.65	1.06	1.08bcd	1.25ab	1.13	2.14	2.54	2.54abc	2.40
NPK	1.31a	1.29a	1.59	1.40	1.90ab	1.70	1.71ab	1.77	1.03	1.50a	1.20abc	1.24	2.07	2.32	2.66abc	2.35
Control	0.81abc	0.49cd	1.30	0.87	1.39c	1.66	1.54b	1.53	0.94	0.69de	1.08c	0.90	2.01	2.20	2.12c	2.11
Mean	0.89	0.97	1.38	1.08	1.70	1.74	1.76	1.74	1.15	1.17	1.20	1.18	2.13	2.42	2.61	2.39
SEM	0.27	0.19	0.21		0.19	0.14	0.22		0.22	0.19	0.08		0.16	0.23	0.29	
CV (%)	41.9	27.8	21.8		16.5	11.6	17.4		26.9	23.2	8.9		10.5	13.3	15.8	
LSD _{T(0.05)}	0.54	0.39	0.44		0.41	0.29	0.44		0.45	0.39	0.15		0.32	0.46	0.59	
					Ottoisdal				Potchefstroom							
Biozone	1.21ab	1.28abcd	1.34	1.27	2.42a	2.55abc	2.90ab	2.63	1.39ab	1.45	1.49	1.44	2.60a	2.73	2.72a	2.68
Gliogrow	0.92b	1.10cd	1.38	1.13	2.33ab	2.84a	2.79ab	2.66	0.90b	1.38	1.54	1.27	2.53ab	2.46	2.31ab	2.43
Gromor	1.31ab	1.05cd	1.35	1.24	2.19b	2.36bc	3.01a	2.52	1.45ab	1.47	1.49	1.47	2.44ab	2.57	2.20ab	2.41
Promis	1.32ab	1.38abc	1.39	1.36	2.28ab	2.42abc	2.71ab	2.47	1.43ab	1.38	1.53	1.45	2.51ab	2.37	2.65a	2.51
Growmax	1.52a	1.52ab	1.41	1.48	2.31ab	2.63ab	2.73ab	2.56	1.50ab	1.39	1.56	1.48	2.39ab	2.70	2.42ab	2.51
Crop care	1.27ab	1.57ab	1.31	1.38	2.35ab	2.41bc	2.93a	2.56	1.27ab	1.57	1.46	1.43	2.41ab	2.90	2.19ab	2.50
K-humate	1.28ab	1.23abcd	1.33	1.28	2.33ab	2.50abc	2.80ab	2.54	1.38ab	1.40	1.48	1.42	2.43ab	2.40	2.74a	2.52
Lanbac	1.09ab	1.68a	1.40	1.39	2.29ab	2.41bc	2.93a	2.54	1.69a	1.49	1.56	1.58	2.63a	2.46	2.56ab	2.55
Montys	1.33ab	1.50abc	1.30	1.38	2.35ab	2.68ab	2.68ab	2.57	1.68a	1.55	1.61	1.62	2.52ab	2.29	2.65a	2.48
NPK	1.01ab	1.56a	1.50	1.36	2.48a	2.71a	3.01a	2.73	1.40ab	1.33	1.66	1.46	2.35b	2.40	2.61a	2.45
Control	0.92b	0.90d	1.46	1.09	2.18b	2.18c	2.44b	2.27	0.95b	1.30	1.45	1.23	2.32b	2.26	2.02b	2.20
Mean	1.20	1.34	1.38	1.31	2.32	2.52	2.81	2.55	1.37	1.43	1.53	1.44	2.47	2.50	2.46	2.48
SEM	0.26	0.20	0.13		0.10	0.21	0.23		0.21	0.20	0.14		0.12	0.41	0.28	
CV (%)	31.0	20.7	13.5		6.1	11.9	11.6		30.4	19.9	12.8		6.6	23.0	16.2	
LSD _{T(0.05)}	0.54	0.40	0.27		0.20	0.42	0.47		0.60	0.41	0.28		0.24	0.83	0.58	

Means with the same letters within the column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

6.3.3.2 **Bothaville**

With respect to LAI at the 9th leaf stage, significant differences amongst the IMBAs were observed in 2007/08 and 2008/09. Plants from treatments with Gliogrow in 2007/08 and Growmax in 2008/09 compared to the other IMBA treatments gave a substantially larger leaf area index. None of the IMBA treatments differed significantly from the NPK treatment throughout the three seasons. In fact plants from plots treated with Gromor, Lanbac, Montys and Promis in 2007/08 performed significantly poorer than the NPK treatment. Generally, Biozone, Gliogrow, Crop care and K-humate treatments gave consistently greater LAI among the nine IMBAs, though not significantly. The LAI values ranged from 1.00 with Biozone to 1.42 with Growmax in 2006/07, 0.61 with Gromor to 1.51 with Gliogrow in 2007/08, and 1.16 with Gromor to 1.32 with Growmax in 2008/09. None of the IMBAs gave lower LAI relative to those in the control plots in all the three seasons.

At silking stage, the range of the LAI values recorded among the IMBAs varied only marginally, but significant only in 2008/09. The lowest and highest LAI was recorded with Promis (2.03) and K-humate (2.26) in 2006/07, K-humate (2.28) and Gliogrow (2.59) in 2007/08, and Gromor (2.42) and K-humate (3.04) in 2008/09. Generally, Biozone and Growmax gave in all the three seasons greater LAI than the NPK check, though not significantly. Similarly, none of the other IMBAs recorded either significantly lower or higher LAI values than the NPK check. Equally, plants from all the IMBA treatments had greater LAI values relative to those in the control plots. The only significant difference in this regard was observed in 2008/09 with Biozone and K-humate.

6.3.3.3 **Ottosdal**

At the 9th leaf stage, the greatest LAI values were recorded with Growmax in 2006/07 (1.52) and 2008/09 (1.41), and Lanbac (1.68) in 2007/08. The smaller values of LAI manifested with Gliogrow (0.92), Gromor (1.05), and Montys (1.30) in 2006/07, 2007/08 and 2008/09, respectively. Significant differences amongst some of the IMBAs were observed only in 2006/07 and 2007/08. In comparison with the NPK treatment, the LAI values was reduced only from Gliogrow plots in 2006/07, while LAI values recorded in 2007/08 and 2008/09 decreased irrespective of the IMBA treatments. In fact Gliogrow and Gromor performed significantly poorer than the NPK check. Generally, plants from

the IMBA treatments had a consistently greater LAI than those in the control treatment. In this regard, significant differences were observed only from Growmax in 2006/07, while virtually all the IMBAs in 2007/08 performed significantly better than the control.

The lowest and highest LAI recorded at silking stage was found, respectively from plants in plots treated with Gromor (2.19) and Biozone (2.42) in 2006/07, Gromor (2.36) and Gliogrow (2.84) in 2007/08, and Montys (2.68) and Gromor (3.01) in 2008/09. These differences were significant in 2006/07 and 2007/08. In none of the three seasons, LAI values amongst the IMBA treatments were either significantly better or poorer than the NPK treatment. Exceptionally, plants from plots treated with Gromor in 2006/07 had a significantly lower LAI than the NPK standard. Likewise, none of the IMBAs gave in each season lower LAI values than the control treatment with significant effects obtained between them.

6.3.3.4 **Potchefstroom**

The percentage increase in LAI amongst some of the IMBA treatments at the 9th leaf stage in 2006/07 was huge in some instances due to the poor performance from Gliogrow, but differed significantly only in 2006/07. For example, the increase in LAI at 9th leaf stage varied between 41% from Crop care and 88% from Lanbac in 2006/07 than the lowest yielded Gliogrow treatment. Similarly in 2007/08, the LAI from Growmax marginally increased by 1% but increased by 14% from Crop care compared to the lowest yielded Gliogrow and Promis treatments. Equally, the increase of LAI recorded in 2008/09 varied between 1% from K-humate and 10% from Montys than the lowest yielded Crop care treatment. Generally, more than half of the IMBAs in 2006/07 and approximately all the IMBAs in 2007/08 gave plants with greater LAI though not significantly than the NPK treatment. This was not the case in 2008/09 since the IMBA treatments resulted in many instances with smaller LAI values. Virtually all the IMBAs gave in each season greater LAI values than the control. However, the only significant difference in this case resulted only in 2006/07 from Lanbac and Montys. In fact only Gliogrow in 2006/07 performed poorer than the control, though not significantly.

At silking stage, the LAI from plots treated with Growmax was reduced during 2006/07 in the range from 1% with Crop care to 10% with Lanbac. Similarly in 2007/08, the LAI from plots treated with Montys decreased from 4% with Promis to 27% with Crop care,

and was reduced in the range from 1% with Gromor to 25% with K-humate in 2008/09. The LAI of plants in plots treated with Biozone and Lanbac in 2006/07 increased significantly than the NPK treatment. Equally, the LAI values recorded amongst most of the IMBA treatments increased than the NPK treatment in 2007/08 and 2008/09, though not significantly. Likewise, plants from the IMBAs had greater LAI values relative to plants of the control treatment, but were only significant following application of Biozone and Lanbac in 2006/07 and of Biozone, Montys and Promis in 2007/08.

6.4 Summary and conclusions

This study on phenological growth of maize was conducted over three seasons at four localities, resulting in 12 response cases per IMBA treatment. The performance of each IMBA for these 12 cases was compared with the relevant NPK treatment to obtain the frequency of significant increases as presented in Table 6.4.

Table 6.4: Frequency of occurrence of significant increases in maize phenological growth parameters following IMBAs application in comparison with NPK treatment over the three production seasons at four sites

IMBAs	Plant height		Biomass yield		Leaf area index	
	9 th leaf	Silking	9 th leaf	Silking	9 th leaf	Silking
Biozone	0	0	0	0	0	1
Gliogrow	0	0	0	1	0	0
Gromor	0	0	0	0	0	0
Promis	0	0	0	0	0	0
Growmax	0	0	0	0	0	0
Crop care	0	0	0	1	0	0
K-humate	0	0	0	0	0	0
Lanbac	0	0	0	1	0	1
Montys	0	0	0	0	0	0

In none of the three seasons and four localities resulted the IMBA treatments in significantly taller plants, higher biomass yields and larger leaf area index in both growth stages compared to the NPK standard. However, only Gliogrow, Crop care and Lanbac resulted in one case in a significant increase of biomass yield at silking stage on the

sandy soil of Bothaville ecotope. Likewise, Biozone and Lanbac showed one case of significant increase in leaf area index during silking stage on the clayey soil of Potchefstroom ecotope.

The higher coefficient of variation across the seasons and ecotopes, especially during the 9th leaf stage could be ascribed to the differences in the growth of plants following application of IMBA treatments that contain different active ingredients with varying NPK contents. Despite this insignificance in the phenological growth parameters measured, plants from manure-based IMBAs like Gromor and Promis were taller at 9th leaf stage but shorter at silking stage. These findings concur with earlier findings by Ayoola and Makinde (2009) who reported significantly taller plants with application of poultry manure during earlier growth stages than those treated with inorganic fertiliser. Plant biomass yield from virtually all the IMBAs was consistently less at silking stage and this could be attributed to the relatively lower content of major plant nutrients (N, P and K) in these treatments (Chen, 2006). Recent studies asserted also that this is an indication that adequate nutrients required to support early growth can be attained from organic fertilisation that is enriched with inorganic nutrients (Ayoola & Makinde, 2009). These results agree well with observations on increased biomass production due to synergy between application of poultry manure and inorganic fertiliser combinations (Boateng *et al.*, 2006). The LAI consistently decreased in both growth stages under Bethlehem sandy soil conditions, particularly in the first planting season (2006/07). This could be related to the consistent stunted plants and less biomass production as a result of lower annual rainfall, viz. 321 mm compared to the long term average of 717 mm at the site. Boateng *et al.* (2006) reported also that low LAI of maize variety Abeleehi resulted from relatively low rainfall (511 mm) compared to the long term average of 700–900 mm.

The IMBAs showed inconsequential effects on the investigated phenological growth characteristics of maize compared to the NPK check. The variable responses of maize phenological traits to the IMBAs were mostly dependent on the soil's fertilisation history. Plant phenological growth was consistently reduced from plots in which Gliogrow was applied at the 9th leaf and silking growth stages due to poor emergence, particularly from soils with higher clay content. Maize phenological growth consistently decreased with Gromor in all the three seasons and four localities, but showed positive effects in heavy textured soil. Applications of Gliogrow and Lanbac gave one case of significant

increase in biomass yield while one case of significantly larger LAI was recorded from Biozone and Lanbac plots compared to the NPK standard. With regard to all the phenological growth data determined, virtually all the IMBAs gave consistently taller plants, higher biomass yield and larger LAI compared to those in the unfertilised plots but not that of the NPK standard check.

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CHAPTER 7

RESPONSE OF MAIZE YIELD AND YIELD COMPONENTS TO APPLICATION OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS UNDER DIFFERENT ECOTOPES

7.1 Introduction

Many areas in South Africa have a reasonable climate and suitable soil conditions, and availability of high yielding maize varieties for efficient maize production. Nonetheless, maize yield on resource-poor farmers' fields is typically very low due to degraded soils and/or poor field management (Mills & Fey, 2003). Intensification of agricultural production contributed to decreased resource use efficiency, land degradation through increased wind and water erosion, and pollution of groundwater (Rozella *et al.*, 1997; Liu & Diamond, 2005; Wang *et al.*, 2007). Therefore, sustainability of high crop yields under intensive cultivation is possible only through the use of fertilisers. Bhakt *et al.* (2006) reported that raising crop yield beyond the prevailing conditions exert huge impact on fertiliser use, which could account for approximately 50% of production cost required to achieve good crop performance. However, the use of conventional inorganic NPK fertiliser has not been helpful as it is associated with increased soil acidity and nutrient imbalance (Wang *et al.*, 2007).

Regrettably, the inability of conventional inorganic NPK fertiliser to condition the soil has directed increased interest in recent times to the use of organic inputs (Wang *et al.*, 2001; Boateng *et al.*, 2006). Low crop yield obtained under resource-poor farmers' condition was reported to be the result of low use of external sources of nutrients and reduced fallow period required to restore soil nutrient base (Vanlauwe *et al.*, 2001). Equally, nutrients contained in organic materials are slowly released over a long period of time, thereby ensuring a long residual effect (Belay *et al.*, 2002) that could possibly reduce the cost of fertilising (Wang *et al.*, 2007).

Numerous studies had revealed that crop yield is usually increased by manure application because of increased nutrient availability and improved soil structure (Chang *et al.*, 1993; Matsi *et al.*, 2003). The application of beef feedlot manure and composted feedlot manure was reported to result in maize yield increases in a manner comparable

to inorganic fertiliser application (Schlegel, 1992; Eghball & Power, 1999). In South Africa, different organic-based fertiliser materials are being manufactured in industries and recommended for farmers' use as growth and yield promoters without sufficient experimental agronomic justification on their efficiency on crop yields. Hence, this study was therefore conducted to evaluate effect of IMBAs as total replacement of NPK and/or growth enhancers on maize productivity.

7.2 Experimental procedure

The detailed description and procedure followed for the field trials are as given in Chapter 3, but for convenience, a concise description is given here. The study assessed nine IMBAs at the rates recommended by either product manufactures or suppliers over three seasons at four sites. Optimum rates for conventional inorganic NPK fertiliser and unamended control treatments were included at each site as standard check. All treatments were replicated four times and arranged in a randomised complete block design. All trials were planted using one maize cultivar PAN 6479 at 0.3 and 1.5 m intra and inter-row spacing, respectively. Trials were harvested manually in an area of 21 m² within two central rows of each plot at physiological maturity. Measurements made were of grain, stover and total biomass yields, harvest index, number of cobs and cob length. Data obtained was subjected to analyses of variance using GenStat Release 14. Differences in treatment means were separated using Tukey HSD at 5% probability level.

7.3 Results and discussion

7.3.1 Grain yield

The grain yield recorded at harvest in the different IMBA treatments during the three seasons at four localities are given in Table 7.1.

7.3.1.1 Bethlehem

The difference in grain yield amongst the IMBAs was significant only in 2006/07 and 2007/08. The grain yield varied between 1863 kg ha⁻¹ with Gromor and 2496 kg ha⁻¹ with K-humate in 2006/07, 1630 kg ha⁻¹ with Gromor and 3120 kg ha⁻¹ with Growmax in 2007/08, and 2448 kg ha⁻¹ with Biozone and 3788 kg ha⁻¹ with Promis in 2008/09. Generally, Promis and Growmax compared to the other IMBA treatments had consistently the highest grain yield throughout the three seasons. In comparison to the

NPK check, none of the IMBAs gave grain yield that was either significantly lower or higher in each of the three seasons. Nevertheless, in 2008/09 grain yield from treatments with Promis (56%) and Growmax (63%) increased substantially, while those from Gliogrow (31%), Crop care (41%), K-humate (22%) and Lanbac (31%) were somewhat less when NPK serves as a check. None of the IMBAs gave lower grain yield in each season compared to the control. In fact Growmax, K-humate, Lanbac and Montys gave significantly higher grain yield than the control in 2006/07. Differences in grain yield of the same magnitude were recorded between the control and Growmax, Crop care and K-humate in 2007/08, and Promis and Growmax in 2008/09.

Table 7.1: Grain yield (kg ha⁻¹) as affected by IMBAs during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville				
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	
Biozone	2266abc	2105ab	2448ab	2273	2696a	3800a	3509a	3335	
Gliogrow	2291abc	2340ab	3187ab	2606	2983a	3267ab	3062ab	3104	
Gromor	1863bc	1630b	2923ab	2139	1820bc	1935bcd	1789bc	1848	
Promis	2290abc	2340ab	3788a	2806	2490a	2969ab	2758ab	2739	
Growmax	2369ab	3120a	3962a	3150	2265ab	3262ab	2610ab	2712	
Crop care	1994abc	2712a	3423ab	2710	2750a	3464ab	3209a	3141	
K-humate	2496a	2633a	2982ab	2704	2386ab	3813a	3529a	3243	
Lanbac	2394ab	1865ab	3186ab	2482	2459ab	2782bc	2574ab	2605	
Montys	2351ab	2451ab	2759ab	2520	2366ab	2803bc	2599ab	2589	
NPK	2247abc	2300ab	2435ab	2328	2334ab	2525bc	2342b	2400	
Control	1774c	1601b	1619b	1665	1520c	1542d	1458c	1507	
Mean	2212	2282	2974	2489	2370	2924	2676	2657	
SEM	275	490	776		321	476	419		
CV (%)	17.6	30.4	36.9		19.1	23.0	22.1		
LSD _{T(0.05)}	561	1001	1585		655	971	855		
		Ottosdal				Potchefstroom			
Biozone	2661	3521a	3985abc	3389	3333ab	5615ab	4441abc	4463	
Gliogrow	3257	3226a	4065abc	3516	3681a	5079abc	4495abc	4418	
Gromor	2868	3094ab	3187bc	3050	1896d	4278bc	3507bcd	3227	
Promis	3113	3414a	3379bc	3302	3314ab	5229abc	3991abc	4178	
Growmax	2461	2421b	4827a	3236	2583cd	5182abc	5434a	4400	
Crop care	3041	3374a	4156abc	3524	2831abc	5333abc	5116ab	4427	
K-humate	3020	3525a	3775bc	3440	3322ab	5726a	4763ab	4604	
Lanbac	3153	3541a	4201ab	3632	3321ab	5589ab	4787ab	4566	
Montys	3192	3386a	4005ab	3528	2800ab	5312abc	3975bcd	4029	
NPK	2788	2923ab	3667bc	3126	2745bc	4599bc	4224b	3856	
Control	2398	2370b	2150d	2306	1995d	2568d	2564d	2376	
Mean	2905	3164	3764	3278	2893	4955	4300	4049	
SEM	465	384	458		351	546	533		
CV (%)	22.6	17.2	17.2		17.1	15.6	17.5		
LSD _{T(0.05)}	945	784	935		716	1116	1088		

Means followed by the same letter within a column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences

7.3.1.2 **Bothaville**

Amongst the IMBA treatments, the highest grain yield was obtained from treatments with Gliogrow (2983 kg ha⁻¹) in 2006/07, Biozone (3800 kg ha⁻¹) in 2007/08, and K-humate (3529 kg ha⁻¹) in 2008/09. The lowest grain yield was recorded in each season in Gromor with values of 1820, 1935 and 1789 kg ha⁻¹ in 2006/07, 2007/08 and 2008/09, respectively. The differences amongst the IMBA treatments were however significant in each of the three seasons due to the poor performance from the Gromor treatment. In comparison with the NPK treatment, lower grain yield from plots in which Gromor was applied resulted throughout the three seasons, though not significantly. On the other hand, grain yield from treatments with Biozone and K-humate, respectively in 2007/08 and 2008/09 and Crop care in 2008/09 increased significantly. Despite the insignificance between NPK and Gliogrow, this IMBA had an average grain yield increase of 29% in all the three seasons. In each season, the different IMBAs resulted in significantly higher grain yield than the control, except for Gromor.

7.3.1.3 **Ottosdal**

Grain yield amongst the IMBAs ranged from 2461 kg ha⁻¹ with Growmax to 3257 kg ha⁻¹ with Gliogrow in 2006/07, 2421 kg ha⁻¹ with Growmax to 3541 kg ha⁻¹ with Lanbac in 2007/08, and 3187 kg ha⁻¹ with Gromor to 4827 kg ha⁻¹ with Growmax in 2008/09. The differences amongst some of the IMBAs were significant in 2007/08 and 2008/09. In comparison with the NPK treatment, grain yield from treatments with Gliogrow (17%) in 2006/07, Biozone (20%), K-humate (21%) and Lanbac (21%) in 2007/08, and Growmax (32%) in 2008/09 increased substantially, but differed significantly only in 2008/09. Comparing to the control, virtually all the IMBA treatments resulted in significantly higher grain yield in 2007/08 and 2008/09, but not in 2006/07.

7.3.1.4 **Potchefstroom**

The differences in grain yield recorded amongst the IMBA treatments differed significantly in all the three seasons. Generally, plots in which Gromor was applied had the lowest grain yield throughout the three seasons. Comparing to the NPK treatment, grain yield from plots treated with Gliogrow, K-humate and Growmax was significantly higher in 2006/07, 2007/08 and 2008/09, respectively. The grain yield from the Gromor treatment was lower in each season than the NPK check, but differed significantly only in 2006/07. In this season, grain yield with Gromor was also lower than the control

though not significantly. However, grain yield from all the other IMBA treatments was significantly higher than the control regardless of the season.

7.3.2 Stover yield

The stover yield obtained at harvest in the IMBA treatments during the three seasons at four localities is given in Table 7.2.

Table 7.2: Stover yield (kg ha⁻¹) as affected by IMBAs during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	1969a	1947ab	3204a	2373	1949ab	3202bc	2418ab	2523
Gliogrow	1632ab	2170ab	2899abc	2234	1798ab	4157a	2172ab	2709
Gromor	1734ab	1648ab	2209c	1864	1981ab	2724bc	1780b	2162
Promis	1818ab	2115ab	3125a	2353	1681ab	3017bc	2810ab	2503
Growmax	1810ab	2455a	2820abc	2362	2353a	3310abc	3608a	3090
Crop care	1658ab	2106ab	2806abc	2190	1598b	3424abc	3313ab	2778
K-humate	1513ab	2421a	2248c	2061	1858ab	3499ab	3241ab	2866
Lanbac	1772ab	2196ab	3008ab	2325	1761ab	3205bc	2960ab	2642
Montys	1447b	2010ab	2539abc	1999	2063ab	3312abc	2895ab	2757
NPK	1505ab	1900ab	2621ab	2009	1643b	2912bc	2788ab	2448
Control	1216b	1442b	2190c	1616	1598b	2506c	1996b	2033
Mean	1643	2037	2697	2126	1867	3206	2726	2600
SEM	255	473	375		265	455	756	
CV (%)	21.9	32.8	19.6		20.0	20.1	39.2	
LSD _{T(0.05)}	521	965	765		541	930	1543	
	Ottosdal				Potchefstroom			
Biozone	2018ab	2855bc	2789b	2554	2355ab	3514ab	3263	3044
Gliogrow	1885b	4877a	3733ab	3498	2491ab	3329ab	3055	2958
Gromor	2185ab	2670c	3843ab	2899	2318ab	2934b	2929	2727
Promis	1885b	3160bc	3907ab	2984	2506ab	3569ab	3181	3085
Growmax	2489a	2993bc	3066ab	2849	2916a	3559ab	2783	3086
Crop care	2199ab	3010bc	4044ab	3084	2852a	3498ab	2975	3108
K-humate	2510a	3421bc	4227a	3386	2638ab	3603a	3316	3186
Lanbac	2286ab	3608b	3264ab	3053	2919ab	3424ab	3206	3183
Montys	1906b	3381bc	4138ab	3142	2492ab	3827a	3414	3244
NPK	2194ab	3060bc	3375ab	2876	2447ab	2943b	2938	2776
Control	1816b	3126bc	2782b	2575	1769b	2846b	2716	2444
Mean	2124	3287	3561	2991	2519	3368	3071	2986
SEM	241	449	669		409	324	420	
CV (%)	16.0	19.3	26.6		22.9	13.6	19.3	
LSD _{T(0.05)}	491	917	1365		835	661	858	

Means followed by the same letter within a column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences

7.3.2.1 Bethlehem

Amongst the IMBA treatments, the highest values of stover yield were recorded from treatments with Biozone respectively in 2006/07 (1969 kg ha⁻¹) and 2008/09 (3204 kg

ha⁻¹), and Growmax (2455 kg ha⁻¹) in 2007/08. The lowest stover yield was obtained with Montys in 2006/07 (1447 kg ha⁻¹) and Gromor respectively in 2007/08 (1648 kg ha⁻¹) and 2008/09 (2209 kg ha⁻¹). The differences in stover yield amongst some of the IMBAs were significant only in 2006/07 and 2008/09. None of the IMBA treatments gave either significantly lower or higher stover yield in comparison with the NPK check in each of the three seasons. Nevertheless, stover yield with Biozone (31%), Promis (21%) and Growmax (20%) were substantially higher to those in the NPK treatment in 2006/07. Similar differences in stover yield were recorded with Growmax (29%) and K-humate (27%) in 2007/08, and Biozone (22%) and Promis (19%) in 2008/09. Comparing to the control, none of the IMBAs had lower yield of stover across the seasons. In fact stover yield with Biozone, Promis, Growmax and Lanbac in 2006/07 was significantly higher. Similar differences in stover yield were recorded with Growmax and K-humate in 2007/08 and Biozone, Promis and Lanbac in 2008/09.

7.3.2.2 **Bothaville**

Stover yield was lowest from plots treated with Crop care (1598 kg ha⁻¹) in 2006/07, and Gromor in 2007/08 (2724 kg ha⁻¹) and 2008/09 (1780 kg ha⁻¹), while Growmax in 2006/07 (2353 kg ha⁻¹) and 2008/09 (3608 kg ha⁻¹), and Gliogrow (4157 kg ha⁻¹) in 2007/08 had the highest stover yield. The stover yield from treatment with Crop care and Gromor was significantly lower than Growmax in 2006/07 and 2008/09, respectively. Equally, Gliogrow in 2007/08 had significantly higher stover yield than Biozone, Gromor, Promis and Lanbac in 2007/08. In comparison with the NPK treatment, none of the IMBAs had significantly lower stover yield in any of the three seasons. However, plots treated with Growmax and Gliogrow gave significantly higher stover yield in 2006/07 and 2007/08, respectively. On the other hand, Gromor had consistently lower stover yield than the NPK (2007/08 and 2008/09), though not significantly. With all the IMBA treatments, only Gromor in 2008/09 performed poorer compared to the control, though not significantly.

7.3.2.3 **Ottosdal**

From the IMBA treatments, the highest and lowest stover yield were recorded with K-humate (2510 kg ha⁻¹) and Gliogrow (1885 kg ha⁻¹) in 2006/07, Gliogrow (4877 kg ha⁻¹) and Gromor (2670 kg ha⁻¹) in 2007/08, and K-humate (4227 kg ha⁻¹) and Biozone (2789 kg ha⁻¹) in 2008/09. In each of the season, the differences amongst some of the IMBAs

were significant. The different IMBAs had an inconsequential effect on stover yield comparing to the NPK check. However, stover yield from plots treated with Gliogrow in 2007/08 was significantly higher than in the NPK check. Likewise, stover yield with K-humate was higher though not significantly than the NPK treatment in each season. In none of the three seasons stover yield from the unfertilised plots was higher than in any of the IMBA treatments. The only exception in this regard was Biozone, Gromor, Growmax and Crop care in 2007/08. In fact stover yield with Growmax and K-humate in 2006/07 was significantly higher than in the control. Similar differences in stover yield were also applicable to Gliogrow in 2007/08 and K-humate in 2008/09.

7.3.2.4 **Potchefstroom**

Stover yield amongst the IMBA treatments varied between 2318 kg ha⁻¹ with Gromor and 2919 kg ha⁻¹ with K-humate in 2006/07, 2934 kg ha⁻¹ with Gromor and 3827 kg ha⁻¹ with Montys in 2007/08, and 2783 kg ha⁻¹ with Growmax and 3414 kg ha⁻¹ with Montys in 2008/09. The differences amongst some of the IMBAs were significantly only in 2007/08. However, Growmax, Crop care and Lanbac compared to the other IMBA treatments gave a substantial higher stover yield in 2006/07. A similar trend was observed with K-humate and Montys in 2007/08. Comparing to the NPK, stover yield with Gromor was constantly lower though not significantly throughout the three seasons. However in 2007/08, stover yield with Promis (21%), Growmax (21%), K-humate (22%) and Montys (30%) was higher than in the NPK treatment, although it was only significant for K-humate and Montys application. The IMBA treatments gave higher stover yield than the control regardless of the season, but differed significantly only in 2006/07 and 2007/08.

7.3.3 **Total biomass yield**

The total biomass yield recorded at harvest under the different IMBA treatments across the seasons and localities are presented in Table 7.3.

7.3.3.1 **Bethlehem**

Total biomass yield amongst the IMBA treatments ranged from 4626 to 6072 kg ha⁻¹ in 2006/07, 3946 to 6293 kg ha⁻¹ in 2007/08, and 4962 to 7006 kg ha⁻¹ in 2008/09. There were significant differences amongst some of the IMBA treatments on total biomass yield in 2006/07 and 2007/08. Generally, total biomass yield were the highest from

treatments with Biozone, Promis, Growmax and Lanbac in 2006/07, and from Growmax and K-humate in 2007/08. In comparison with the NPK check, total biomass yield from the Gromor plots was lower in 2006/07 and 2007/08, but differed significantly only in 2006/07. Conversely, total biomass yield from plots treated with Promis and Growmax was higher in each of the seasons, though not significantly. The average increase of 700 kg ha⁻¹ with Promis and 1152 kg ha⁻¹ with Growmax represented 35 to 41%, respectively. Plots treated with Biozone, Promis, Growmax and Lanbac in 2006/07 had significantly higher total biomass yield compared to the control treatment. Similar differences in total biomass yield were recorded with Growmax and K-humate in 2007/08 and Promis, Growmax and Crop care in 2008/09.

Table 7.3: Effect of IMBAs on total biomass yield (kg ha⁻¹) in three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	6072a	4782ab	4962ab	5272	6341a	6978a	6123a	6481
Gliogrow	5413ab	5278ab	5764ab	5485	7029a	6263ab	5409a	6234
Gromor	4626b	3946b	5625ab	4732	4992b	4209b	4264b	4488
Promis	6006a	5079ab	6736a	5940	6053ab	6434a	5094ab	5860
Growmax	5863a	6293a	7006a	6387	6084ab	6712a	5273a	6023
Crop care	5342ab	5476ab	6247a	5688	6295a	7552a	5582a	6476
K-humate	5382ab	5780a	5390ab	5517	6435a	7812a	6145a	6797
Lanbac	6016a	4820ab	5625ab	5487	6191a	6152ab	4917ab	5753
Montys	5492ab	5184ab	5025ab	4757	6226a	6310ab	5274a	5937
NPK	5836ab	4888ab	4983ab	5236	7074a	6818a	5579a	6490
Control	4566b	3728b	3594b	4440	5373b	4193b	3861b	4476
Mean	5511	5023	5541	5358	6190	6312	5229	5910
SEM	529	879	1133		583	1066	493	
CV (%)	13.6	24.7	28.9		13.3	23.9	13.3	
LSD _{T(0.05)}	1081	1794	2315		1190	2176	1007	
	Ottosdal				Potchefstroom			
Biozone	6051b	7308abc	6455b	6605	7444b	10181a	7485bc	8370
Gliogrow	10514a	8259a	6736b	8503	9760a	8441abc	7857abc	8686
Gromor	7457b	6624bc	6073bc	6718	5367c	8033bc	6539bcd	6646
Promis	7383b	7307ab	6029bc	6906	7228b	9787ab	7311bc	8109
Growmax	7087b	6306c	8283a	7225	5578c	9699ab	9348a	8208
Crop care	7797b	7198abc	7242ab	7412	6435bc	9790ab	8864ab	8363
K-humate	7980ab	7895ab	6806bc	7560	7223b	10459a	8345ab	8676
Lanbac	6664b	7394abc	7368ab	7142	6535bc	10015a	8590ab	8380
Montys	8128b	7637abc	6757bc	7507	6846bc	10133a	7219bc	8066
NPK	6805b	7758abc	7390ab	7318	7027b	9428ab	7577bc	8011
Control	6074b	7130abc	4943c	6049	6195bc	7659c	5422d	6425
Mean	7449	7347	6735	7177	6876	9420	7687	7994
SEM	1281	697	714		836	862	863	
CV (%)	24.3	13.4	15.0		17.2	12.9	15.9	
LSD _{T(0.05)}	2617	1423	1459		1707	1760	1762	

Means followed by the same letter within a column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences

7.3.3.2 **Bothaville**

The differences in total biomass yield from nearly all the IMBA treatments were significant probably on account of the poor performance from treatment with Gromor in all the three seasons. The IMBA treatments Gliogrow in 2006/07 and K-humate respectively in 2007/08 and 2008/09 gave the highest total biomass yield amongst the other IMBAs though not significantly from one another. The total biomass yield from the IMBAs was in most instances lower than in the NPK treatment, but significant differences was found only from Gromor application in each season. In comparison with the control, only Gromor in 2006/07 had lower yield of total biomass, though not significantly. However, total biomass yield obtained from all the other IMBAs was significantly higher irrespective of the season of assessment.

7.3.3.3 **Ottosdal**

Total biomass yield amongst the IMBA treatments varied between 6051 kg ha⁻¹ and 10514 kg ha⁻¹ in 2006/07, 6306 kg ha⁻¹ and 8259 kg ha⁻¹ in 2007/08, and 6029 kg ha⁻¹ and 8283 kg ha⁻¹ in 2008/09. The total biomass yield from plots treated with Gliogrow in 2006/07 was significantly higher than the other IMBA treatments. The only exception was K-humate and Montys. Similarly in 2007/08, total biomass yield with Gliogrow and K-humate was significantly higher than Gromor and Growmax. However in 2008/09, total biomass yield from plots treated with Growmax was significantly higher than nearly all the other IMBA treatment, except for Crop care and Lanbac. The total biomass yield from virtually all the IMBA treatments was higher than the NPK treatment with significant differences found in 2006/07. Conversely, total biomass yield from Growmax was significantly lower than the NPK check in 2007/08. In comparison with the control, Biozone in 2006/07 and Gromor and Growmax in 2007/08 performed poorer, though not significantly. However, plots treated with Gliogrow had significantly higher total biomass yield in 2006/07. Similar observations were also applicable to treatments with Biozone, Gliogrow, Growmax, Crop care and Lanbac in 2008/09.

7.3.3.4 **Potchefstroom**

For the IMBA treatments, Biozone and K-humate exerted significantly higher total biomass yield than Gromor in 2006/07, but were also significantly lower than with Gliogrow in the same season. However, the difference in total biomass yield following application of Biozone, K-humate, Lanbac and Montys in 2007/08 and Growmax, Crop

care, K-humate and Lanbac in 2008/09 were significantly higher compared to some of the IMBAs. The IMBA treatments had inconsequential effect on total biomass yield comparing to the NPK treatment. However, total biomass yield from Gromor was in every season lower, though not significantly. In fact, of all the IMBA treatments, only K-humate had consistently higher total biomass yield when the NPK treatment served as a reference. These differences were significant in 2006/07 and 2008/09. Gromor and Growmax in 2006/07 had lower total biomass yield though not significantly than the control. All the other IMBAs gave in each season significantly higher total biomass yield than the control.

7.3.4 Harvest index

The harvest index (HI) in the IMBA treatments during the three seasons at four localities is given in Table 7.4.

7.3.4.1 Bethlehem

The values of HI ranged from 0.36 with Gliogrow to 0.47 with K-humate in 2006/07, 0.39 with Lanbac to 0.53 with Crop care in 2007/08, and 0.44 with Biozone to 0.57 with Promis in 2008/09. Amongst some of the IMBAs, the differences in HI were significant in 2006/07 and 2007/08. Generally, K-humate and Crop care in 2006/07 and 2007/08, respectively compared to the other IMBAs gave substantial higher values of HI. None of the IMBA treatments had significantly lower HI values than the NPK treated plots in each of the three seasons. Of all the IMBA treatments, Growmax and K-humate had higher values of HI comparing to the NPK check in all the seasons, though not significantly. The HI from all the IMBAs was higher than those in the control plots, except for Lanbac in 2007/08. However, only the values of HI from K-humate were significantly higher in 2006/07. Similar significant differences in HI were recorded from treatments with Growmax and Crop care in 2007/08, and Promis, Growmax, Crop care and Lanbac in 2008/09.

7.3.4.2 Bothaville

From the IMBA treatments, the HI from plots treated with Biozone were significantly higher than Gromor in 2006/07. Similar significant differences were obtained from treatments with Biozone, Gliogrow, Crop care and K-humate than Growmax in 2007/08, and with Biozone, Crop care and K-humate compared to Gromor in 2008/09. The IMBA

treatments gave in most cases higher HI values than the NPK treatment, but differences were significant only in 2008/09. With regard to the control, only Growmax in 2007/08 performed poorer, though not significantly. However, HI values from all the other IMBA treatments were significantly higher in each of the three seasons.

Table 7.4: Harvest index as influenced by IMBAs in three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	0.37b	0.45abc	0.44ab	0.42	0.46a	0.55a	0.57a	0.53
Gliogrow	0.36b	0.48ab	0.53ab	0.46	0.41abc	0.54a	0.56ab	0.50
Gromor	0.40ab	0.41bc	0.51ab	0.44	0.36bc	0.46ab	0.42bc	0.42
Promis	0.37b	0.45abc	0.57a	0.46	0.41ab	0.46ab	0.54ab	0.47
Growmax	0.43ab	0.50ab	0.56a	0.49	0.38abc	0.38b	0.44abc	0.40
Crop care	0.38b	0.53a	0.55a	0.48	0.37abc	0.48ab	0.57a	0.47
K-humate	0.47a	0.44abc	0.52ab	0.48	0.39abc	0.50a	0.57a	0.49
Lanbac	0.40ab	0.39bc	0.56a	0.45	0.38abc	0.48ab	0.52ab	0.46
Montys	0.42ab	0.49abc	0.52ab	0.48	0.42ab	0.44ab	0.49abc	0.45
NPK	0.40ab	0.44abc	0.49ab	0.44	0.37ab	0.45ab	0.47bc	0.43
Control	0.36b	0.40c	0.41b	0.39	0.34c	0.42b	0.42c	0.39
Mean	0.40	0.45	0.51	0.45	0.39	0.47	0.51	0.46
SEM	0.03	0.04	0.06		0.04	0.05	0.05	
CV (%)	12.3	13.7	17.1		12.9	15.7	12.8	
LSD _{T(0.05)}	0.07	0.09	0.13		0.07	0.11	0.09	
	Ottosdal				Potchefstroom			
Biozone	0.45ab	0.48a	0.57ab	0.50	0.45abcd	0.55a	0.59a	0.53
Gliogrow	0.44ab	0.45ab	0.60a	0.50	0.48a	0.54a	0.57a	0.53
Gromor	0.38bc	0.47a	0.54b	0.46	0.35d	0.53a	0.54a	0.47
Promis	0.37bc	0.47a	0.56ab	0.47	0.46ab	0.53a	0.55a	0.51
Growmax	0.40ab	0.38b	0.57ab	0.45	0.40bcd	0.53a	0.58a	0.50
Crop care	0.39abc	0.47a	0.58ab	0.48	0.44ab	0.54a	0.58a	0.52
K-humate	0.38bc	0.44ab	0.55ab	0.46	0.47ab	0.55a	0.57a	0.53
Lanbac	0.47a	0.48a	0.57ab	0.51	0.42abc	0.56a	0.56a	0.51
Montys	0.39abc	0.44ab	0.59a	0.48	0.41bcd	0.54a	0.56a	0.50
NPK	0.36bc	0.42ab	0.54b	0.44	0.42abc	0.53a	0.55a	0.50
Control	0.31c	0.30c	0.52b	0.38	0.39bcd	0.42b	0.41b	0.40
Mean	0.40	0.44	0.56	0.47	0.43	0.54	0.56	0.51
SEM	0.04	0.03	0.03		0.03	0.02	0.03	
CV (%)	13.8	11.0	7.70		10.4	5.00	8.80	
LSD _{T(0.05)}	0.08	0.07	0.06		0.06	0.04	0.07	

Means followed by the same letter within a column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences

7.3.4.3 **Ottosdal**

The lowest and highest values of HI were recorded from Promis (0.37) and Lanbac (0.47) in 2006/07, Growmax (0.38) and Biozone (0.48) in 2007/08, and Gromor (0.54) and Gliogrow (0.60) in 2008/09. For each season, there were significant differences between some of the IMBAs. Concerning the NPK treatment, the values of HI from Lanbac were significantly higher in 2006/07. Similar differences were also noted with Gliogrow and Montys in 2008/09. The IMBA treatments gave in many instances higher HI values than the control in every season with significant differences observed amongst some of the IMBAs and the control in any of the three seasons.

7.3.4.4 **Potchefstroom**

The values of HI varied between 0.35 with Gromor and 0.48 with Gliogrow in 2006/07, 0.53 with Gromor, Promis and Growmax and 0.56 with Lanbac in 2007/08, and 0.54 with Gliogrow and 0.59 with Biozone in 2008/09. However, the HI values from treatments with Biozone, Gliogrow, Promis, Crop care, K-humate and Lanbac were the highest across IMBA treatments. The HI values between some of the IMBAs differed significantly only in 2006/07. In comparison with the NPK check, none of the IMBAs gave significantly higher HI values in any of the three seasons. Generally, the HI values were higher in each season from treatments with Biozone, Gliogrow, Crop care and K-humate. However, the HI values with Gromor were significantly lower than the NPK check in 2006/07. Only plots treated with Gromor had lower HI values in 2006/07 than the control, though not significantly. However, all the IMBA treatments gave significantly higher HI values in 2007/08 and 2008/09. Treatment with Gliogrow, Promis and K-humate gave in 2006/07 a similar effect.

7.3.5 **Number of cobs**

The number of cobs at harvest in the IMBA treatments during the three seasons at four localities is given in Table 7.5.

7.3.5.1 **Bethlehem**

Amongst the IMBA treatments, the smallest and largest number of cobs was recorded from Montys (18452 cobs ha⁻¹) and Growmax (29762 cobs ha⁻¹) in 2006/07, Gromor (19762 cobs ha⁻¹) and Crop care in 2007/08, and Gromor (34008 cobs ha⁻¹) and Gliogrow (47933 cobs ha⁻¹) in 2008/09. The differences amongst some of the IMBAs

were significant in 2006/07 and 2008/09. In comparison with the NPK plots, Growmax had more cobs in 2006/07 (29%) and 2007/08 (16%), respectively. In the same seasons gave Crop care 16% and 18% more cobs. Equally, Gliogrow had 26% more cobs in 2008/09. However, the number of cobs from treatments with Growmax, Crop care and Lanbac was more than in the NPK check in all the three seasons, though not always significantly. Comparing to the control, the number of cobs from treatments with Biozone, Gliogrow and Montys was lower in 2006/07, though not significantly. Conversely, the number of cobs recorded from all the IMBA treatments in 2007/08 and 2008/09 were higher than the control, with significant differences only in 2008/09.

Table 7.5: Effect of IMBAs on the number of cobs (cobs ha⁻¹) at harvest during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	19762b	21190	43720ab	28224	26204a	35495	26504ab	29401
Gliogrow	21548ab	22500	47933a	30660	23704ab	38384	24004abc	28697
Gromor	25000ab	19762	34008bc	26257	21296ab	36873	21940abc	26703
Promis	25952ab	21071	42398ab	29807	24259ab	35440	24559abc	28086
Growmax	29762a	26071	39230bc	31688	21111ab	38612	21411bc	27045
Crop care	27500ab	26429	39712bc	31214	25000ab	39342	25300ab	29881
K-humate	22738ab	24048	40036bc	28941	26481a	40538	26781a	31267
Lanbac	25595ab	25119	41827a	30847	22037ab	41282	22337abc	28552
Montys	18452b	23690	36347bc	26163	22037ab	41120	22337abc	28498
NPK	23095ab	22381	38094bc	27857	24444ab	41544	24744abc	30244
Control	22381ab	17500	33659c	24513	20093b	32681	19877c	24217
Mean	23799	22706	39724	28743	23333	38301	23618	28417
SEM	4686	5218	3824		2665	5424	2627	
CV (%)	27.8	32.5	13.6		16.1	20.0	15.7	
LSD _{T(0.05)}	9570	10656	7810		5442	11078	5365	
	Ottosdal				Potchefstroom			
Biozone	24710	29643b	23690ab	26014	30238a	38228bc	27619ab	32028
Gliogrow	30082	28571abc	25952ab	28202	25119ab	48408a	29048ab	34192
Gromor	29290	27024b	22619b	26311	24405b	32115bc	24762bc	27094
Promis	26361	28095b	22976ab	25811	27976ab	37022bc	26071bc	30356
Growmax	27818	29286ab	29405a	28836	28333ab	33217bc	32738a	31429
Crop care	29563	29167ab	25119ab	27950	27500ab	38228bc	29643ab	31790
K-humate	32096	32024a	26071ab	30064	28452ab	40070b	29167ab	32563
Lanbac	31055	30595ab	26071ab	29240	26667ab	33897b	28452ab	29672
Montys	32849	29048ab	25000ab	28966	27500ab	36376bc	28810ab	30895
NPK	25836	28095bc	24881ab	26271	26548ab	36387bc	25952bc	29629
Control	24026	23690c	21429b	23048	25119ab	31782c	23095c	26665
Mean	28517	28658	24838	27338	27078	36896	27760	30578
SEM	4623	1540	2371		2760	2823	2908	
CV (%)	22.9	7.60	13.5		14.4	10.8	14.8	
LSD _{T(0.05)}	9441	3146	4843		5637	5764	5938	

Means followed by the same letter within a column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences

7.3.5.2 **Bothaville**

The number of cobs ranged from 21111 cobs ha⁻¹ with Growmax to 26481 cobs ha⁻¹ with K-humate in 2006/07, 35440 cobs ha⁻¹ with Promis to 41282 cobs ha⁻¹ with Lanbac in 2007/08, and 21411 cobs ha⁻¹ with Growmax to 26781 cobs ha⁻¹ with K-humate in 2008/09. The number of cobs from K-humate compared to the other IMBA treatments was consistently the most in all the three seasons, but differed only significantly from the other IMBAs in 2008/09. Nearly all the IMBA treatments had a smaller number of cobs throughout the three seasons when NPK served as a reference, though not significantly. In comparison with the control, all the IMBA treatments had a larger number of cobs across the three seasons, although the differences were significantly only in 2006/07 and 2008/09.

7.3.5.3 **Ottosdal**

The IMBA treatments Montys (32849 cobs ha⁻¹), K-humate (32024 cobs ha⁻¹) and Growmax (29405 cobs ha⁻¹) had the most cobs in 2006/07, 2007/08 and 2008/09, respectively. The least number of cobs resulted from Biozone (24710 cobs ha⁻¹) in 2006/07, and Gromor in 2007/08 (27024 cobs ha⁻¹) and 2008/09 (22619 cobs ha⁻¹). Plots treated with Growmax, K-humate and Lanbac had consistently the largest number of cobs amongst the IMBA treatments in each season, but significant differences with the other IMBAs were found only in 2007/08 and 2008/09. In comparison with the NPK check, the number of cobs recorded in 2006/07 from K-humate, Lanbac and Montys treatments was 24, 20 and 27% respectively more, while cobs were respectively 16 and 14% more with Gliogrow and Crop care in 2008/09. The number of cobs from Gliogrow, Growmax, Crop care, K-humate, Lanbac and Montys in each season was higher than in the NPK treatment, but differed significantly only in 2007/08. Virtually all of the IMBAs had more cobs compared to the unfertilised plots across the three seasons. Significant differences manifested only in 2007/08 and 2008/09.

7.3.5.4 **Potchefstroom**

The number of cobs amongst some of the IMBA treatments differed significantly in each of the three seasons. This can be attributed to the low number of cobs that realised from treatment with Gromor. On the other hand, the number of cobs recorded following application of Gliogrow in 2007/08 increased significantly compared to the other IMBA treatments. Generally, throughout the three seasons the number of cobs was most

from treatment with Biozone (30238 cobs ha⁻¹), Gliogrow (48408 cobs ha⁻¹) and Growmax (32738 cobs ha⁻¹). In 2007/08, plots treated with Gliogrow had significantly more cobs when NPK served as a standard. The difference in the number of cobs was of the same magnitude following application with Growmax in 2008/09. Of all the IMBAs, only the number of cobs recorded from treatment with Gromor in 2006/07 was less though not significantly than those in the control.

7.3.6 Cob length

The length of cobs at harvest under the different IMBA treatments during the three seasons at four localities is given in Table 7.6.

7.3.6.1 Bethlehem

Amongst the IMBA treatments, the shortest and longest cobs were recorded respectively in 2006/07 and 2007/08 with Gromor (15.9 cm and 17.4 cm) and Lanbac (18.7 cm and 18.8 cm), and in 2008/09 respectively from K-humate (15.1 cm) and Crop care (18.8 cm). These differences were significant only in 2006/07. Despite the lack of significant effects between some of the IMBAs and the NPK check, Gliogrow, Promis and Crop care had longer cobs in each of the three seasons. On the contrary, plots treated with Gromor respectively in 2006/07 and 2007/08, and K-humate respectively in 2007/08 and 2008/09 had shorter cobs compared to those in the NPK treatment, though not significantly. In comparison with the control, the cobs from treatments with Gromor in 2007/08 and Biozone and K-humate in 2008/09 were shorter, though not significantly. Nonetheless, the cobs amongst virtually all the IMBA treatments were significantly longer than those of the control in 2006/07.

7.3.6.2 Bothaville

The cob lengths for the IMBA treatments ranged from 15.7 cm with Montys to 18.6 cm with Crop care in 2006/07, 14.7 cm with Gromor to 19.6 cm with Gliogrow in 2007/08, and 19.0 cm with Promis to 21.4 cm with Growmax in 2008/09. However, significant differences were observed only in 2007/08 when K-humate measured significantly longer cobs than Gromor and Promis treatments. Cobs from treatment with Biozone, Gliogrow, Growmax, Crop care and K-humate were generally longer in each season compared to those in the NPK treatment, though not significantly. On the other hand, plots treated with Gromor respectively in 2006/07 and 2007/08, and Promis respectively

in 2007/08 and 2008/09 had shorter cobs in comparison with the NPK treatment. In none of the three seasons cobs resulted in the IMBA treatments were shorter than in the control. The only exception in this regard was Gromor in 2007/08. Significantly longer cobs from the IMBAs than the control were found less frequently in 2006/07 and 2007/08 than in 2008/09.

Table 7.6: Effect of IMBAs on cob length (cm) at harvest during three growing seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	16.9ab	18.6	16.2	17.2	17.2ab	18.7ab	19.7ab	18.5
Gliogrow	17.3ab	18.7	18.4	18.2	17.3ab	19.6a	20.3a	19.0
Gromor	15.9bc	17.4	17.2	16.8	16.2ab	14.7c	19.8a	16.9
Promis	17.4ab	18.0	17.5	17.6	16.8ab	16.4bc	19.0ab	17.4
Growmax	17.2ab	18.0	16.9	17.3	17.5ab	18.1ab	21.4a	19.0
Crop care	17.4ab	18.4	18.8	18.2	18.6a	17.4ab	21.1a	19.0
K-humate	17.6ab	17.9	15.1	16.9	17.1ab	18.9a	20.1a	18.7
Lanbac	18.7a	18.8	16.7	18.1	15.7ab	17.8ab	20.5a	18.0
Montys	16.7ab	18.0	17.7	17.4	17.2ab	17.3abc	19.2ab	17.9
NPK	17.1ab	17.9	16.7	17.2	16.8ab	17.1abc	19.4ab	17.8
Control	14.5c	17.4	16.2	16.0	14.7b	16.1bc	16.3b	15.7
Mean	17.0	18.1	17.0	17.4	16.8	17.5	19.7	18.0
SEM	0.90	0.79	1.82		1.52	1.30	1.68	
CV (%)	7.50	6.20	15.1		12.8	10.5	12.0	
LSD _{T(0.05)}	1.84	1.61	3.71		3.11	2.65	3.43	
	Ottosdal				Potchefstroom			
Biozone	19.3ab	20.1ab	21.6ab	20.3	18.9a	22.7ab	21.5	21.0
Gliogrow	19.9a	22.1a	22.4a	21.5	19.6a	22.8a	22.2	21.5
Gromor	18.6b	18.4b	19.3bc	18.8	16.1bc	20.7abc	20.3	18.6
Promis	19.2ab	19.2ab	22.1a	20.1	16.4bc	22.2ab	21.6	20.1
Growmax	18.8ab	18.9ab	21.3ab	19.7	18.1ab	21.9ab	20.0	20.0
Crop care	19.1ab	20.4ab	20.9ab	20.1	17.3abc	22.7ab	21.8	20.6
K-humate	19.4ab	22.2a	20.8ab	20.8	18.7ab	22.1ab	21.1	20.7
Lanbac	20.4a	19.8ab	22.4a	20.9	17.8ab	22.2ab	20.7	20.2
Montys	19.5ab	19.5ab	22.3a	20.4	17.4ab	21.0abc	19.6	19.3
NPK	19.1ab	19.4ab	20.4ab	19.6	17.1abc	20.2bc	21.2	19.5
Control	18.4b	16.7b	17.2c	17.4	14.7c	19.2c	20.7	18.7
Mean	19.2	19.7	21.0	20.0	17.5	21.8	21.0	20.1
SEM	0.82	1.55	1.00		1.30	1.25	2.04	
CV (%)	6.10	11.1	6.80		10.5	8.10	13.8	
LSD _{T(0.05)}	1.68	3.16	2.05		2.65	2.54	4.17	

Means followed by the same letter within a column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences

7.3.6.3 **Ottosdal**

The cob length measured from the IMBA treatments differed significantly in each of the three seasons. These differences were due to the consistently shorter cobs recorded from treatment with Gromor. The cobs were with Gromor treated plots slightly shorter and were with Biozone, Gliogrow, K-humate and Lanbac consistently slightly longer than those in the NPK treatment. None of the IMBAs had cobs that were shorter than the control treatment in any of the three seasons. The cobs from Gliogrow and Lanbac treatments in 2006/07, Gliogrow and K-humate treatments in 2007/08 were significantly longer than those in the control plots. However in 2008/09, all IMBA treatments recorded significantly longer cobs.

7.3.6.4 **Potchefstroom**

Amongst the IMBA treatments gave Gliogrow in each season the longest cobs, while Gromor in 2006/07 and 2007/08, and Montys in 2008/09 registered the shortest cobs. Significant differences amongst some of the IMBA treatments were found only in 2006/07. The cobs from treatments with Biozone, Gliogrow, K-humate and Lanbac were longer in the three seasons than the NPK treatment, but differed significantly only in 2007/08. In comparison with the control, plots treated with Gromor in 2008/09 and Growmax and Montys in 2008/09 had shorter cobs, though not significantly. However, the cobs from Gliogrow and K-humate in 2006/07 and nearly all the IMBAs in 2007/08 were significantly longer.

7.4 **Summary and conclusions**

The study on the yield and yield components was conducted over three seasons at four localities, resulting in 12 response cases per IMBA treatment. The performance of each IMBA for these 12 cases was compared with the relevant NPK treatment to obtain the frequency of significant increase as presented in Table 7.7.

The effect of virtually all the manure-based IMBAs like Gromor and Promis on yield and components of yield parameters across the seasons and localities were very similar. These IMBAs did not exert any significant positive effect on all measured grain yield and yield component parameters compared to the NPK check. However, Promis resulted in significant total biomass yield increase only in one case. Nonetheless, Growmax (manure-based IMBAs coincided with inorganic NPK fertiliser) resulted in few instances

with significantly higher yield and yield components parameters than the NPK standard, except on harvest index and cob length. More of these significant increases manifested in inherently fertile soils due to recurring fertiliser application typical at the Ottosdal and Potchefstroom ecotopes. Despite the less cases of significant increase following IMBAs application compared to the recommended NPK check, Gliogrow amongst other IMBA treatments exerted significant increases for all the yield parameters measured and also resulted in more cases of significant increase than any other IMBA treatment. With regard to grain yield, K-humate gave the highest number of cases of significant increase followed by Biozone and Growmax applications, respectively. The IMBA treatments gave positive effects on grain and stover yields at Bothaville and Potchefstroom ecotopes, and total biomass yield and the number of cobs at Bethlehem and Potchefstroom ecotopes. Concerning harvest index, the different IMBAs resulted also in few cases with significant increases compared to the NPK check on the sandy soils of Bothaville and Ottosdal ecotopes.

Table 7.7: Frequency of occurrence of significant increases of grain yield and yield components parameters following IMBAs application in comparison with NPK treatment over the three production seasons at four sites

IMBAs	Grain yield	Stover yield	Total biomass yield	Harvest index	Number of cobs	Cob length
Biozone	2	0	0	1	0	0
Gliogrow	1	1	2	1	2	1
Gromor	0	0	0	0	0	0
Promis	0	0	1	0	0	0
Growmax	2	1	2	0	1	0
Crop care	1	0	1	1	0	0
K-humate	3	1	0	1	1	0
Lanbac	0	0	1	1	1	0
Montys	0	1	2	2	0	0

The effect of IMBA treatments evaluated was more apparent under the Ottosdal and Potchefstroom ecotopes. This could be ascribed to the inherent fertility of soils in these localities as a result of recurring fertiliser application over the years. The lower grain

yield at Bethlehem and Bothaville compared to that at Potchefstroom could possibly be attributed to delayed growth, especially at silking stage which hindered kernel maturation and consequently led to late kernel filling at these sites (Ali *et al.*, 1999). The IMBA treatments that coincided either with optimum or reduced fertiliser application gave consistently higher grain, stover and total biomass yields than the manure-based IMBAs used as the total replacement of conventional inorganic NPK fertiliser. Work by Ayoola & Makinde (2009) revealed that maize grain yield was highest from poultry manure application fortified with 100 kg urea, whereas pacesetter fertiliser (2.5 t ha⁻¹ cow dung) and the NPK fertiliser (20-10-10) gave comparable yields. Several reports have also documented higher maize grain yield from combined use of NPK fertiliser and poultry manure compared to sole application of either source. Such studies revealed that organic fertilisers should be enriched with inorganic nitrogen to obtain maize grain yields which are comparable to those realised with inorganic fertilisers (Palm *et al.*, 1997; Makinde *et al.*, 2001; Adeniyani & Ojeniyi, 2005; Khan *et al.*, 2005; Boateng *et al.*, 2006; Ayoola & Makinde, 2009).

The synergy between poultry manure and inorganic fertiliser also resulted in better maize stover yield (Wang *et al.*, 2001; Boateng *et al.*, 2006). A report by Mweta *et al.* (2007) indicated that applying *Gliricidia* prunings and inorganic N and P significantly increased maize grain and total biomass yield as compared to the unfertilised plots. Findings from a long-term study by Nel *et al.* (1996) however indicated that manure gave consistently higher maize stover yields without addition of inorganic fertiliser. This is possibly due to ample nutrient supply and the marginally higher soil organic matter levels in the sole manure plots than in the balanced NPK treatments.

In approximately 70% cases, the IMBAs utilised in this study increased photosynthesis and photosynthate accumulation in seeds substantially. Ahmed *et al.* (2007) indicated that the harvest index of modern wheat, rice, maize, sorghum, sunflower, dry bean, soybean and lentil cultivars is far below the international standards (0.8) and falls usually within the range of 0.4 to 0.6, which concur with values recorded in this study. The low harvest index of grain crops could be attributed to a number of factors. Such factors included the cultivation of non-recommended crop cultivars, unapproved seed used for sowing, late sowing, improper sowing methods, low plant population, poor crop protection and proliferation of weeds, imbalanced use of fertiliser and non-availability of

water at critical crop growth stages that subsequently cause less crop yield (Ahmed *et al.*, 2007). They indicated further that harvest index of existing crops has approached the upper limits and therefore, future grain yield will have to be sought through increased biomass production. They concluded that adequate rainfall and/or irrigation at critical crop growth stage is essential for crop growth and development, the absence of which, crop harvest index is significantly reduced. The low HI values from this study could be related to the unreliability of rainfall across the ecotopes which ultimately delayed planting and promoted poor stand establishment in some treatments. Similarly, one cultivar of maize was used across the study sites and therefore potentially this cultivar could not have been well adapted under certain localities.

The results of this study revealed that the IMBA treatments exerted inconsequential effects on maize performance across the seasons and ecotopes. However, the use of IMBAs that coincide with either blanket or reduced conventional inorganic NPK fertiliser application appeared to be the most promising for sustainable crop production. Conversely, no significant case of increase in grain yield was recorded following Lanbac and Montys applications. The manure-based IMBAs like Gromor and Promis gave no cases of significant influence for all yield and yield components parameters measured across the seasons and ecotopes. This suggests comparable yields with IMBAs of this nature are only possible through enrichment with inorganic NPK fertiliser. These results were evident therefore with Growmax that is a manure-based IMBA coincided with inorganic NPK fertiliser and recorded in many instances significantly higher yield and yield components parameters than sole NPK application. Gromor had the highest P (16 mg kg⁻¹ P) content of all the IMBA treatments which could possibly increase crop yields in soils where P is limiting. However, the constantly lower yields could be attributed to the fact that the soils in this study were not P deficient due fertilisation.

Application of Gliogrow had in comparison with the other IMBAs a deleterious effect on maize plant stand count throughout the three seasons of assessment, but gave comparative yield which could be attributed possibly to its prolific effects on cob length and kernel mass. Gliogrow, Growmax, K-humate and Montys gave only one case of significant stover yield increases compared to the NPK check while no significant case of increase was recorded with any of the other IMBAs. With regard to total biomass yield, Biozone, Gromor and K-humate applications registered no cases of significant

increase relative to the NPK standard. However, applications of Gliogrow, Growmax and Montys recorded more cases of significant increases compared to all the other IMBAs. The IMBA treatments assessed in this study promoted higher harvest index values in most cases, and therefore justify their recommendation and adoption while no significant cases of increase was registered with all the manure-based IMBAs like Gromor, Promis and Growmax. Higher values of harvest index were recorded more frequently in clayey than sandy soils. Applications of Gliogrow, Growmax, K-humate and Lanbac gave a significant positive effect on the number of cobs comparing to the NPK check. Of all the IMBAs, only Gliogrow measured significantly longer cobs compared to the NPK standard. The parameters of yield and yield components were in many instances steadily higher in the IMBA plots than unfertilised plots, particularly from IMBAs used as growth boosters other than the IMBAs used as complete replacement of conventional NPK fertiliser.

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CHAPTER 8

EFFECT OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS ON NITROGEN CONTENT, UPTAKE AND AGRONOMIC USE EFFICIENCY OF MAIZE UNDER DIFFERENT ECOTOPES

8.1 Introduction

Maize requires adequate amount of N for profitable production. Therefore, as a result of its dynamic nature, N should be managed efficiently throughout the growing period to minimise losses through different processes. Inadequate N supply during the first two to six weeks after planting can result in lower yield potentials (Jones, 1985). However maximum N uptake occurs during the month prior to tasseling and silking (Alley *et al.*, 2009). Thus, adequate N should be available for the crops during this period so that plant growth and hence yield are not limited by nutrient supplies. At this stage, significant amounts of N are transferred from leaf tissue to grain during the grain-fill process (Alley *et al.*, 2009).

The uptake of nutrients and their distribution to different parts of maize plants have been found to vary primarily with soil fertility, inorganic fertiliser application, growth stage and environmental conditions (Ologunde, 1974 cited by Hussaini *et al.*, 2008). Depending on the prevailing climatic conditions during plant growth, quantities of mineral substances taken up from soil may differ (Petr *et al.*, 1988). It is cardinal therefore from an agricultural point of view to study the content of nutritional elements in soil and plants (Alexandrova & Donovan, 2003). Mengel *et al.* (1982) indicated that the nitrogen content in maize depends not only on the peculiarities of the varieties of the cultivated hybrids, but also on the conditions of cultivation.

Plant tissue analyses have been used to reveal the deficiency, adequacy or excessive status of various nutrient elements in a soil-plant system. Regrettably, a serious limitation to its utility is the dynamic nature of nutrient concentration in plants in relation to their availability in the soil, either in the native state or through their addition to the soil in fertiliser (Hussaini *et al.*, 2008).

Many farmers on the African continent sometimes do not adopt the practice of blanket fertiliser recommendations and as a result, low nutrient-use efficiency prevails (FAO, 1978). However, correcting nutrient deficiency with the application of huge quantity of inorganic fertiliser is not a viable option for smallholder farmers due to high product prices (Carr, 1997 cited by Mweta *et al.*, 2007). Inorganic fertiliser application across the African continent is very low with an average of 20 kg NPK ha⁻¹ compared to a South African average of 69 kg NPK ha⁻¹ (Eilitta, 2006). However, inorganic fertiliser applications could amount from 80-100 kg NPK ha⁻¹ in Asia and North America (FAO, 2006). This study was therefore conducted to assess the influence of IMBAs on nitrogen content, uptake and agronomic use efficiency under different ecotopes.

8.2 Experimental procedure

The detailed procedure and description of this trial were duly given in Chapter 3, nevertheless, a concise description is provided herein. The trial assessed nine IMBAs at rates recommended by either the product manufacturers or suppliers in three production seasons at four sites. Recommended rates of inorganic NPK fertiliser at each site and the unamended control treatments were included as standard check. The inorganic NPK fertiliser treatment was applied in the form of limestone ammonium nitrate, superphosphate and potassium chloride, respectively. A randomised complete block design was used and each treatment replicated four times. Measurements were made of N content in plant biomass at 9th leaf, silking, and in grain and stover at harvest to calculate N uptake by these components and eventually agronomic use efficiency on applied N. The N content, uptake and agronomic use-efficiency data were subjected to analyses of variance using GenStat Release 14. Differences in treatment means were separated using Tukey's honestly significant difference post-hoc test at 5% probability level.

8.3 Results and discussion

8.3.1 Nitrogen content

The N content measured in plant biomass at 9th leaf, silking and harvesting under the different IMBA treatments across the seasons and localities is given in Table 8.1.

Table 8.1: Effect of IMBAs on N content (%) in plant biomass at 9th leaf, silking and harvesting during three production seasons at four sites

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
9th leaf stage																
Biozone	1.99	2.53	1.79bc	2.10	2.42a	2.68	2.62ab	1.77	2.77bc	2.37bc	2.55a	2.56	1.85bc	3.16a	3.60	2.87
Gliogrow	2.12	2.58	2.25a	2.32	2.27b	2.65	2.74a	1.80	3.04b	2.68ab	2.22b	2.65	1.97ab	3.10ab	3.52	2.86
Gromor	2.16	2.45	1.99abc	2.20	2.09cd	2.45	2.65ab	1.70	3.05b	2.59abc	2.00c	2.55	1.63bc	3.12a	3.78	2.84
Promis	1.92	2.33	1.70c	1.98	2.14bc	2.33	2.73a	1.69	3.03b	2.51abc	2.58a	2.71	2.18a	2.96ab	3.63	2.92
Growmax	2.13	2.43	2.03ab	2.20	2.07cd	2.43	3.03a	1.82	2.88b	2.59abc	2.65a	2.71	1.47cd	2.87b	3.62	2.65
Crop care	2.10	2.60	2.00abc	2.23	2.46a	2.45	2.67ab	1.71	3.02b	2.59abc	2.64a	2.75	1.82bc	3.08ab	3.54	2.81
K-humate	2.20	2.41	2.13ab	2.25	2.40ab	2.70	2.78ab	1.83	2.92b	2.82a	2.50a	2.75	1.53cd	3.02ab	3.54	2.70
Lanbac	2.27	2.65	1.81bc	2.24	2.10cd	2.26	2.48b	1.58	2.92b	2.45abc	2.29b	2.55	1.60bcd	2.87b	3.46	2.64
Montys	2.19	2.46	1.92bc	2.19	2.44a	2.46	2.40bc	1.62	3.03b	2.61ab	2.02c	2.55	1.41cd	2.95ab	3.43	2.60
NPK	2.10	2.47	1.88bc	2.15	2.25b	2.47	2.40b	1.62	3.40a	2.52abc	2.50a	2.81	1.83bc	2.96ab	3.50	2.76
Control	1.87	2.26	1.68c	1.94	1.98d	2.29	2.19c	1.49	2.54c	2.27c	2.20b	2.34	1.33d	2.85b	3.38	2.52
Mean	2.09	2.47	1.92		2.24	2.47	2.61		2.96	2.54	2.38		1.69	2.99	3.54	
SEM	0.19	0.24	0.15		0.06	0.23	0.13		0.15	0.16	0.08		0.13	0.12	0.13	
CV (%)	13.1	13.9	13.5		4.1	13.1	7.3		7.4	8.9	4.8		11.8	5.6	5.2	
LSD _{T(0.05)}	0.40	0.49	0.30		0.13	0.47	0.28		0.32	0.33	0.16		0.29	0.24	0.26	
Silking stage																
Biozone	1.23ab	2.03ab	1.23bcd	1.50	0.83bc	1.78ab	1.38de	1.05	2.05ab	1.68ab	2.06abc	1.93	1.49ab	1.83ab	1.59abc	1.64
Gliogrow	1.20b	2.22a	1.05cd	1.49	1.00ab	1.94a	1.76ab	1.23	1.90abc	1.89a	2.24ab	2.01	1.55a	1.93ab	1.99a	1.82
Gromor	0.65cd	1.92ab	1.45b	1.34	0.82bc	1.65ab	1.42de	1.02	1.34de	1.59bc	2.03abc	1.65	1.30abc	1.69b	1.25bc	1.41
Promis	0.87bcd	1.81b	1.38bc	1.35	0.73bc	1.79ab	1.57cd	1.12	1.34de	1.56bc	1.90bc	1.60	1.54a	2.02a	1.22c	1.59
Growmax	1.30ab	2.00ab	1.90a	1.73	1.33a	1.60ab	1.46d	1.02	1.68bcd	1.43bc	2.15ab	1.75	1.04cd	1.73ab	1.90ab	1.56
Crop care	0.98bc	1.69b	1.28bc	1.32	0.87bc	1.80ab	1.68bc	1.16	1.90abc	1.64abc	2.17ab	1.90	1.14cd	1.76ab	1.45abc	1.45
K-humate	1.13bc	2.05ab	1.58ab	1.59	1.03ab	1.66ab	1.67bc	1.11	2.27a	1.68ab	2.30a	2.08	1.20cd	1.92ab	1.64abc	1.59
Lanbac	1.62a	1.96ab	1.00cd	1.53	0.94bc	1.83ab	1.75b	1.19	1.58cd	1.60bc	2.15ab	1.78	1.34abc	1.95ab	1.62abc	1.64
Montys	0.78cd	2.28a	1.38bc	1.48	0.75bc	1.72ab	1.61c	1.11	1.28de	1.72ab	2.14ab	1.71	1.32abc	2.01a	1.47abc	1.60
NPK	0.99bc	1.99ab	1.25bcd	1.41	0.84bc	1.60ab	1.87a	1.16	1.58cd	1.53bc	1.99bc	1.70	1.23bc	1.97ab	1.67abc	1.62
Control	0.48d	1.71b	0.88d	1.02	0.63c	1.49b	1.33e	0.94	1.10e	1.40c	1.82c	1.44	0.93d	1.67b	1.34abc	1.31
Mean	1.02	1.97	1.30		0.89	1.71	1.59		1.64	1.61	2.09		1.28	1.86	1.56	
SEM	0.19	0.23	0.18		0.17	0.16	0.06		0.19	0.13	0.14		0.14	0.14	0.19	
CV (%)	26.8	16.3	15.8		27.2	13.6	4.9		16.3	11.1	9.7		14.8	11.0	17.6	
LSD _{T(0.05)}	0.39	0.46	0.38		0.35	0.34	0.11		0.39	0.26	0.29		0.27	0.30	0.40	

Table 8.1: Continue

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Grain at harvest																
Biozone	1.09ab	1.32ab	1.32bc	1.24	1.70ab	1.27cd	1.35a	1.44	1.49a	1.37bc	1.43ab	1.43	1.39a	1.49abc	1.52ab	1.47
Gliogrow	1.17ab	1.39ab	1.33bc	1.30	1.74a	1.34bc	1.21bcd	1.43	1.49a	1.46ab	1.47a	1.47	1.35ab	1.52abc	1.51ab	1.46
Gromor	1.13ab	1.18c	1.40a	1.24	1.70ab	1.24d	1.07def	1.34	1.43abc	1.33c	1.25c	1.34	1.19cd	1.53abc	1.40c	1.37
Promis	1.12ab	1.28bc	1.40a	1.27	1.49c	1.36b	1.06def	1.30	1.39abc	1.49ab	1.40ab	1.43	1.21cd	1.44bcd	1.47bc	1.37
Growmax	1.08bc	1.32ab	1.37ab	1.26	1.57b	1.32bc	1.04ef	1.31	1.38bc	1.39bc	1.28c	1.35	1.18d	1.43cd	1.53ab	1.38
Crop care	1.11ab	1.33ab	1.34bc	1.26	1.67abc	1.33bc	1.28ab	1.43	1.49a	1.51a	1.39abc	1.46	1.27bcd	1.56a	1.54ab	1.46
K-humate	1.19a	1.27bc	1.41a	1.29	1.68ab	1.44a	1.15cde	1.42	1.48ab	1.38bc	1.44ab	1.43	1.26bcd	1.54a	1.61 a	1.47
Lanbac	1.07bc	1.24bc	1.28cd	1.20	1.73a	1.37ab	1.13cde	1.41	1.41abc	1.53a	1.44ab	1.46	1.24cd	1.47abcd	1.52ab	1.41
Montys	1.10ab	1.42a	1.37ab	1.30	1.66abc	1.38ab	1.23bc	1.42	1.48ab	1.41bc	1.39abc	1.43	1.26bcd	1.57a	1.53ab	1.45
NPK	1.07bc	1.37ab	1.36ab	1.27	1.72a	1.36b	1.20bcd	1.43	1.44abc	1.45ab	1.05d	1.31	1.27bcd	1.53abc	1.50bc	1.43
Control	0.99c	1.18c	1.24d	1.14	1.54c	1.28cd	1.01f	1.28	1.34c	1.39bc	1.03d	1.25	1.23cd	1.38d	1.25d	1.29
Mean	1.10	1.30	1.34		1.65	1.33	1.16		1.44	1.43	1.32		1.26	1.49	1.48	
SEM	0.05	0.06	0.03		0.06	0.03	0.05		0.05	0.06	0.05		0.05	0.05	0.05	
CV (%)	6.4	6.7	2.9		5.5	3.5	5.8		5.0	5.5	5.6		5.3	4.5	4.8	
LSD _{T(0.05)}	0.10	0.12	0.06		0.13	0.07	0.10		0.10	0.11	0.11		0.10	0.10	0.10	
Stover at harvest																
Biozone	0.51	0.65c	0.74ab	0.63	0.63a	0.78a	0.42a	0.61	1.01ab	1.07ab	0.52bc	0.87	0.62ab	0.73b	0.44b	0.60
Gliogrow	0.60	0.79bc	0.75ab	0.71	0.53ab	0.58cd	0.30cde	0.47	0.91abc	0.94b	0.58ab	0.81	0.74a	0.94b	0.57ab	0.75
Gromor	0.41	0.68bc	0.52bc	0.54	0.48ab	0.49cd	0.29cde	0.42	0.66d	0.60d	0.44cd	0.57	0.47bc	0.95b	0.45b	0.62
Promis	0.42	0.73bc	0.39bc	0.51	0.63a	0.45d	0.25de	0.44	0.88abcd	0.98b	0.36d	0.74	0.44c	0.72b	0.48b	0.55
Growmax	0.46	0.76bc	0.59abc	0.60	0.46ab	0.60bc	0.25de	0.44	1.03a	1.35a	0.55bc	0.98	0.52bc	0.78b	0.60ab	0.63
Crop care	0.60	0.73bc	0.80abc	0.71	0.44ab	0.55cd	0.40a	0.46	0.88abcd	1.07ab	0.55bc	0.83	0.44c	1.28a	0.51b	0.74
K-humate	0.55	1.55a	0.86a	0.99	0.58a	0.53cd	0.33bcd	0.48	1.01ab	0.77bcd	0.70a	0.83	0.51bc	0.83b	0.74a	0.69
Lanbac	0.48	0.86b	0.54bc	0.63	0.64a	0.74ab	0.36abc	0.58	0.87abc	0.72cd	0.61ab	0.73	0.47bc	0.83b	0.46b	0.59
Montys	0.54	0.73bc	0.59abc	0.62	0.46ab	0.60bc	0.39ab	0.48	0.99ab	0.78bcd	0.47cd	0.75	0.50b	1.44a	0.53b	0.82
NPK	0.48	0.78bc	0.82ab	0.69	0.63a	0.53cd	0.40a	0.52	1.02ab	0.85bcd	0.66ab	0.84	0.47b	0.88b	0.60ab	0.65
Control	0.49	0.65c	0.33c	0.49	0.37b	0.50cd	0.24e	0.37	0.75cd	0.72cd	0.44cd	0.64	0.37c	0.76b	0.48b	0.54
Mean	0.50	0.81	0.63		0.53	0.58	0.33		0.91	0.89	0.53		0.50	0.92	0.53	
SEM	0.10	0.10	0.15		0.11	0.07	0.04		0.11	0.15	0.06		0.08	0.15	0.09	
CV (%)	26.8	16.8	33.4		28.8	16.9	16.9		16.6	23.2	16.9		22.3	23.3	24.7	
LSD _{T(0.05)}	0.20	0.20	0.30		0.22	0.14	0.08		0.22	0.30	0.13		0.16	0.31	0.19	

Means with the same letters within a column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

8.3.1.1 **Bethlehem**

Concerning N content in plant biomass at 9th leaf stage, none of the IMBAs differed significantly from one another and also from either the NPK or control treatments in 2006/07 2007/08. The only significant difference manifested in 2008/09 when Gliogrow gave higher plant biomass N content than any of the IMBAs including either the NPK or control treatments. In this regard, the only exception was Gromor, Growmax, Crop care and K-humate. More so, none of the IMBAs had lower N content compared to the control in all three seasons. The content of N in plant biomass amongst the IMBAs ranged from 1.92 to 2.27% in 2006/07, 2.33 to 2.65% in 2007/08, and 1.70 to 2.25% in 2008/09.

At silking stage, none of the IMBAs caused a significantly lower N content in plant biomass compared to the NPK treatment and also to the control. In fact Lanbac in 2006/07 and Growmax 2008/09 gave significantly higher N content in plant biomass when the NPK treatment served as reference. For the IMBA treatments, the plant biomass N content from Lanbac in 2006/07 was significantly higher than any of the IMBA treatment, except for Biozone and Growmax. However in 2008/09, the N content of plant biomass with Growmax was significantly higher than any of the other IMBA treatment. The only exception was K-humate in this regard. The N content of plant biomass varied between 0.65% with Gromor and 1.62% with Lanbac in 2006/07, 1.69% with Crop care and 2.28% with Montys in 2007/08, and 1.00% with Lanbac and 1.90% with Growmax in 2008/09. In comparison with the control, plant biomass N content from virtually all the IMBA treatments was significantly higher in all three seasons.

Grain N content ranged from 1.07% with Lanbac to 1.19% with K-humate in 2006/07, 1.18% with Gromor to 1.42% with Montys in 2007/08, and 1.28% with Lanbac to 1.41% with K-humate in 2008/09. With regard to the NPK check, significantly higher grain N content was with K-humate in 2006/07 and was with Gromor in 2007/08 significantly lower. The difference in N content of grain at harvest amongst some of the IMBAs was significant in all the three seasons. Generally, grain N content from treatments with K-humate in 2006/07, Montys in 2007/08, and Gromor, Promis and K-humate in 2008/09 was consistently higher than all the other IMBA treatments. In comparison with the control, none of the IMBAs gave significantly lower grain N content in any of the three seasons. However, virtually all the IMBAs resulted in significantly higher grain N

content than in the unfertilised plots. The only exception in this regard was Lanbac in 2006/07 and K-humate and Lanbac in 2007/08.

The N content of stover at harvest varied between 0.41% with Gromor and 0.60% with Gliogrow in 2006/07, 0.65% with Biozone and 1.55% with K-humate in 2007/08, and 0.39% with Promis and 0.86% with K-humate in 2008/09. These differences in stover N content were significant only in 2007/08 and 2008/09. In these seasons, K-humate had significantly higher N content of stover than any of the other IMBAs and also from the NPK treatment only in 2007/08. More so, stover N content from K-humate plots was higher compared to the NPK treatment in each season. In comparison with the control, Gromor, Promis, Growmax and Lanbac in 2006/07 had lower N content in stover, though not significantly. In fact stover N content from treatment with K-humate was significantly higher in 2007/08 and 2008/09, and also Biozone and Gliogrow in 2008/09.

8.3.1.2 **Bothaville**

Amongst the IMBA treatments, the lowest and highest N content in plant biomass at 9th leaf stage was 2.07% with Growmax and 2.46% with Crop care in 2006/07, 2.26% with Lanbac and 2.70% with K-humate in 2007/08, and 2.40% with Montys and 3.03% with Growmax in 2008/09. Significant differences amongst some of the IMBAs and also between the IMBAs and the NPK check were observed in 2006/07 and 2008/09. Generally amongst the IMBAs, N content from treatments with Biozone, Crop care, K-humate and Montys in 2006/07 and Growmax in 2008/09 was highest. Comparing to the NPK check, plant biomass N content with Biozone, Crop care and Montys in 2006/07 and Gliogrow and Growmax in 2008/09 was significantly higher. Likewise, Biozone, Gliogrow and K-humate had higher plant biomass N content in each season. Only Lanbac in 2007/08 gave lower plant biomass N content in comparison with the control, though not significantly. However, the N content of plant biomass from Biozone, Gliogrow, Crop care, K-humate and Montys treatments was significantly higher than the control in 2006/07. Similar differences in plant biomass N content were recorded with Gliogrow, Promis, Growmax, Crop care and K-humate in 2008/09.

At silking stage, some of the IMBAs gave significantly higher plant biomass N content compared to those in the control check in each of the three seasons, but differed significantly compared to the NPK check only in 2006/07. Significantly higher plant

biomass N content was obtained with Growmax in 2006/07 while virtually all the IMBAs resulted in 2008/09 with significantly lower N content of plant biomass than the NPK check, except for Gliogrow. For the IMBA treatments in 2006/07, N content in plant biomass from treatment with nearly all the IMBAs was significantly lower than Growmax plots, except for Gliogrow and K-humate. Similarly in 2008/09, Biozone, Gromor, Promis, Growmax and Montys had significantly lower plant biomass N content than Gliogrow. The plant biomass N content ranged from 0.73 to 1.33% in 2006/07, 1.60 to 1.94% in 2007/08, and 1.38 to 1.87% in 2008/09.

The grain N content recorded at harvest for the IMBAs differed significantly in every season. For example, Gliogrow in 2006/07 recorded significantly higher grain N content than Growmax, K-humate in 2007/08 than any of the IMBAs, except for Lanbac and Montys, and Biozone in 2008/09 than any of the IMBAs, except for Crop care. Grain N content recorded with K-humate in 2007/08 and Biozone in 2008/09 was significantly higher than in the NPK check. Compared to the control, Promis in 2006/07 and Biozone and Gromor in 2007/08 had lower N content in grain, though not significantly. However, grain N content recorded with all the other IMBAs was significantly higher in all three seasons. The grain N content amongst the IMBAs ranged from 1.49 to 1.74% in 2006/07, 1.24 to 1.44% in 2007/08, and 1.04 to 1.35% in 2008/09.

The N content in stover at harvest varied between 0.44% in Crop care and 0.64% in Lanbac in 2006/07, 0.45% with Promis and 0.78% with Biozone in 2007/08, and 0.25% with Promis and 0.42% with Biozone in 2008/09. The differences in stover N content amongst some of the IMBAs were significant in 2007/08 and 2008/09. Stover N content was with Promis in 2007/08 significantly lower, and was with Biozone and Lanbac in 2008/09 significantly higher than with the NPK treatment. None of the IMBAs recorded lower N content in stover compared to the control with the exception of Gromor in 2007/08, though not significantly. However, Biozone and Lanbac (all seasons), Crop care and K-humate (2006/07 and 2008/09), Promis in 2006/07 and Montys in 2008/09 gave significantly higher N content in stover than in the unfertilised plots.

8.3.1.3 **Ottosdal**

The N content in plant biomass at 9th leaf stage varied between 2.77% with Biozone and 3.40% with Gromor in 2006/07, 2.37% with Biozone and 2.82% with K-humate in

2007/08, and 2.02% with Montys and 2.65% with Growmax in 2008/09. These differences amongst some of the IMBAs were significant only in 2007/08 and 2008/09. In not any of the three seasons the IMBAs had either significantly higher plant biomass N content than the NPK check. In fact the NPK treatment gave significantly higher plant biomass N content than any of the IMBA treatment in 2006/07 and Gliogrow, Gromor, Lanbac and Montys in 2008/09. For each of the three seasons, only Gromor and Montys in 2008/09 performed poorer than the control, though not significantly. In fact, the IMBA treatments had in many instances significantly higher plant biomass N content than in the unfertilised plots.

At silking stage, none of the IMBA treatments gave lower N content in plant biomass compared to those in the control with significant differences observed between them in all three seasons. Comparing to the NPK treatment, Biozone and K-humate in 2006/07, Gliogrow in 2007/08 and K-humate in 2008/09 exerted significantly higher plant biomass N content. On the other hand, plant biomass N content from treatments with Biozone, Gliogrow, Crop care, K-humate and Lanbac was consistently highest throughout the three seasons. Amongst the IMBAs, Biozone and K-humate gave significantly higher plant biomass N content than Gromor, Promis and Montys in 2006/07, while Growmax gave significantly lower plant biomass N content than Gliogrow in 2007/08. However in 2008/09, Promis recorded significantly lower plant biomass N content than in the K-humate plots. Plant biomass N content amongst the IMBAs ranged from 1.28 to 2.27% in 2006/07, 1.43 to 1.89% in 2007/08, and 1.90 to 2.30% in 2008/09.

For the IMBA treatments, Biozone, Gliogrow and Crop care (2006/07), Crop care and Lanbac (2007/08), and Gliogrow (2008/09) gave the highest grain N content at harvest. However, significant differences amongst some of the IMBAs were found in all three seasons. Grain N content ranged amongst the IMBA treatments from 1.38 to 1.49% in 2006/07, 1.33 to 1.53% in 2007/08, and 1.25 to 1.47% in 2008/09. None of the IMBAs had significantly lower N content in grain compared to the NPK check. However, grain N content was significantly higher in 2008/09 irrespective of the IMBA type. Only Biozone, Gromor, Growmax and K-humate in 2007/08 performed poorer than the control, though not significantly. However, several of the other IMBAs recorded significantly higher grain N content than the unfertilised plots in all the three seasons.

The differences in stover N content at harvest for the IMBA treatments were significant in all the three seasons. Generally, stover N content from treatments with Growmax, K-humate and Lanbac was highest. These three IMBAs also differed significantly from one another. The N content of stover amongst the IMBAs ranged from 0.66 to 1.03% in 2006/07, 0.60 to 1.35% in 2007/08, and 0.34 to 0.70% in 2008/09. Comparing to the NPK treatment, significantly higher N content in stover was recorded with Growmax in 2007/08 and was with Promis significantly lower in 2008/09. Concerning the control, Gromor respectively in 2006/07 and 2007/08, Lanbac in 2007/08 and Promis in 2008/09 had lower N content in stover, though not significantly. However, Biozone, Growmax, K-humate and Monty in 2006/07, Growmax in 2007/08, and Gliogrow, K-humate and Lanbac in 2008/09 had significantly higher stover N content.

8.3.1.4 **Potchefstroom**

At 9th leaf stage, none of the IMBAs had lower N content in plant biomass than the control in each season. Significant differences amongst some of the IMBAs and control were found in 2006/07 and 2007/08. In comparison with the NPK check, Promis in 2006/07 recorded significantly higher plant biomass N content. More so, plant biomass N content of Biozone, Gliogrow, Gromor and Promis was higher than the NPK treatment in any of the three seasons. The N content in plant biomass ranged from 1.04% with Growmax to 1.55% with Gliogrow in 2006/07, 2.87% with Growmax to 3.16% with Biozone in 2007/08, and 3.43% with Montys to 3.78% with Gromor in 2008/09. Some significant differences amongst the IMBAs were observed in 2006/07 and 2007/08.

The differences in plant biomass N content at silking stage amongst some of the IMBAs were significant in all three seasons. Generally, plots treated with Gliogrow and Promis in 2006/07, Promis and Montys in 2007/08, and Gliogrow in 2008/09 had higher N content in plant biomass than the other IMBA treatments. None of the IMBAs gave during the three seasons significantly lower plant biomass N content than the NPK treatment. In fact Gliogrow and Promis gave in 2006/07 significantly higher biomass N content. In comparison with the control, only plots treated with Gromor and Promis had lower plant biomass N content in 2008/09. However, N content in plant biomass of virtually all the IMBAs in 2006/07, Promis and Montys in 2007/08, and Gliogrow in 2008/09 were significantly higher. Plant biomass N content ranged amongst the IMBAs from 1.41 to 2.18% in 2006/07, 1.69 to 2.02% in 2007/08, and 1.22 to 1.99% in 2008/09.

The N content of grain at harvest ranged from 1.18% with Growmax to 1.39% with Biozone in 2006/07, 1.43% with Growmax to 1.57% with Montys in 2007/08, and 1.40% with Gromor to 1.61% with K-humate in 2008/09. However, the differences amongst them were significant in any of the three seasons. Plots treated with Biozone and Gliogrow in 2006/07, Crop care, K-humate and Montys in 2007/08, and K-humate in 2008/09 generally had the highest grain N content. Comparing to the NPK check, Biozone and K-humate in 2006/07 and 2008/09 respectively resulted in significantly higher grain N content. With regard to the control, the IMBA treatments had in many instances significantly higher N content of grain.

The lowest and highest N content of stover amongst the IMBA treatments was found with Promis (0.44%) and Gliogrow (0.74%) in 2006/07, Promis (0.72%) and Montys (1.44%) in 2007/08, and Biozone (0.44%) and K-humate (0.74%) in 2008/09. These differences were significant in each of the three seasons. With regard to the NPK check, Gliogrow in 2006/07, and Crop care and Montys in 2007/08 recorded significantly higher stover N content. These IMBAs gave also significantly higher stover N content than the control in the respective seasons and also K-humate in 2008/09.

8.3.2 Nitrogen uptake

The N uptake calculated in plant biomass recorded at 9th leaf, silking and harvesting in the different IMBAs across the seasons and localities are given in Table 8.2.

8.3.2.1 Bethlehem

For each of the three seasons, none of the IMBAs differed significantly than the NPK check on N uptake in plant biomass at 9th leaf stage. Similarly, none of the IMBAs gave lower plant biomass N uptake than the control, except for Gromor in 2007/08. However, the differences amongst some of the IMBAs (all seasons) and between some of the IMBAs and the control were significant (2006/07 and 2007/08). The plant biomass N uptake varied between 4.86 kg ha⁻¹ (Promis) and 11.4 kg ha⁻¹ (K-humate) in 2006/07, 4.68 kg ha⁻¹ (Gromor) and 16.0 kg ha⁻¹ (K-humate) in 2007/08, and 17.9 kg ha⁻¹ (Gliogrow and Gromor) and 27.8 kg ha⁻¹ (Lanbac) in 2008/09.

Table 8.2: Effect of IMBAs on N uptake (kg ha⁻¹) in plant biomass at 9th leaf, silking and harvesting during three production seasons at four sites

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
9th leaf stage																
Biozone	8.7ab	11.7abc	21.2ab	13.9	15.6abc	16.7ab	38.6abc	23.6	29.3ab	25.9a	37.7a	31.0	17.2a	32.2a	58.7ab	36.0
Gliogrow	5.8bcd	9.9abc	17.9b	11.2	18.6ab	18.1ab	34.3abc	23.7	32.7ab	20.7ab	28.3ab	27.2	17.7a	27.0ab	55.1ab	33.3
Gromor	6.8abcd	4.7c	17.9b	9.8	19.0ab	8.3c	33.5abc	20.3	34.3a	19.2b	29.6ab	27.7	18.3a	24.5ab	42.9bc	28.6
Promis	4.9cd	8.6abc	21.9ab	11.8	15.2abc	12.1bc	33.1abc	20.1	34.7a	25.7ab	31.7ab	30.7	15.2ab	25.8ab	50.3abc	30.4
Growmax	10.1ab	9.9abc	25.9ab	15.3	17.3ab	13.5abc	50.9a	27.2	32.3ab	30.4a	43.1a	35.3	14.0ab	22.6b	47.0abc	27.9
Crop care	7.7ab	15.8a	20.8ab	14.8	20.2ab	18.5ab	44.7ab	27.8	33.2ab	28.3a	35.5a	32.3	13.0ab	24.4ab	44.6bc	27.3
K-humate	11.4a	16.0a	20.0ab	15.8	20.3ab	21.9a	41.4abc	27.9	39.3a	28.6a	33.7ab	33.9	15.0ab	26.8ab	48.0abc	29.9
Lanbac	5.4c	14.1ab	27.8ab	15.8	16.6abc	12.9bc	38.2abc	22.6	32.3ab	29.1a	26.6ab	29.3	11.0ab	26.6ab	58.2ab	31.9
Montys	7.5abcd	11.6abc	24.7ab	14.6	22.1a	15.3abc	32.1abc	23.2	36.4a	24.3ab	29.1ab	29.9	16.6a	25.9ab	63.5a	35.3
NPK	9.8ab	14.6ab	31.7a	18.7	14.1abc	18.3ab	28.4bc	20.3	36.6a	28.2a	28.7ab	31.2	18.8a	22.2b	53.6ab	31.5
Control	3.0d	7.9bc	14.9b	8.6	8.0c	11.6bc	23.8c	14.5	22.4b	19.1b	17.3b	19.6	7.5b	20.7b	35.2c	18.6
Mean	7.4	11.3	22.2		17.0	15.2	36.3		33.0	25.4	31.0		14.9	25.3	50.6	
SEM	2.22	3.45	6.63		4.22	4.04	9.31		5.30	2.23	8.66		3.88	4.10	9.18	
CV (%)	42.7	45.4	42.2		35.1	37.6	36.3		22.7	17.9	39.5		36.7	22.9	25.6	
LSD _{T(0.05)}	4.54	7.45	13.6		8.62	8.23	19.0		10.8	6.59	17.7		7.92	8.37	18.7	
Silking stage																
Biozone	41.3ab	53.5a	60.6abc	51.8	19.9a	69.2a	47.4c	45.5	80.2ab	63.0ab	73.6abc	72.3	74.8ab	60.3ab	56.7abc	63.9
Gliogrow	42.5ab	59.5a	76.8a	59.6	23.5a	71.2ab	57.8b	50.8	60.5cd	60.9ab	78.5ab	66.6	69.6ab	58.7ab	68.1a	65.5
Gromor	20.4bc	49.0a	71.8ab	47.1	17.6ab	38.4bc	45.7c	33.9	36.8ef	49.7b	81.8a	56.1	66.1b	51.8bc	36.6d	51.5
Promis	31.0abc	59.1a	56.7abc	48.9	12.9ab	55.4ab	54.3b	40.9	42.7def	63.8ab	61.8cd	56.1	80.6a	63.0ab	46.9cd	63.5
Growmax	37.4b	61.3a	53.1bc	50.6	28.1a	55.4ab	53.6b	45.7	61.9bc	58.2ab	73.3abc	64.5	55.1bc	54.3abc	57.0abc	55.5
Crop care	26.6bc	53.0a	65.3ab	48.3	21.5a	71.8a	57.1b	50.1	60.6cd	64.4ab	80.3ab	68.4	74.3ab	58.9ab	47.8cd	60.3
K-humate	29.3bc	66.9a	74.6ab	56.9	22.1a	66.6ab	58.2b	49.0	89.4a	64.8a	66.5bcd	73.6	48.8c	64.7ab	57.8abc	57.1
Lanbac	60.0a	62.8a	68.5ab	63.8	25.0a	69.9ab	56.8b	50.6	56.9cd	63.7ab	74.4abc	65.0	60.9bc	68.4a	60.0abc	63.1
Montys	24.4bc	64.9a	61.4abc	50.2	14.0ab	59.4ab	55.7b	43.0	37.2ef	69.0a	77.1ab	61.1	54.3bc	64.3ab	56.9abc	58.5
NPK	32.5b	60.2a	63.2ab	52.0	15.3a	71.5ab	69.0a	51.9	52.9cde	62.2ab	74.6ab	63.2	68.8abc	67.3a	63.7ab	66.6
Control	11.3c	27.5b	41.0c	26.6	9.9b	26.4c	30.1d	22.1	25.9f	31.1c	52.3d	36.4	30.4d	42.4c	34.1d	35.6
Mean	32.4	56.1	63.0		19.1	59.6	53.2		55.0	59.2	72.2		62.2	59.5	53.2	
SEM	9.99	9.18	10.2		4.36	13.0	3.54		9.23	7.31	7.04		6.61	7.11	7.39	
CV (%)	43.6	23.1	22.8		32.3	30.9	9.4		23.7	15.6	13.8		15.0	16.9	19.6	
LSD _{T(0.05)}	20.4	18.7	20.8		8.90	26.5	7.24		18.9	14.9	14.4		13.5	14.5	15.1	

Table 8.2: Continue

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Grain at harvest																
Biozone	24.6abc	27.7abc	32.5abc	28.3	45.5ab	48.1ab	47.5a	47.0	39.3abc	48.0ab	52.5abc	46.6	46.5ab	83.7ab	67.3abc	65.8
Gliogrow	26.3ab	32.6abc	38.7abc	32.5	40.8ab	43.6abc	37.1abc	40.5	48.6a	34.1c	59.7a	47.5	49.9a	69.6bc	68.0abc	62.5
Gromor	21.1bc	19.2c	40.4abc	26.9	31.1bc	24.0de	19.3cd	24.8	41.0abc	41.1bc	40.0c	40.7	22.6e	65.3c	48.8d	45.6
Promis	26.3ab	30.0abc	52.9ab	36.4	37.3b	39.9bc	29.1bcd	35.4	38.8abc	50.8ab	47.6bc	45.7	40.2abc	75.2abc	58.7cd	58.0
Growmax	26.2ab	41.0a	53.9a	40.4	35.7b	33.4cd	24.3cd	31.1	34.1bc	33.6bc	61.9a	43.2	30.7bcde	73.9abc	83.0a	62.5
Crop care	22.1bc	35.7ab	45.9ab	34.6	45.8ab	46.0abc	41.3ab	44.4	45.3abc	50.7ab	57.7ab	51.2	35.6cd	82.9abc	78.7ab	65.7
K-humate	29.8a	33.7ab	41.8abc	35.1	40.3ab	55.1a	40.0ab	45.1	44.8abc	48.6ab	54.1abc	49.2	41.6abc	88.3a	76.3abc	68.7
Lanbac	25.7ab	24.3bc	43.8ab	31.3	42.0ab	38.2bc	29.0bcd	36.4	44.3abc	53.8a	60.4ab	52.8	33.8cd	81.9abc	72.6abc	62.8
Montys	26.2ab	34.7ab	37.3abc	32.7	39.2b	38.5bc	32.2bcd	36.6	47.0ab	47.6ab	55.9ab	50.2	35.1cd	83.3abc	60.2cd	59.5
NPK	24.6abc	32.0ab	33.03abc	29.9	51.5a	44.7abc	31.4bcd	42.5	44.6ab	46.7ab	41.9c	44.4	42.4abc	77.7abc	63.4bcd	61.2
Control	17.7c	19.1c	19.9c	18.9	23.4c	19.8e	14.7d	19.3	32.1c	40.6bc	21.9d	20.8	24.5de	35.1d	32.1e	30.6
Mean	24.6	30.0	40.0		39.3	39.2	31.4		41.8	45.1	50.3		36.6	74.3	64.5	
SEM	3.4	6.8	10.5		5.6	6.8	5.2		6.7	5.2	6.5		4.8	8.9	7.9	
CV (%)	19.7	31.9	37.0		20.0	24.4	23.4		22.8	16.4	18.3		18.4	16.9	17.3	
LSD _{T(0.05)}	6.98	13.8	21.4		11.4	13.8	10.6		13.8	10.7	13.3		9.7	18.1	16.1	
Stover at harvest																
Biozone	15.9ab	12.7b	15.2a	14.6	12.8a	24.1a	10.0ab	15.6	20.5abc	30.5bc	14.5c	21.8	13.9ab	25.5b	14.1ab	17.8
Gliogrow	15.9ab	17.8b	11.3ab	15.0	8.66ab	24.4a	6.55bc	13.2	15.8cd	45.8a	19.4bc	27.0	18.0a	27.5b	15.9ab	20.5
Gromor	9.07c	11.2b	9.01abcd	9.8	9.51ab	13.5abc	5.00bc	9.3	14.4cd	16.2d	16.6bc	15.7	10.7bc	27.7b	13.1b	17.2
Promis	13.6abc	15.4b	6.76cd	11.9	10.6ab	13.7abc	7.00bc	10.4	16.2cd	30.5bc	14.0c	20.2	10.6bc	25.6b	16.0ab	17.4
Growmax	12.6abc	18.5b	10.8ab	14.0	11.0ab	20.5ab	8.85abc	13.5	25.2abc	40.9ab	16.9bc	27.7	14.8ab	27.5b	16.0ab	19.4
Crop care	17.4a	15.3b	13.6ab	15.4	6.79ab	16.1bc	12.3a	11.7	19.6c	31.1bc	23.1abc	24.6	12.6b	44.1a	14.3ab	23.7
K-humate	12.0abc	36.7a	12.8ab	20.5	11.0ab	18.0abc	11.1ab	13.4	22.2ab	26.3cd	29.0a	25.8	13.2ab	29.4b	22.1a	21.6
Lanbac	14.3abc	19.3b	9.00abcd	14.2	11.5ab	23.8a	10.1ab	15.1	19.8bc	21.6cd	17.0bc	19.5	13.3ab	28.2b	14.6ab	18.7
Montys	13.5abc	14.3b	8.41abcd	12.1	9.36ab	20.0ab	11.4ab	13.6	19.4c	26.2cd	19.4bc	21.7	12.7ab	53.9a	18.7ab	28.4
NPK	13.8abc	14.7b	14.6ab	14.4	12.7ab	17.9abc	11.7ab	14.1	25.5a	29.9bc	25.3ab	26.9	11.7bc	29.0b	18.7ab	19.8
Control	11.1bc	9.45b	3.97d	8.2	6.53b	11.9c	4.78c	7.7	13.8d	22.2cd	14.3c	16.8	6.55c	21.5b	14.0ab	14.0
Mean	13.6	16.9	10.5		10.4	18.5	9.0		19.3	29.2	19.0		12.6	30.9	16.1	
SEM	2.8	4.6	3.3		3.0	3.6	2.5		2.7	5.6	4.6		2.6	6.4	3.2	
CV (%)	29.6	38.7	45.2		42.5	27.4	39.7		19.9	27.0	34.3		29.0	29.4	28.2	
LSD _{T(0.05)}	5.8	9.4	6.8		6.2	7.3	5.1		5.5	11.4	9.4		5.3	13.1	6.6	

Means with the same letters within a column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

At silking stage, N uptake in plant biomass from all the IMBA treatments was not significantly lower compared to the NPK check in any of the three seasons. In fact, Lanbac in 2006/07 recorded significantly higher plant biomass N uptake. Significant differences in plant biomass N uptake amongst some of the IMBAs were observed in 2006/07 and 2008/09, but the differences amongst some of the IMBAs and the control check were significant in any of the three seasons. For the IMBA treatments, the lowest and highest N uptake in plant biomass were recorded from Gromor (20.4 kg ha⁻¹) and Lanbac (60.0 kg ha⁻¹) in 2006/07, Gromor (49.0 kg ha⁻¹) and K-humate (66.9 kg ha⁻¹) in 2007/08, and Growmax (53.1 kg ha⁻¹) and Gliogrow (76.8 kg ha⁻¹) in 2008/09.

With regard to grain N uptake, the IMBA treatments differed significantly from one another in 2006/07 and 2007/08 while no significant result obtained between the IMBAs and NPK treatment in all three seasons. Despite this insignificance, Gliogrow, Growmax, Crop care, K-humate and Montys had consistently higher N uptake in grain than the NPK check. Grain N uptake ranged from 21.1 kg ha⁻¹ with Gromor to 29.8 kg ha⁻¹ with K-humate in 2006/07, 19.2 kg ha⁻¹ with Gromor to 41.0 kg ha⁻¹ with Growmax in 2007/08, and 32.5 kg ha⁻¹ with Biozone to 53.9 kg ha⁻¹ with Growmax in 2008/09. In relation to the control, Crop care in 2006/07, K-humate in 2007/08 and nearly all the IMBAs in 2008/09 resulted with significantly higher grain N uptake at harvest.

The stover N uptake at harvest amongst the IMBAs and between the IMBAs and control differed significantly from one another in each season while significant differences manifested only in 2007/08 compared to the NPK check. The significant differences in 2007/08 were due to the substantial higher stover N uptake from K-humate plots. The lowest values of stover N uptake was recorded from Gromor respectively in 2006/07 (9.07 kg ha⁻¹) and 2007/08 (11.2 kg ha⁻¹), and Promis in 2008/09 (6.76 kg ha⁻¹), while Crop care (17.4 kg ha⁻¹) in 2006/07, K-humate (36.7 kg ha⁻¹) in 2007/08, and Biozone (15.6 kg ha⁻¹) in 2008/09 had the highest stover N uptake

8.3.2.2 Bothaville

At 9th leaf stage, N uptake in plant biomass ranged from 15.2 kg ha⁻¹ with Promis to 22.1 kg ha⁻¹ with Montys in 2006/07, 8.35 kg ha⁻¹ with Gromor to 21.9 kg ha⁻¹ with K-humate in 2007/08, and 32.1 kg ha⁻¹ with Montys to 51.0 kg ha⁻¹ with Growmax in 2008/09. The plant biomass N uptake amongst the IMBAs did not differ significantly in

any of the three seasons. However, the plant biomass N uptake recorded amongst some of the IMBAs and the NPK check was significant in 2008/09 when Growmax recorded a substantial higher N uptake of plant biomass. More so, K-humate had consistently higher plant biomass N uptake compared to the NPK treatment. Concerning to the control, Gliogrow, Gromor, Crop care, K-humate and Montys in 2006/07, K-humate in 2007/08, and Growmax and Crop care in 2008/09 recorded significantly higher biomass plant N uptake.

For the IMBA treatments at silking stage, N uptake in plant biomass varied between 12.9 kg ha⁻¹ with Promis and 28.1 kg ha⁻¹ with Growmax in 2006/07, 38.4 kg ha⁻¹ with Gromor and 71.8 kg ha⁻¹ with Crop care in 2007/08, and 45.7 kg ha⁻¹ with Gromor to 58.2 kg ha⁻¹ with K-humate in 2008/09. These differences amongst some of the IMBAs were significant only in 2008/09. None of the IMBAs had plant biomass N uptake that was significantly higher compared to the NPK treatment throughout the three seasons. In fact the NPK treatment resulted in significantly higher N uptake of plant biomass than any of the IMBA treatment in 2008/09. Comparing to the control check, none of the IMBA treatments had lower plant biomass N uptake. Significant differences amongst the IMBAs and the control were found in some instances in all three seasons.

Grain N uptake amongst the IMBAs at harvest ranged from 31.1 kg ha⁻¹ with Gromor to 45.8 kg ha⁻¹ with Crop care in 2006/07, 24.0 kg ha⁻¹ with Gromor to 55.1 kg ha⁻¹ with K-humate in 2007/08, and 19.3 kg ha⁻¹ with Gromor to 47.5 kg ha⁻¹ with Biozone in 2008/09. These differences were significant only in 2007/08 and 2008/09. In these seasons, N uptake by grain from treatments with K-humate and Biozone were highest. In comparison with the NPK treatment, Biozone application resulted in 2008/09 in significantly higher grain N uptake while significantly lower grain N uptake resulted with Gromor, Promis, Growmax and Montys in 2006/07, and Gromor in 2007/08. The IMBA treatments had higher grain N uptake than the control with significant differences manifested between them in all three seasons.

Significant differences in stover N uptake at harvest amongst the IMBAs were observed in 2008/09 when all manure-based IMBAs like Gromor, Promis and Growmax recorded lower values compared to Crop care. However, no significant differences were found between the IMBAs and NPK standard in all three seasons, but manifested compared to

those in the unfertilised plots in any of the three seasons. In this regard, Biozone in 2006/07, Biozone, Gliogrow and Lanbac in 2007/08, and Crop care in 2008/09 recorded the highest N uptake of stover at harvest. Therefore, stover N uptake varied between 6.79 kg ha⁻¹ with Crop care and 12.8 kg ha⁻¹ with Biozone in 2006/07, 13.5 kg ha⁻¹ with Gromor and 24.4 kg ha⁻¹ with Gliogrow in 2007/08, and 5.00 kg ha⁻¹ with Gromor and 12.3 kg ha⁻¹ with Crop care in 2008/09.

8.3.2.3 **Ottosdal**

Plant biomass N uptake amongst the IMBAs at the 9th leaf stage differed significantly from one another only in 2007/08, but significant in each season compared to those in the unfertilised plots. With reference to the NPK treatment, none of the IMBA treatments had in any of the three seasons either significantly lower or higher N uptake in plant biomass. Despite non-significant differences, N uptake in plant biomass was with K-humate consistently higher and with Gliogrow consistently lower than the NPK treatment. The lowest and highest N uptake in plant biomass was recorded from Biozone (29.3 kg ha⁻¹) and K-humate (39.3 kg ha⁻¹) in 2006/07, Gromor (19.2 kg ha⁻¹) and Growmax (30.4 kg ha⁻¹) in 2007/08, and Lanbac (26.6 kg ha⁻¹) and Growmax (43.1 kg ha⁻¹) in 2008/09.

At silking, none of the IMBAs had lower N uptake in plant biomass compared to those in the control treatment. However, significant differences were observed between the control and some of the IMBA treatments in each of the three seasons, though less frequently in 2006/07 and 2008/09 than in 2007/08. The plant biomass N uptake from some of the IMBAs differed significantly from those in the NPK check. Plant biomass N uptake with Biozone and K-humate in 2006/07 was higher than in the NPK treatment. For the IMBAs, the difference in plant biomass N uptake was significant in 2006/07 and 2008/09. However, K-humate (89.4 kg ha⁻¹) in 2006/07, Montys (69.0 kg ha⁻¹) in 2007/08, and Gromor (81.8 kg ha⁻¹) in 2008/09 gave the highest plant biomass N uptake. The lowest values of plant biomass N uptake was recorded with Gromor in 2006/07 (36.8 kg ha⁻¹) and 2007/08 (49.7 kg ha⁻¹), and Promis (61.8 kg ha⁻¹) in 2008/09.

The lowest and highest grain N uptake was recorded with Growmax (34.1 kg ha⁻¹) and Gliogrow (48.6 kg ha⁻¹) in 2006/07, Growmax (33.6 kg ha⁻¹) and Lanbac (53.8 kg ha⁻¹) in 2007/08, and Gromor (40.0 kg ha⁻¹) and Growmax (61.9 kg ha⁻¹) in 2008/09. The

difference between some of the IMBAs was significant in all three seasons. The grain N uptake following application of Gliogrow, Growmax, Crop care, Lanbac and Montys in 2008/09 was significantly higher when NPK treatment served as a reference. More so, Crop care, K-humate and Montys registered higher N uptake than the NPK treatment in any of the three seasons. In comparison with the control, none of the IMBAs resulted in lower grain N uptake in any of the three seasons. In this regard, the only exception was Gliogrow and Growmax in 2007/08, though not significantly. However, Gliogrow and Montys in 2006/07, Lanbac in 2007/08, and nearly all the IMBAs in 2008/09 gave significantly higher grain N uptake than the unamended plots.

For the IMBA treatments, Growmax, Gliogrow and K-humate had the highest stover N uptake values. The differences between some of the IMBAs were significant in each of the three seasons. In comparison with the NPK treatment, stover N uptake at harvest was significantly higher with Gliogrow in 2007/08 while virtually all the IMBAs gave in many instances significantly lower values of stover N uptake in 2006/07, and Biozone and Promis in 2008/09. Plots treated with Lanbac and Gromor in 2007/08 and Promis in 2008/09 performed poorer than the control, though not significantly. However, significantly higher N uptake of stover at harvest was obtained in each of the three seasons between some of the IMBAs and the control check.

8.3.2.4 **Potchefstroom**

The uptake of N by plant biomass at 9th leaf stage differed significantly amongst the IMBAs in 2007/08 and 2008/09. In these particular seasons, the plant biomass N uptake with Biozone and Montys were highest. However, compared to the NPK treatment, plant biomass N uptake increased significantly following application of Biozone in 2007/08. The differences in plant biomass N uptake between some of the IMBAs and control were significant in any of the three seasons. Plant biomass N uptake ranged from 11.0 kg ha⁻¹ with Lanbac to 18.8 kg ha⁻¹ with Gromor in 2006/07, 22.6 kg ha⁻¹ with Growmax to 32.2 kg ha⁻¹ with Biozone in 2007/08, and 42.9 kg ha⁻¹ to 63.5 kg ha⁻¹ with Montys in 2008/09.

At silking stage, significant differences in N uptake by plant biomass were noted amongst the IMBA treatments in all three seasons. Generally, plant biomass N uptake with Biozone, Promis and Crop care in 2006/07, Lanbac in 2007/08, and Gliogrow and

Lanbac in 2008/09 was the highest. None of the IMBAs gave in any of the three seasons a significantly higher N uptake than the NPK treatment, but exerted variable significant effects compared to the control. In fact the NPK treatment recorded significantly higher plant biomass N uptake than Gromor (2007/08 and 2008/09), and Promis and Crop care (2008/09). The N uptake by plant biomass was highest following application of Promis (80.6 kg ha⁻¹) in 2006/07, Lanbac (68.4 kg ha⁻¹) in 2007/08, and Gliogrow (68.1 kg ha⁻¹) in 2008/09, while application of K-humate (48.8 kg ha⁻¹) in 2006/07, and Gromor in 2007/08 (51.8 kg ha⁻¹) and 2008/09 (36.6 kg ha⁻¹) resulted in the lowest values of plant biomass N uptake.

Grain N uptake at harvest recorded amongst some of the IMBA treatments differed significantly in any of the three seasons. This is ascribed due to poor performance following Gromor application. Likewise, grain N uptake at harvest from the Gromor treatment was significantly lower in 2006/07 and 2007/08 while Growmax gave in 2008/09 significantly higher N uptake of grain when NPK check serves as a reference. Comparing to the control, grain N uptake at harvest was in many instances significantly higher in all three seasons, except for Gromor in 2006/07.

Stover N uptake ranged at harvest from 10.6 kg ha⁻¹ with Promis to 18.0 kg ha⁻¹ with Gliogrow in 2006/07, 25.5 kg ha⁻¹ with Biozone to 53.9 kg ha⁻¹ with Montys in 2007/08, and 13.1 kg ha⁻¹ with Gromor to 22.1 kg ha⁻¹ with K-humate in 2008/09. However, the differences amongst some of the IMBAs differed significantly throughout the three seasons. The stover N uptake recorded following application of Gliogrow in 2006/07, and Crop care and Montys in 2007/08 was significantly higher compared to either the NPK or unamended control treatments. Similar significant increases in stover N uptake resulted with virtually all the other IMBAs compared to the control in 2006/07. The only exception in this particular season was Gromor and Promis.

8.3.3 Nitrogen agronomic use efficiency

The agronomic use efficiency of applied N (AE_N) under the different IMBA treatments across the seasons and localities is given in Table 8.3.

Table 8.3: Effect of IMBAs on nitrogen agronomic use efficiency (kg kg^{-1}) of maize during three production seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	12.3	52.6ab	61.2	42.0	11.8ab	38.0a	35.1a	28.3
Gliogrow	11.9	58.5ab	79.7	50.0	8.1c	34.6ab	32.4a	25.0
Gromor	3.6	1.16c	52.2	19.0	12.0ab	15.7b	13.3b	13.7
Promis	12.5	28.7bc	54.2	31.8	12.9ab	35.7ab	32.5a	27.0
Growmax	14.9	78.0a	99.0	64.0	7.5c	25.3ab	23.4ab	18.7
Crop care	7.9	39.7b	64.5	37.4	17.6a	27.5ab	25.0ab	23.4
K-humate	18.1	65.8a	74.5	52.8	8.7c	38.1a	35.3a	27.4
Lanbac	15.5	46.6ab	79.7	47.3	9.4bc	25.9ab	24.0ab	19.8
Montys	28.9	42.5ab	57.0	42.8	16.9ab	25.2ab	22.8ab	21.6
NPK	12.9	58.5ab	60.9	44.1	14.6ab	32.6ab	26.1ab	24.4
Mean	13.8	47.2	68.3	43.1	11.9	29.9	27	22.9
SEM	10.4	17.1	31.3		3.8	9.4	7.8	
LSD _{T(0.05)}	106.6	35.2	64.3		7.8	19.2	16.0	
	Ottosdal				Potchefstroom			
Biozone	3.8ab	50.3a	52.4abc	35.5	16.7bc	70.2a	55.5ab	47.5
Gliogrow	12.3ab	33.9ab	58.1ab	34.8	21.1ab	57.5ab	56.2ab	44.9
Gromor	18.8ab	6.43b	41.5bc	22.2	-4.0c	68.4a	37.7b	34.0
Promis	5.2ab	12.0bc	30.7c	16.0	33.0a	36.5b	35.7b	35.1
Growmax	0.9a	34.6ab	69.0a	34.8	7.3bc	64.8a	67.9a	46.7
Crop care	13.1ab	9.00c	40.9bc	21.0	14.9bc	49.4ab	64.0a	42.8
K-humate	8.9ab	50.4a	53.9abc	37.7	16.6bc	71.6a	59.5ab	49.2
Lanbac	10.8ab	50.6a	60.0ab	40.5	9.4bc	69.9a	59.8ab	46.4
Montys	22.7a	12.9bc	53.0abc	29.5	20.1ab	68.6a	49.7ab	46.1
NPK	10.2ab	46.1ab	56.9ab	37.7	16.6bc	63.5a	52.8ab	44.3
Mean	10.7	30.6	51.6	31.0	15.2	62.0	53.9	43.7
SEM	9.4	11.9	11.5		6.9	10.9	12.4	
LSD _{T(0.05)}	19.2	24.3	23.6		14.2	22.4	25.4	

Means followed by the same letters within a column are not significantly different at 5% probability level; where letters are not shown indicate no significant differences

8.3.3.1 Bethlehem

For the IMBA treatments, AE_N ranged from 3.58 (Gromor) to 28.9 kg kg^{-1} (Montys) in 2006/07, 1.16 (Gromor) to 78.0 kg kg^{-1} (Growmax) in 2007/08, and 52.2 (Gromor) to 99.0 kg kg^{-1} (Growmax) in 2008/09. In two out of the three seasons, Gromor and Growmax recorded the lowest and highest values of agronomic use efficiency of applied N. The differences in AE_N amongst the IMBAs were significant only in 2007/08. In comparison with the NPK treatment, none of the IMBAs gave in any of the three seasons either significantly lower or higher AE_N values. The AE_N of the NPK treatment was 12.9 kg kg^{-1} in 2006/07, 58.5 kg kg^{-1} in 2007/08, and 60.9 kg kg^{-1} in 2008/09.

8.3.3.2 Bothaville

Significant differences in AE_N values amongst some of the IMBA treatments were observed in any of the three seasons while no significant differences were found between the IMBAs and the NPK treatment. These significant differences were on account of the poor performance from Gromor application. The values of AE_N varied between 7.45 kg kg^{-1} with Growmax and 17.6 kg kg^{-1} with Crop care in 2006/07, 15.7 kg kg^{-1} with Gromor and 38.1 kg kg^{-1} with Biozone in 2007/08, and 13.3 kg kg^{-1} with Gromor and 35.3 kg kg^{-1} with Biozone in 2008/09. Thus in two of three seasons the lowest and highest AE_N amongst the IMBAs coincided with Gromor and Biozone application, respectively.

8.3.3.3 Ottosdal

For the IMBA treatments, AE_N ranged from 0.90 kg kg^{-1} with Growmax to 22.7 kg kg^{-1} with Montys in 2006/07, 6.43 kg kg^{-1} with Gromor to 50.6 kg kg^{-1} with Lanbac in 2007/08, and 30.7 kg kg^{-1} with Promis to 69.0 kg kg^{-1} with Growmax in 2008/09. These differences amongst some of the IMBAs were significant in 2007/08 and 2008/09. Generally, Gromor, Crop care and Montys were significantly least efficient compared to Biozone, K-humate and Lanbac application in 2007/08 while Promis was significantly least efficient compared to Gliogrow, Growmax and Lanbac in 2008/09. None of the IMBAs gave significantly lower or higher AE_N values than the NPK treatment in any of the three seasons.

8.3.3.4 Potchefstroom

The IMBA treatments Promis (33.0 kg kg^{-1}) in 2006/07, K-humate (71.6 kg kg^{-1}) in 2007/08, and Growmax (67.9 kg kg^{-1}) in 2008/09 were most efficient on the utilisation of applied N. Applied N was used least efficiently with treatments of Gromor (3.97 kg kg^{-1}) in 2006/07, Promis in 2007/08 (36.5 kg kg^{-1}) and 2008/09 (35.7 kg kg^{-1}). The differences amongst some of the IMBAs were significant in each of the three seasons. With respect to the NPK check, the AE_N values recorded with Promis in 2006/07 was significantly higher.

8.4 Summary and conclusions

The study on plant biomass N content and uptake at 9th leaf, silking, and harvesting and also the agronomic efficiency of applied N from the IMBAs was conducted over three

seasons at four localities, resulting in 12 response cases per IMBA treatment. The performance of each IMBA for these 12 cases was compared with the relevant NPK treatment to obtain the frequency of significant increase as presented in Table 8.4.

The plant biomass N content and uptake recorded at the 9th leaf, silking and harvesting was rarely significantly higher than those in the NPK standard. The same is also true for the agronomic efficiency of applied N.

Table 8.4: Frequency of occurrence of significant increases in plant biomass N content and uptake at 9th leaf, silking and harvesting and also the agronomic efficiency of applied N (AE_N) following IMBAs application in comparison with the NPK treatment over the three production seasons at four sites

IMBAs	N content				N uptake				AE _N
	9 th leaf	Silking	Grain	Stover	9 th leaf	Silking	Grain	Stover	
Biozone	2	1	3	1	1	1	1	1	0
Gliogrow	2	2	1	1	0	0	1	2	0
Gromor	0	0	1	0	0	0	0	0	0
Promis	2	1	1	0	0	0	0	0	1
Growmax	1	1	1	1	1	0	2	0	0
Crop care	1	0	1	1	0	0	1	1	0
K-humate	0	2	4	1	0	1	0	1	0
Lanbac	0	1	1	1	0	1	1	0	0
Montys	1	0	1	1	0	0	1	1	0

The higher N content measured in plant biomass at 9th leaf stage as opposed to silking stage is typical for the maize crop (Subedi & Ma, 2005). Despite the poor plant growth observed at Bethlehem, the mean plant biomass, grain and stover N content across the three seasons was comparable, except in 2008/09. Several studies showed that variation in N supply affect growth and development of maize (Muchow & Davis, 1988; McCullough *et al.*, 1994; Uhart & Adrade, 1995) while N shortage and/or excess affect assimilate partitioning between vegetative and reproductive organs (Subedi & Ma, 2005). The significant increase of plant biomass N content from Growmax plots as opposed to the other manure-based IMBAs like Gromor and Promis could possibly due

to synergy of the organic and inorganic fertiliser added with this product. These results also lend support with observations reported by Boateng *et al.* (2006).

At the Ottosdal and Potchefstroom ecotopes where maize succeeded cowpea, the plant biomass, grain and stover N uptake were during the first season of IMBA applications consistently higher. These results lend support to the study by Kumbhar *et al.* (2007) who reported higher N uptake during the first season when wheat was planted after legume. In many instances, the IMBAs performed better than the NPK treatment, although it was infrequently significant. These findings agreed with those of Murwira and Kirchmann (1993) and Wang *et al.* (2007) who observed better nutrient use efficiency of crops following combined application of organic manure and inorganic fertiliser. Moreover, they reported comparable maize growth with complementary inorganic-organic and sole inorganic fertiliser application. This is probably because nutrients are released early from the inorganic fertiliser and that maize, which is an aggressive feeder, was able to utilise these nutrients for its growth.

Wang *et al.* (2007) showed soil incorporation of various mixtures of maize stover, manure and inorganic fertiliser over the long-term as alternative nutrient management practice improved soil fertility and nutrient use efficiencies. Using a mucuna based fertiliser strategy together with optimum NPK rate, Fofana *et al.* (2004) reported at silking stage mean values of N uptake of 9.3 kg ha⁻¹ to 45.6 kg ha⁻¹ in the first season and 27.6 kg ha⁻¹ to 63.8 kg ha⁻¹ in second season. These values are at par with values recorded in this study from treatments with the different IMBA treatments.

Across the different soil types and localities, the AE_N values recorded in 2007/08 and 2008/09 were comparable, but were higher than in 2006/07. The increased AE_N over the seasons is attributed to residual effect from recurring applications of the different IMBAs (Kimetu *et al.*, 2004) and possibly better field management (van Veen *et al.*, 1985). The values of AE_N recorded during the first and second year of this study were similar to those reported by Fofana *et al.* (2004) who found that the mean values of apparent agronomic efficiency of applied N across different rates ranged from 11 to 28 kg kg⁻¹ in the first year and 7 to 20 kg kg⁻¹ in the second year.

The results of this study revealed that the various IMBAs exerted inconsequential but significant effects on N content, uptake and agronomic use efficiency of maize. The IMBAs like Biozone, Gliogrow and Promis at 9th leaf stage, Gliogrow and K-humate at silking, and Biozone and K-humate at harvesting showed promising potential in increasing N content compared to the NPK check. Manure-based IMBAs like Gromor and Promis resulted seldom in a significant increase of the measured parameters. This could be ascribed to lower N content in these materials coupled with their characteristic slower N releasing potential. However, application of a manure-based IMBA together with inorganic NPK fertiliser like Growmax gave more often a significant increase in plant biomass N content and uptake. The agronomic efficiency of applied N amongst the IMBA treatments was significantly increased only with Promis than that of the NPK standard. The N content and uptake from IMBA treatments that coincided with either optimum or reduced application rates of inorganic NPK fertiliser were in all cases higher than those in the unfertilised plots. Likewise, sole application of manure-based IMBAs like Gromor and Promis resulted in most cases in higher N content and uptake. They showed however inconsequential effects in sites with better field management and higher residual soil N.

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CHAPTER 9

EFFECT OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS ON PHOSPHORUS CONTENT, UPTAKE AND AGRONOMIC USE EFFICIENCY OF MAIZE UNDER DIFFERENT ECOTOPES

9.1 Introduction

Phosphorus ranks second to nitrogen as a limiting factor among the major nutrient elements for plant growth and development (Zia *et al.*, 1988). In most South African soils, P is the most deficient nutrient (Laker, 1976). Accordingly, van Averbek and Yoganathan (2003) asserted that should one have to choose between the application of N or P, crop yields would largely increase when P is added to the soil and thus, addition of N would only increase crop yields after the needs of P has been satisfied. Typically in a healthy plant, P concentration is much lower than N (Zia *et al.*, 1988).

Maize plants require P soon after germination to initiate the growth of stems, leaves and cob structures (Alley *et al.*, 2009). Maize is quite sensitive to low P availability, especially in the early growth stages (PDA, 2008). Application of P enhance maize crop to reach 50% tasselling and to silk earlier (Chapman & Carter, 1976). Since P is less mobile in soils, available soil P levels can be built with P fertiliser applications and/or applications of manures. Earlier studies reported that due to relatively low soil P levels, marked yield responses in maize have been recorded with inorganic fertiliser P applications (Marley, 1969 cited by Zia *et al.*, 1988). However, recent studies indicated that P mineralised from organic matter is more beneficial than adding inorganic fertiliser since organic P is available for longer in the soil solution for plant uptake (PDA, 2008).

The uptake of P poses a problem for plants when its concentration in the soil solution is low under high plant requirements (Schachtman *et al.*, 1998). The form of P most readily accessed by plants is orthophosphate, the concentration of which rarely exceeds 10µM P in soil solution due to low solubility products of inorganic P salts (Bielecki, 1973). Likewise, P uptake is more constant throughout the season and generally parallels plant biomass increases (Alley *et al.*, 2009). A report by Potash & Phosphate Institute (2007) indicated that at flowering stages, there is a high demand for water and the uptake of N and P is rapid. During kernel filling stage, N and P uptake continues at

a rapid rate and the kernel size may be affected by unfavourable conditions (Chapman & Carter, 1976). The analyses of plant materials are often used to evaluate and help explain crop responses to fertiliser practices. Therefore, the critical concentration could be used as a reliable tool in the diagnosis of crop yield responses (Alley *et al.*, 2009). This study was therefore conducted to examine the effect of IMBAs on phosphorus content, uptake and agronomic use efficiency under different ecotopes.

9.2 Experimental procedure

The detailed procedure and description of this trial were duly given in Chapter 3, however, a concise description is provided herein. The trial assessed nine IMBAs at rates given by either the product manufacturers or suppliers in three production seasons at four sites. Recommended rates of conventional inorganic NPK fertiliser at each site and unamended control treatments were included as check. The inorganic NPK fertiliser treatment was applied in the form of limestone ammonium nitrate, superphosphate and potassium chloride, respectively. A randomised complete block design was used and each treatment replicated four times. Measurements were made of P content in plant biomass at 9th leaf and silking growth stages, and in grain and stover at harvest to calculate P uptake by these components and eventually agronomic use efficiency of applied P. The P content, uptake and agronomic use efficiency data were subjected to analyses of variance using GenStat Release 14. Differences in treatment means were separated using Tukey's honestly significant difference post-hoc test at 5% probability level.

9.3 Results and discussion

9.3.1 Phosphorus content

The P content measured in plant biomass at 9th leaf, silking and harvesting under the various IMBA treatments across the seasons and localities is given in Table 9.1.

Table 9.1: Effect of IMBAs on P content (%) in plant biomass at 9th leaf, silking and harvesting during three production seasons at four sites

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
9th leaf stage																
Biozone	0.255ab	0.490e	0.265ab	0.337	0.310ab	0.523ab	0.465abc	0.433	0.300c	0.313abc	0.290bc	0.301	0.410b	0.585ab	0.560a	0.518
Gliogrow	0.265ab	0.500c	0.265ab	0.343	0.310ab	0.558ab	0.460abcd	0.443	0.425a	0.320abc	0.275cd	0.340	0.465ab	0.675a	0.515bc	0.552
Gromor	0.238bc	0.560a	0.210cd	0.336	0.280cd	0.585a	0.405de	0.423	0.345bc	0.303bc	0.280cd	0.309	0.580a	0.585ab	0.555ab	0.573
Promis	0.273a	0.515c	0.270a	0.353	0.305abc	0.515ab	0.490ab	0.437	0.360abc	0.315abc	0.330a	0.335	0.420b	0.570ab	0.535abc	0.508
Growmax	0.260ab	0.505c	0.255abc	0.340	0.285cd	0.505ab	0.475abc	0.422	0.395abc	0.288bc	0.310ab	0.331	0.395b	0.600ab	0.525bc	0.507
Crop care	0.245abc	0.513cd	0.255abc	0.338	0.315a	0.480ab	0.425cde	0.407	0.375abc	0.300bc	0.305abc	0.327	0.375b	0.633ab	0.550ab	0.519
K-humate	0.243abc	0.558ab	0.235abcd	0.345	0.270d	0.493ab	0.460abcd	0.408	0.350bc	0.343ab	0.260d	0.318	0.415b	0.625ab	0.500cd	0.513
Lanbac	0.235bc	0.440f	0.210cd	0.295	0.290bcd	0.500abc	0.430cde	0.407	0.305c	0.308abc	0.275cd	0.296	0.455b	0.600ab	0.510cd	0.322
Montys	0.260ab	0.453f	0.265ab	0.326	0.315a	0.453b	0.495a	0.421	0.410ab	0.363a	0.315ab	0.363	0.370b	0.595ab	0.520c	0.495
NPK	0.223c	0.475de	0.260ab	0.319	0.305abc	0.475ab	0.395de	0.392	0.405ab	0.318abc	0.280cd	0.334	0.375b	0.585ab	0.535abc	0.498
Control	0.220c	0.493de	0.190d	0.301	0.290bcd	0.440b	0.385e	0.372	0.375ab	0.280c	0.270cd	0.308	0.355b	0.513b	0.480d	0.449
Mean	0.247	0.502	0.244		0.298	0.502	0.444		0.368	0.314	0.290		0.420	0.597	0.526	
SEM	0.015	0.059	0.024		0.011	0.058	0.028		0.032	0.027	0.014		0.061	0.052	0.015	
CV (%)	8.3	16.5	12.2		5.4	16.4	9.1		12.2	12.3	8.7		20.5	12.4	4.1	
LSD _{T(0.05)}	0.030	0.021	0.049		0.023	0.119	0.058		0.065	0.056	0.028		0.124	0.107	0.031	
Silking stage																
Biozone	0.200a	0.310	0.240ab	0.250	0.205a	0.278a	0.250d	0.244	0.205ab	0.243bc	0.310cd	0.25	0.300b	0.338abc	0.395b	0.34
Gliogrow	0.175ab	0.340	0.315a	0.277	0.160abc	0.270ab	0.290b	0.240	0.200ab	0.313a	0.365ab	0.29	0.330a	0.355ab	0.425b	0.37
Gromor	0.085 c	0.323	0.280ab	0.229	0.145bc	0.243ab	0.245de	0.211	0.145bc	0.258bc	0.325bcd	0.24	0.320ab	0.315bc	0.473ab	0.37
Promis	0.140abc	0.320	0.260ab	0.240	0.170abc	0.245ab	0.280bc	0.232	0.155bc	0.245bc	0.290d	0.23	0.260bc	0.370a	0.335b	0.32
Growmax	0.185ab	0.310	0.285ab	0.260	0.180ab	0.275a	0.240de	0.232	0.180b	0.243bc	0.370a	0.26	0.325ab	0.290c	0.625a	0.41
Crop care	0.140abc	0.285	0.265ab	0.230	0.200a	0.268ab	0.270c	0.246	0.205ab	0.248bc	0.320cd	0.26	0.340a	0.323ab	0.415b	0.34
K-humate	0.180ab	0.330	0.310ab	0.273	0.190ab	0.250ab	0.285bc	0.242	0.235a	0.253bc	0.360abc	0.28	0.255c	0.328ab	0.355b	0.31
Lanbac	0.155ab	0.330	0.265ab	0.250	0.190ab	0.255ab	0.325a	0.257	0.155bc	0.255bc	0.320cd	0.24	0.295bc	0.318abc	0.370b	0.33
Montys	0.145abc	0.315	0.320a	0.260	0.185ab	0.255ab	0.285bc	0.242	0.130c	0.268b	0.350ab	0.25	0.345a	0.338abc	0.358b	0.35
NPK	0.145abc	0.323	0.280ab	0.249	0.140bc	0.230b	0.295b	0.222	0.170bc	0.225c	0.320cd	0.24	0.325ab	0.358ab	0.380b	0.35
Control	0.100bc	0.283	0.230b	0.204	0.135c	0.243ab	0.225e	0.201	0.130c	0.230bc	0.290d	0.22	0.255c	0.295c	0.365b	0.31
Mean	0.150	0.315	0.277		0.173	0.256	0.272		0.174	0.253	0.329		0.305	0.330	0.409	
SEM	0.030	0.030	0.040		0.023	0.021	0.011		0.020	0.020	0.020		0.019	0.025	0.080	
CV (%)	28.2	13.3	23.3		19.1	11.8	5.6		16.0	11.0	6.6		9.0	10.8	27.6	
LSD _{T(0.05)}	0.061	0.060	0.082		0.048	0.044	0.022		0.040	0.040	0.041		0.040	0.052	0.163	

Table 9.1: Continue

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	0.35abc	0.60ab	0.46ab	0.47	0.41ab	0.62bc	0.59a	0.54	0.34	0.67ab	0.39bc	0.47	0.39	0.68bc	0.66ab	0.58
Gliogrow	0.35abc	0.60abc	0.48ab	0.48	0.42ab	0.61bc	0.42cd	0.48	0.38	0.67ab	0.40ab	0.48	0.39	0.79ab	0.62b	0.60
Gromor	0.37a	0.58c	0.48ab	0.48	0.36ab	0.65abc	0.43cd	0.48	0.36	0.57c	0.34c	0.42	0.36	0.76b	0.62b	0.58
Promis	0.32ab	0.66ab	0.49a	0.49	0.43a	0.70ab	0.41cd	0.51	0.35	0.63bc	0.37abc	0.45	0.36	0.75b	0.65ab	0.59
Growmax	0.29c	0.64abc	0.46ab	0.46	0.35ab	0.71ab	0.44bcd	0.50	0.29	0.66b	0.34c	0.43	0.42	0.72bc	0.64b	0.59
Crop care	0.33abc	0.67a	0.50a	0.50	0.37ab	0.60bc	0.48bc	0.48	0.36	0.74a	0.38bc	0.49	0.35	0.77ab	0.69a	0.60
K-humate	0.36ab	0.63abc	0.50a	0.50	0.40ab	0.72a	0.43cd	0.52	0.38	0.63bc	0.41ab	0.47	0.37	0.82ab	0.64b	0.61
Lanbac	0.30bc	0.60abc	0.44abc	0.45	0.42ab	0.71ab	0.42cd	0.52	0.30	0.63bc	0.45a	0.46	0.36	0.69bc	0.60bc	0.55
Montys	0.32ab	0.60abc	0.48ab	0.47	0.38ab	0.69ab	0.47bc	0.51	0.38	0.66b	0.34c	0.46	0.41	0.80ab	0.64b	0.62
NPK	0.30bc	0.61abc	0.43bc	0.45	0.36ab	0.72a	0.51b	0.53	0.35	0.64bc	0.38bc	0.46	0.40	0.86a	0.67ab	0.64
Control	0.29c	0.57c	0.39c	0.42	0.32b	0.59c	0.39d	0.43	0.31	0.61bc	0.34c	0.42	0.36	0.64c	0.57c	0.52
Mean	0.32	0.61	0.46		0.38	0.66	0.45		0.34	0.64	0.37		0.38	0.75	0.63	
SEM	0.027	0.035	0.027		0.044	0.040	0.035		0.043	0.034	0.026		0.035	0.044	0.020	
CV (%)	11.8	8.1	8.3		16.2	8.5	10.8		17.7	7.6	9.9		13.0	8.3	4.5	
LSD _{T(0.05)}	0.055	0.072	0.055		0.090	0.081	0.070		0.088	0.070	0.053		0.071	0.090	0.041	
Stover at harvest																
Biozone	0.060ab	0.050bc	0.075b	0.062	0.063	0.060ab	0.075a	0.066	0.058ab	0.085b	0.045ab	0.063	0.113abc	0.065abc	0.110bc	0.096
Gliogrow	0.068ab	0.065bc	0.078b	0.070	0.055	0.035bc	0.040c	0.043	0.068ab	0.080b	0.033c	0.060	0.110abc	0.085ab	0.160ab	0.118
Gromor	0.045b	0.040bc	0.080b	0.055	0.055	0.055ab	0.055bc	0.055	0.035b	0.035d	0.045ab	0.038	0.190ab	0.082ab	0.165a	0.146
Promis	0.043b	0.040bc	0.055bc	0.046	0.043	0.020bc	0.070ab	0.044	0.058ab	0.085b	0.035bc	0.059	0.053c	0.045c	0.115abc	0.071
Growmax	0.060ab	0.050bc	0.040c	0.050	0.050	0.050abc	0.040c	0.047	0.063ab	0.120a	0.040abc	0.074	0.165a	0.060bc	0.095c	0.107
Crop care	0.085a	0.035c	0.085b	0.068	0.065	0.085a	0.055bc	0.068	0.050ab	0.090b	0.035bc	0.058	0.095abc	0.065abc	0.095c	0.085
K-humate	0.065ab	0.205a	0.135a	0.135	0.068	0.015c	0.040c	0.041	0.080a	0.060cd	0.050a	0.063	0.123abc	0.067abc	0.080c	0.090
Lanbac	0.065ab	0.080b	0.058bc	0.068	0.055	0.045bc	0.065ab	0.055	0.050ab	0.045cd	0.035bc	0.043	0.155ab	0.050bc	0.055c	0.087
Montys	0.070ab	0.040bc	0.065bc	0.058	0.058	0.020bc	0.065ab	0.048	0.088ab	0.050cd	0.038bc	0.052	0.088ab	0.085ab	0.070c	0.081
NPK	0.063ab	0.045bc	0.085b	0.064	0.060	0.020bc	0.065ab	0.048	0.063ab	0.065bc	0.035bc	0.054	0.083abc	0.095a	0.115abc	0.098
Control	0.063ab	0.035c	0.050bc	0.049	0.075	0.055ab	0.050c	0.060	0.050ab	0.045cd	0.040abc	0.045	0.065bc	0.055bc	0.065c	0.062
Mean	0.06	0.06	0.07		0.06	0.04	0.06		0.06	0.07	0.04		0.11	0.07	0.10	
SEM	0.018	0.016	0.017		0.018	0.017	0.008		0.019	0.014	0.005		0.043	0.014	0.025	
CV (%)	41.6	37.2	32.1		43.1	58.4	20.5		45.6	28.0	17.8		54.6	29.9	34.8	
LSD _{T(0.05)}	0.037	0.033	0.034		0.036	0.035	0.017		0.038	0.028	0.010		0.089	0.030	0.051	

Means with the same letters within a column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

9.3.1.1 **Bethlehem**

The P content in plant biomass at 9th leaf stage was highest with Promis in 2006/07 (0.27%) and 2008/09 (0.27%), and Gromor in 2007/08 (0.59%), while Lanbac consistently recorded the lowest plant biomass P content which represented 0.24, 0.44 and 0.21% in 2006/07, 2007/08 and 2008/09, respectively. However, the differences amongst some of the IMBAs were significant (all three seasons) and also between some of the IMBAs and the NPK check (2006/07 and 2007/08). In this regard, Biozone, Gliogrow, Promis and Montys in 2006/07, and Gliogrow, Gromor, Promis, Growmax and K-humate in 2007/08 recorded a substantially higher plant biomass P content compared to the NPK treatment. In comparison with the control treatment, lower plant biomass P content resulted only from plots treated with Biozone, Lanbac and Montys in 2007/08, though not significantly. However, the different IMBAs resulted in many instances with significantly higher plant biomass P content values. These differences were more frequently in 2007/08 than in 2006/07 and 2008/09.

For the IMBA treatments at silking stage, plant biomass P content ranged from 0.09% with Gromor to 0.20% with Biozone in 2006/07, 0.29% with Crop care to 0.34% with Gliogrow in 2007/08, and 0.24% with Biozone to 0.32% with Montys in 2008/09. These differences in plant biomass P content amongst some of the IMBAs were significant in 2006/07. In comparison with the NPK check, none of the IMBAs gave either significantly lower or higher P content in each season. Despite this insignificance, P content in plant biomass was with Gliogrow and K-humate consistently higher, and was with Promis and Crop care consistently lower than the NPK check. In any of the three seasons, the IMBAs had consistently higher P content than the control, except for Gromor in 2006/07. However, significant differences in plant biomass P content between some of the IMBAs and control plots manifested in 2006/07 and 2008/09.

In each of the three seasons, the grain P content amongst some of the IMBAs differed significantly. Generally, grain P content following application with Gromor and Promis was substantially higher than any of the IMBAs and resulted also with significantly higher values of grain P content in 2006/07 and 2008/09 when NPK treatment served as a reference. The IMBA treatments gave higher P content in grain than the control for each of the three seasons, except for Growmax in 2006/07. However, only those of the Gromor, Promis, K-humate and Montys in 2006/07, Promis and Crop care in 2007/08,

and nearly all the IMBAs in 2008/09, except for Lanbac were significantly higher.

The stover P content between some of the IMBAs at harvest was significantly different in 2007/08 and 2008/09. This is attributed due to the substantial higher stover P content from K-humate plots. In every season, stover P content with K-humate was higher when NPK treatment served as a reference, but differed significantly only in 2007/08 and 2008/09. In these particular seasons, K-humate also gave significantly higher N content of stover compared to the unfertilised plots. Similar significant increases realised from Lanbac in 2007/08. In 2006/07, stover P content with Biozone, Gromor, Promis and Growmax was lower than the control, though not significantly. Treatments with Crop care and Promis gave in 2007/08 and 2008/09 similar effects.

9.3.1.2 **Bothaville**

Amongst the IMBA treatments at 9th leaf stage, P content in plant biomass from Crop care (0.32%) in 2006/07, Gromor (0.59%) in 2007/08, and Montys (0.50%) in 2008/09 was highest, and was lowest with K-humate (0.27%), Montys (0.45%), and Gromor (0.41%) in 2006/07, 2007/08 and 2008/09, respectively. Significant differences amongst some of the IMBAs were observed in any of the three seasons. For each growing season, none of the IMBAs gave significantly lower plant biomass P content than either the NPK or control treatments. In fact Biozone, Promis, Growmax and Montys gave significantly higher plant biomass P content than the NPK check in 2008/09. Moreover, Crop care in 2006/07 and Gromor in 2007/08 recorded significantly higher plant biomass P content than the control treatment. A similar significant difference was obtained with virtually all the IMBAs in 2008/09.

Concerning mean P content in plant biomass at silking stage, the differences amongst the IMBA treatments were significant (2006/07 and 2008/09) including those of the IMBAs and the NPK treatment (all seasons). The plant biomass P content from treatments with Biozone and Crop care in 2006/07, Biozone and Growmax in 2007/08, and Lanbac in 2008/09 was significantly higher than the NPK check. In comparison to the control, only Gromor in 2007/08 performed poorer, though not significantly. Significant differences between some of the IMBA treatments and the control were observed in 2006/07 and 2008/09.

Grain P content amongst the IMBAs at harvest ranged from 0.35% with Growmax to 0.43% with Promis in 2006/07, 0.60% with Crop care to 0.72% with K-humate in 2007/08, and 0.41% with Promis to 0.59% with Biozone in 2008/09. However, grain P content among some of the IMBAs was significant in 2007/08 and 2008/09. Comparing to the NPK treatment, grain P content was with Biozone, Gliogrow and Crop care in 2007/08 significantly lower and was with Biozone in 2008/09 significantly higher. The IMBAs gave in every season higher grain P content than the control. Significant differences between some of the IMBAs and control was obtained in each season.

With respect to P content in stover at harvest, the lowest and highest values was recorded with Promis (0.04%) and K-humate (0.07%) in 2006/07, K-humate (0.02%) and Crop care (0.09%) in 2007/08, and K-humate (0.04%) and Biozone (0.07%) in 2008/09. The differences among some of the IMBAs were significant in 2007/08 and 2008/09. With reference to the NPK treatment, Crop care resulted in significantly higher stover P content in 2007/08. Equally, stover P content with Biozone was higher in each season than the NPK treatment. In comparison with the control treatment, the IMBAs recorded lower stover P content values in most cases, though not significantly. However, plots from treatment with Biozone, Promis, Lanbac and Montys in 2008/09 recorded significantly higher P content of stover compared to the unfertilised plots.

9.3.1.3 **Ottosdal**

The P content in plant biomass at 9th leaf stage was highest with Gliogrow (0.43%) in 2006/07, Montys (0.36%) in 2007/08, and Promis (0.33%) in 2008/09, and was lowest with Biozone (0.30%), Growmax (0.29%) and K-humate (0.26%) in 2006/07, 2007/08 and 2008/09, respectively. These differences in plant biomass P content amongst some of the IMBAs were significant in all three seasons. With regard to NPK treatment, Promis, Growmax and Montys gave significantly higher plant biomass P content in 2008/09. Similarly, in any of the three seasons, plant biomass P content was with Montys higher and was with Lanbac consistently lower than the NPK check. In comparison with the control, only Biozone, Gromor, Promis, Crop care, K-humate and Lanbac in 2006/07 and K-humate in 2008/09 gave lower plant biomass P content, though not significantly. Nonetheless, K-humate and Montys in 2007/08 and Promis, Growmax and Montys in 2008/09 gave significantly higher P content of plant biomass.

At silking stage, plant biomass P content of several IMBA treatments differed significantly from one another and also to either the NPK or control treatments in every season. These significant differences were more frequently in 2006/07 than in 2007/08 and 2008/09. Nevertheless, Montys in 2006/07 and Promis in 2008/09 gave lower plant biomass P content than the control, though not significantly. Comparing to the NPK treatment, plant biomass P content from treatment with K-humate in 2006/07, Gliogrow in 2007/08, and Gliogrow, Growmax, K-humate and Montys in 2008/09 was consistently higher. The lowest and highest plant biomass P content for the IMBA treatments coincided with Montys (0.13%) and K-humate (0.24%) in 2006/07, Growmax (0.24%) and Gliogrow (0.31%) in 2007/08, Promis (0.29%) and Growmax (0.37%) in 2008/09.

The grain P content following application of Crop care and Lanbac in 2007/08 and 2008/09, respectively was significantly higher than the NPK check. Amongst the IMBAs, grain P content of Gromor was significantly lower than with Crop care in 2007/08, while Lanbac gave significantly higher grain P content than with Gromor, Growmax and Montys in 2008/09. For each season, grain P content from all the IMBA plots was consistently higher than the control. In this regard, the only exception was Gromor in 2007/08 and 2008/09, and Growmax and Montys in 2008/09. More so, Crop care in 2007/08, and Gliogrow, K-humate and Lanbac gave significantly higher grain P content relative to that in the unfertilised plots.

Stover P content at harvest was highest with K-humate in 2006/07 (0.08%) and 2008/09 (0.07%), and Growmax (0.12%) in 2007/08. The lowest P content in stover was recorded from Gromor in 2006/07 (0.04%) and 2007/08 (0.04%), and Gliogrow (0.03%) in 2008/09. There were significant differences between some of the IMBAs and also to the NPK check in 2007/08 and 2008/09. In these particular seasons, Growmax and K-humate applications gave significantly higher stover P content than the NPK check. In comparison with the control, lower stover P content resulted from treatments with Gromor in 2006/07 and 2007/08, and half of the IMBAs in 2008/09, though not significantly. This could be mainly that in the IMBA plots a substantial amount of P was translocated from stover to grain during grain-filling period. Nevertheless, Biozone, Gliogrow, Growmax and Crop care in 2007/08 resulted with significantly higher P content of stover.

9.3.1.4 Potchefstroom

The P content in plant biomass for the IMBA treatments at 9th leaf stage ranged from 0.37% with Montys to 0.58% with Gromor in 2006/07, 0.57% with Promis to 0.68% with Gliogrow in 2007/08, and 0.50% with K-humate to 0.56% with Biozone in 2008/09. However, the differences amongst some of the IMBAs were significant in 2006/07 and 2008/09. In comparison with the NPK treatment, plots that received Gromor application gave significantly higher biomass P content in 2008/09. Differences in plant biomass P content between some of the IMBAs and unfertilised control were significant in any of the three seasons, although significant differences were most frequently in 2008/09.

At silking, plant biomass P content amongst the IMBAs varied between 0.26% with K-humate and 0.35% with Montys in 2006/07, 0.29% with Growmax and 0.37% with Montys in 2007/08, and 0.34% with Growmax and 0.63% with Promis in 2008/09. Significant differences in biomass P content among some of the IMBAs were observed in each of the three seasons. With regard to the NPK standard, the application of Growmax in 2008/09 gave significantly higher P content of plant biomass. In comparison with the control, plots in which K-humate in 2006/07, and Promis, K-humate and Montys in 2008/09 were applied gave lower plant biomass P content, though not significantly. However, Biozone, Gliogrow, Growmax, Crop care and Montys in 2006/07, Gliogrow, Growmax, Crop care and K-humate in 2007/08, and Growmax in 2008/09 had significantly higher plant biomass P content than the control.

Generally, plots treated with Growmax and Montys in 2006/07, K-humate and Montys in 2007/08, and Crop care in 2008/09 gave the highest grain P content amongst the IMBA treatments. The differences in grain P content amongst some of the IMBAs were significant only in 2008/09. In each of the three seasons, none of the IMBA treatments resulted in significantly higher grain P content than the NPK treatment. In fact grain P content following application of Biozone and Lanbac in 2007/08 was significantly lower. In comparison to the control, grain P content with K-humate and Montys was significantly higher in 2007/08. A similar trend was observed with Biozone, Promis, Crop care and K-humate in 2008/09.

No significant differences were observed between the stover P content of the IMBAs and NPK check in the three seasons. Amongst the IMBA treatments, stover P content

was highest with Gromor in 2006/07, Gliogrow and Montys in 2007/08, and Gromor and Gliogrow in 2008/09. Some significant differences were observed amongst several of the IMBAs throughout the three seasons. With reference to the control, Promis gave lower stover P content in 2006/07, though not significantly. Similar trends were noted with Promis in 2007/08, and Lanbac in 2007/08 and 2008/09. Conversely, Growmax in 2007/08, and Gliogrow and Gromor measured significantly higher stover P content than those in the unamended control.

9.3.2 Phosphorus uptake

The P uptake calculated in plant biomass recorded at 9th leaf, silking and harvesting for the IMBA treatments across the seasons and localities are presented in Table 9.2.

9.3.2.1 Bethlehem

The P uptake by plant biomass at 9th leaf stage varied between 2.00 kg ha⁻¹ with Gromor and 3.20 kg ha⁻¹ with Growmax in 2006/07, 1.17 kg ha⁻¹ with Gromor and 3.67 kg ha⁻¹ with K-humate in 2007/08, and 0.97 kg ha⁻¹ with Gromor and 1.82 kg ha⁻¹ with Biozone in 2008/09. A significant difference in plant biomass P uptake amongst some of the IMBAs was observed only in 2007/08 during which, plant biomass P uptake with K-humate was higher than Gliogrow, Gromor, Promis, Growmax and Montys applications. In each of the three seasons, plant biomass P uptake between the IMBAs and NPK treatment did not differ significantly. However, P uptake by plant biomass from the IMBA treatments was in many cases lower in the three seasons when NPK served as a check. Comparing to the control, plant biomass P uptake in several of the IMBAs was higher in all three seasons, but differed significantly only in 2006/07 and 2007/08.

Table 9.2: Effect of IMBAs on P uptake (kg ha^{-1}) in plant biomass at 9th leaf, silking stage and harvesting during three production seasons at four sites

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
9th leaf stage																
Biozone	2.77ab	2.28abc	1.82	2.29	2.01abc	3.28abc	6.87abc	4.05	3.18b	3.42ab	4.47ab	3.69	5.17ab	5.98a	9.19ab	6.78
Gliogrow	2.26bc	2.18bc	1.43	1.96	2.56ab	3.82ab	5.72abc	4.03	4.57ab	2.48abc	3.52ab	3.52	5.33ab	5.94a	8.17ab	6.48
Gromor	2.00bc	1.17c	1.01	1.39	2.54ab	2.05c	5.10abc	3.23	3.88ab	2.21d	4.24ab	3.44	8.13a	4.56ab	6.34bc	6.34
Promis	3.10ab	1.90bc	0.97	1.99	2.14abc	2.67abc	5.99abc	3.60	4.15ab	3.20abcd	4.06ab	3.80	4.35b	5.00ab	7.97ab	5.77
Growmax	3.20ab	2.06bc	1.43	2.23	2.38abc	2.81abc	7.92a	4.37	4.44ab	3.48ab	5.05a	4.32	4.94ab	4.75ab	6.80abc	5.50
Crop care	2.38bc	2.95ab	1.53	2.29	2.60ab	3.45abc	7.12ab	4.39	4.16ab	3.23abc	4.13ab	2.76	4.29b	5.04ab	6.95abc	5.43
K-humate	2.17bc	3.67a	1.67	2.50	2.29abc	4.03a	6.65abc	4.32	4.71ab	3.58ab	3.55ab	3.95	5.23ab	5.60ab	6.80abc	5.88
Lanbac	2.87ab	2.39abc	1.14	2.13	2.36abc	2.93abc	6.63abc	3.97	3.46ab	3.66a	3.21ab	3.44	4.20b	5.59ab	6.80abc	6.13
Montys	2.91ab	1.94bc	1.48	2.11	2.82a	2.62abc	6.67abc	4.04	4.88a	3.37ab	4.58a	4.28	4.60b	5.08ab	9.65a	6.44
NPK	3.40a	2.76ab	2.03	2.73	1.87abc	3.47abc	4.68bc	3.34	4.37ab	3.56ab	3.15ab	3.69	5.71ab	4.38ab	8.20ab	6.10
Control	1.74c	1.68bc	0.64	1.35	1.17c	2.22bc	4.17c	2.52	3.30b	2.35cd	2.12b	2.59	3.07b	3.83b	4.66c	3.85
Mean	2.62	2.27	1.38		2.25	3.03	6.14		4.10	3.14	3.83		5.00	5.07	7.57	
SEM	0.47	0.71	0.75		0.59	0.75	1.43		0.72	0.50	1.16		1.65	0.95	1.41	
CV (%)	48.0	44.3	40.6		37.3	34.9	32.8		24.7	22.3	42.9		46.7	26.6	26.3	
LSD _{T(0.05)}	0.95	1.45	1.54		1.21	1.53	2.91		1.46	1.01	2.37		3.37	1.94	2.88	
Silking stage																
Biozone	6.76a	8.14b	8.14abc	7.68	4.87a	10.7a	8.66c	8.08	8.04ab	9.12ab	11.2b	9.45	12.1abc	11.2ab	13.8ab	12.37
Gliogrow	6.12a	8.83ab	10.5ab	8.48	3.81ab	9.92ab	9.55abc	7.76	6.60bc	10.0ab	12.8a	9.80	11.7abc	10.7ab	14.7ab	12.37
Gromor	2.69b	8.31ab	10.1ab	7.03	3.13bc	5.67bc	7.94c	5.58	3.98def	8.09b	13.1a	8.39	13.2a	9.78abc	13.8ab	12.26
Promis	5.08abc	10.3ab	8.54ab	7.97	3.14bc	7.55abc	9.73abc	6.81	4.94cd	9.99ab	9.44bc	8.12	9.63cd	11.5ab	13.2b	11.44
Growmax	5.25abc	9.46ab	7.53b	7.41	3.82ab	9.70ab	8.86c	7.46	6.65bc	9.92ab	12.7ab	9.76	12.3ab	9.15bc	18.8a	13.42
Crop care	3.89abc	9.06ab	8.60ab	7.18	4.78a	10.7a	9.22bc	8.23	6.53bc	9.72ab	11.9ab	9.38	13.9a	10.9ab	13.7ab	12.83
K-humate	4.73abc	10.9a	10.8a	8.81	4.08ab	9.95ab	9.95abc	7.99	9.28a	9.72ab	10.5bc	9.83	8.14de	11.0ab	12.4b	10.51
Lanbac	5.69ab	10.5ab	10.0ab	8.73	5.06a	9.74ab	10.5ab	8.43	5.61cde	10.2ab	11.1b	8.97	11.2abc	11.1ab	13.7ab	12.00
Montys	5.04abc	9.16ab	10.3a	6.49	3.75b	8.61ab	9.88abc	7.41	3.79ef	10.8a	12.6ab	9.06	13.5a	10.8ab	13.8ab	12.70
NPK	4.76abc	9.65ab	9.39ab	6.35	2.50b	10.3ab	10.9a	7.90	5.71cde	9.17ab	12.0ab	8.96	12.3ab	12.2a	14.5ab	13.00
Control	2.34c	4.39c	5.61c	4.11	2.14c	4.24c	5.11d	3.83	3.07f	5.14c	8.36c	5.52	5.99e	7.51c	9.37b	5.12
Mean	4.76	8.97	9.05		3.73	8.83	9.12		5.84	9.26	11.4		11.3	10.5	13.8	
SEM	1.63	1.28	1.42		0.63	1.81	0.69		1.05	1.19	1.10		1.23	1.27	2.66	
CV (%)	48.4	20.2	22.1		23.8	29.1	10.8		25.4	18.2	10.7		15.4	17.1	27.3	
LSD _{T(0.05)}	3.33	2.62	2.89		1.28	3.71	1.42		2.14	2.43	2.24		2.50	2.59	5.43	

Table 9.2: Continue

IMBAs	Bethlehem				Bothaville				Ottosdal				Potchefstroom			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	8.06ab	12.5bcd	11.5abc	10.7	11.1a	23.5ab	20.6a	18.4	8.90ab	23.5ab	14.4bc	15.6	13.0abc	38.1ab	29.2ab	26.8
Gliogrow	7.98ab	14.3abcd	13.8abc	12.0	9.61ab	19.7b	13.0bc	14.1	12.5a	15.7c	16.4ab	14.9	14.5a	36.0ab	27.8bc	26.1
Gromor	6.90bc	9.44cd	13.8abc	10.0	6.52de	12.5cd	7.70de	8.91	10.6ab	17.4bc	10.8cd	12.9	6.98e	32.0b	21.5c	20.2
Promis	7.27ab	15.2abcd	18.6a	13.7	10.8ab	20.2bc	11.3bcd	14.1	9.79ab	21.3abc	12.7bc	14.6	12.0abc	39.2ab	25.9c	25.7
Growmax	6.72bc	20.0a	18.0a	14.9	7.67cd	17.9bc	10.2cd	11.92	7.28b	16.0bc	16.2ab	13.2	10.7cd	37.0ab	34.1ab	27.3
Crop care	6.55bc	18.0ab	16.9ab	13.8	10.3ab	20.5b	15.4b	15.4	10.83ab	24.8a	15.5ab	17.0	9.87cde	41.1ab	35.3a	28.8
K-humate	9.11a	16.8ab	14.7ab	13.5	9.41ab	27.3a	14.6bc	17.1	11.3ab	22.1ab	15.2b	16.2	12.3abc	47.3a	30.4ab	30.0
Lanbac	7.35ab	12.2bcd	14.8ab	11.5	9.97ab	19.7b	10.8cd	13.5	9.60ab	22.1ab	19.0a	16.9	9.71cde	38.3ab	28.7ab	25.6
Montys	7.30ab	14.7abcd	13.0abc	11.7	8.96abcd	19.0bc	12.3bc	13.4	12.1a	22.2ab	13.6bc	16.0	11.7ab	42.2ab	25.0c	26.3
NPK	6.87bc	14.2abcd	10.4bc	10.5	10.9ab	23.8ab	13.4bc	16.0	10.5ab	20.7abc	15.1b	15.4	13.6ab	43.5ab	28.1bc	28.4
Control	5.17c	9.07d	6.33c	6.9	4.85e	9.02d	5.67e	6.51	7.41b	17.7bc	7.20d	10.8	7.31d	16.3c	14.5d	12.7
Mean	7.21	14.2	13.8		9.10	19.4	12.3		10.1	20.3	14.2		11.1	37.4	27.3	
SEM	0.96	3.55	3.82		1.29	3.24	2.17		2.22	2.72	1.87		1.77	5.62	3.23	
CV (%)	18.7	35.3	39.1		20.0	23.6	24.9		31.1	18.9	18.6		22.7	21.3	16.7	
LSD _{T(0.05)}	1.95	7.24	7.80		2.63	6.62	4.42		4.53	5.55	3.81		3.62	11.5	6.60	
Stover at harvest																
Biozone	1.82ab	0.97b	1.52ab	1.44	1.27	1.78ab	1.76abc	1.60	1.16ab	2.45bc	1.26bc	1.62	2.58ab	2.30abc	3.67ab	2.85
Gliogrow	1.80ab	1.59b	1.13bcd	1.51	0.88	1.57ab	0.91c	1.12	1.11ab	3.88a	1.15bc	2.05	2.63ab	2.48abc	4.50ab	3.20
Gromor	1.00b	0.66b	1.41ab	1.02	1.07	1.55ab	0.90c	1.17	0.77b	0.97d	1.69ab	1.14	4.21a	2.44abc	4.94a	3.86
Promis	1.36b	0.85b	0.71cd	0.97	0.69	0.63bc	2.02a	1.11	1.02ab	2.67bc	1.42bc	1.70	1.19b	1.61bc	3.57abc	2.12
Growmax	1.64ab	1.20b	1.09bcd	1.31	1.20	1.81ab	1.34abc	1.45	1.49ab	3.63ab	1.30bc	2.14	4.22a	2.12bc	2.49bc	2.94
Crop care	2.51a	0.74b	1.44ab	1.56	1.05	2.45a	1.32abc	1.61	1.11ab	2.62c	1.43bc	1.72	2.79ab	2.29abc	2.86abc	2.65
K-humate	1.31b	4.96a	2.03a	2.77	1.25	0.48c	1.47abc	1.07	1.83a	2.03c	2.20a	2.02	3.11ab	2.41abc	3.00abc	2.84
Lanbac	1.87ab	1.59b	0.99bcd	1.48	0.99	1.47abc	1.95ab	1.47	1.14ab	1.36d	0.97c	1.16	4.26a	1.72bc	1.78c	2.59
Montys	1.73ab	0.78b	0.97bcd	1.16	1.16	0.64bc	1.96ab	1.25	1.35ab	1.64cd	1.48bc	1.49	2.34ab	3.30a	2.89abc	2.84
NPK	1.71ab	0.84b	1.52ab	1.36	1.21	0.70bc	1.93ab	1.28	1.58ab	2.28c	1.36bc	1.74	2.11ab	3.05ab	3.87ab	3.01
Control	1.44b	0.51b	0.57d	0.84	1.45	1.16bc	1.05bc	1.22	0.94b	1.36d	1.39bc	1.23	1.17b	1.57c	1.95c	1.56
Mean	1.65	1.34	1.22		1.11	1.29	1.51		1.23	2.26	1.42		2.78	2.30	3.23	
SEM	0.48	0.57	0.35		0.43	0.51	0.42		0.42	0.51	0.33		1.20	0.57	1.02	
CV (%)	41.1	60.4	41.2		55.1	55.9	39.7		48.2	31.7	48.7		61.1	35.2	44.7	
LSD _{T(0.05)}	0.98	1.17	0.72		0.88	1.05	0.86		0.85	1.03	0.68		2.45	1.17	2.08	

Means with the same letters within a column are not significantly different at 5% probability level; where no letters are shown indicate no significant differences

Plant biomass P uptake at silking ranged from 2.69 kg ha⁻¹ with Gromor to 6.76 kg ha⁻¹ with Biozone in 2006/07, 8.14 kg ha⁻¹ with Biozone to 10.9 kg ha⁻¹ with K-humate in 2007/08, and 7.53 kg ha⁻¹ with Growmax to 10.8 kg ha⁻¹ with K-humate in 2008/09. These differences were significant only in 2007/08 when K-humate recorded a substantial higher P uptake of plant biomass compared to Biozone application. In any of the three seasons, the differences in plant biomass P uptake between the IMBAs and NPK check were not significant. Despite non-significant differences, plant biomass P uptake was with Lanbac consistently higher compared to the NPK treatment. In comparison with the control, none of the IMBAs gave lower plant biomass P uptake in any of the three seasons. Significantly higher plant biomass P uptake between the IMBAs and control plots was found in some instances throughout the three seasons.

Grain P uptake at harvest ranged from 6.55 kg ha⁻¹ with Crop care to 9.11 kg ha⁻¹ with K-humate in 2006/07, 9.44 kg ha⁻¹ with Gromor to 20.0 kg ha⁻¹ with Growmax in 2007/08, and 11.5 kg ha⁻¹ with Biozone to 18.6 kg ha⁻¹ with Promis in 2008/09. Significant differences amongst some of the IMBAs manifested in 2006/07 and 2007/08. With regard to the NPK treatment, K-humate in 2006/07, and Promis and Growmax in 2008/09 gave significantly higher grain P uptake. More so, Gliogrow, Promis, K-humate and Montys gave in every season higher grain P uptake than the NPK check. Concerning grain P uptake in the control plots, the IMBA treatments gave in each season higher grain P uptake. Significant differences between some of the IMBAs and control were observed in every season, but were more frequently in 2006/07.

Concerning stover P uptake at harvest, the IMBA treatments differed significantly from one another in all three seasons. The observed significant difference could be ascribed to the substantial higher stover P content from Crop care in 2006/07 and K-humate in 2007/08 and 2008/09. Equally, stover P uptake with K-humate in 2007/08 was significantly higher than the NPK check and also to the control in 2007/08 and 2008/09. However, Crop care recorded significantly higher P uptake of stover than that in the unfertilised plots. Nevertheless, lower stover P uptake was recorded with Gromor than the NPK treatment in each of the three seasons.

9.3.2.2 Bothaville

With respect to P uptake by plant biomass at 9th leaf stage, the IMBAs differed significantly from one another when K-humate gave substantially higher plant biomass N uptake than Gromor application. Comparing to the NPK treatment, Growmax recorded significantly higher P uptake of plant biomass in 2008/09. However, the differences between some of the IMBAs and the control were significant in all three seasons. The plant biomass P uptake ranged from 2.01 kg ha⁻¹ with Biozone to 2.82 kg ha⁻¹ with Montys in 2006/07, 2.05 kg ha⁻¹ with Gromor to 4.03 kg ha⁻¹ with K-humate in 2007/08, and 5.10 kg ha⁻¹ with Gromor to 7.92 kg ha⁻¹ with Growmax in 2008/09.

At silking, the highest plant biomass P uptake coincided with Lanbac in 2006/07 (5.06 kg ha⁻¹) and 2008/09 (10.9 kg ha⁻¹), and Crop care (10.7 kg ha⁻¹) in 2007/08. The lowest plant biomass P uptake was recorded consistently with Gromor in 2006/07 (3.13 kg ha⁻¹), 2007/08 (5.67 kg ha⁻¹) and 2008/09 (7.94 kg ha⁻¹). Significant differences amongst some of the IMBAs were observed in every season. The P uptake by plant biomass from virtually all the IMBAs in 2006/07 and 2007/08 was significantly higher than those in the control plots, except for Gromor and Promis in both seasons. Equally, in 2008/09, none of the IMBAs resulted with significantly lower plant biomass P uptake than that in the unfertilised plots. In comparison with NPK treatment, plant biomass P uptake from treatments with Biozone, Crop care and Lanbac in 2006/07 was significantly higher.

For the IMBA treatments, plots treated with Gromor had consistently the lowest grain P uptake in 2006/07 (6.52 kg ha⁻¹), 2007/08 (12.5 kg ha⁻¹) and 2008/09 (7.70 kg ha⁻¹). The highest grain P uptake coincided with Biozone in 2006/07 (11.1 kg ha⁻¹) and 2008/09 (20.6 kg ha⁻¹), and K-humate (27.3 kg ha⁻¹) in 2007/08. The differences amongst some of the IMBAs were significant for each of the three seasons, mainly on account of the poor performance of Gromor. This could be related to the low P of grain that coincided with Gromor treatment. The grain P uptake from IMBA treatments was in many cases lower than the NPK check, but significant differences only resulted with Gromor in 2007/08. However, grain P uptake following application of Biozone in 2008/09 was significantly higher than that in the NPK check. Comparing to the control, virtually all the IMBAs in each season resulted in many cases with significant higher P uptake of grain. The only exception in this regard was Gromor in every season.

The stover P uptake at harvest amongst some of the IMBAs differed significantly from one another (2007/08 and 2008/09) and also between the IMBAs and the NPK treatment (2007/08). However, the differences between some of the IMBAs and control were significant in any of the three seasons. Amongst the IMBA treatments, Promis, K-humate and Montys gave significantly lower stover P uptake than Crop care in 2007/08, while significantly higher P uptake of stover was recorded with Promis compared to Gliogrow and Gromor in 2008/09. The highest stover P uptake was recorded with Biozone (1.27 kg ha⁻¹) in 2006/07, Crop care (2.45 kg ha⁻¹) in 2007/08, and Promis (2.02 kg ha⁻¹) in 2008/09. Promis (0.69 kg ha⁻¹), K-humate (0.48 kg ha⁻¹) and Gromor (0.90 kg ha⁻¹) resulted in the lowest stover P uptake in 2006/07, 2007/08 and 2008/09, respectively.

9.3.2.3 **Ottosdal**

Despite the significant difference in plant biomass P content in some of the seasons at 9th leaf stage, P uptake by plant biomass between the IMBAs and the NPK treatment did not differ significantly in any of the three seasons. However, the differences amongst the IMBAs (2006/07 and 2007/08) and also between the IMBAs and the control (all three seasons) were significant. The P uptake by plant biomass ranged from 3.18 kg ha⁻¹ with Biozone to 4.88 kg ha⁻¹ with Montys in 2006/07, 2.21 kg ha⁻¹ with Gromor to 3.66 kg ha⁻¹ with Lanbac in 2007/08, and 3.21 kg ha⁻¹ with Lanbac to 5.05 kg ha⁻¹ with Growmax in 2008/09.

At silking stage, plant biomass P uptake varied between 3.79 kg ha⁻¹ with Montys and 9.28 kg ha⁻¹ with K-humate in 2006/07, 8.09 kg ha⁻¹ with Gromor and 10.8 kg ha⁻¹ with Montys in 2007/08, and 9.44 kg ha⁻¹ with Promis and 13.1 kg ha⁻¹ with Gromor in 2008/09. The differences amongst some of the IMBAs were significant throughout the three seasons. In these particular seasons, K-humate in 2006/07, Montys in 2007/08, and Gliogrow and Gromor in 2008/09 gave substantially higher plant biomass P uptake than the other IMBAs. In comparison with the NPK check, plant biomass P uptake following application of K-humate was significantly higher in 2006/07. More so, P uptake by plant biomass with Gliogrow and Growmax was higher than the NPK check regardless of the season. In any of the three seasons, none of the IMBAs resulted in lower P uptake than the control. Nonetheless, the differences in plant biomass P

uptake between the IMBAs and control were significant in every season, although more frequently in 2006/07.

Amongst the IMBAs, grain P uptake at harvest ranged from 7.28 kg ha⁻¹ with Growmax to 12.5 kg ha⁻¹ with Gliogrow in 2006/07, 15.7 kg ha⁻¹ with Gliogrow to 24.8 kg ha⁻¹ with Crop care in 2007/08, and 10.8 kg ha⁻¹ with Gromor to 19.0 kg ha⁻¹ with Lanbac in 2008/09. Significant differences amongst some of the IMBAs were observed in all three seasons. With regard to the NPK check, Lanbac application recorded significantly higher grain P uptake in 2008/09. More so, grain P uptake from treatments with Crop care and K-humate was higher when the NPK treatment served as a check, though not significantly regardless of the season. In comparison with the control, Growmax in 2006/07 performed poorer, though not significantly. Treatments with Gromor, Growmax and Gliogrow gave in 2007/08 a similar effect. Conversely, Gliogrow and Montys in 2006/07, Crop care in 2007/08, and Lanbac in 2008/09 exerted significantly higher P uptake by grain compared to those in the unfertilised plots.

The stover P uptake amongst some of the IMBA treatments differed significantly in any of the three seasons. Generally, P uptake by stover was with K-humate in 2006/07, Gliogrow and Growmax in 2007/08, and K-humate and Gromor in 2008/09 highest. Concerning to the NPK treatment, plots from treatment with Gliogrow and Growmax in 2007/08 and K-humate in 2008/09 measured significantly higher stover P uptake values. Equally, consistently lower stover P uptake was recorded with Promis. Comparing to the control, lower stover P uptake resulted with Gromor in 2006/07 and 2007/08, though not significantly. These trends were also applicable to Biozone, Gliogrow, Growmax and Lanbac in 2007/08. Nevertheless, the different IMBAs gave in each season higher stover P uptake than unamended control. Significant differences between some of the IMBAs and control were found in each season.

9.3.2.4 **Potchefstroom**

The P uptake by plant biomass at 9th leaf stage ranged from 4.20 kg ha⁻¹ with Lanbac to 8.13 kg ha⁻¹ with Gromor in 2006/07, 4.56 kg ha⁻¹ with Gromor to 5.98 kg ha⁻¹ with Biozone in 2007/08, and 6.34 kg ha⁻¹ with Gromor to 9.64 kg ha⁻¹ with Montys in 2008/09. These differences in plant biomass P uptake were significant in 2006/07 and 2008/09. Plant biomass P uptake between the IMBAs and NPK treatment differed not

significantly in all three seasons. None of the IMBAs gave lower P uptake values than the control during the three seasons. In fact plant biomass P uptake from treatment with Gromor in 2006/07, Biozone and Gliogrow in 2007/08 and 2008/09, and Promis, Lanbac and Montys in 2008/09 was significantly higher than the control treatment.

At silking, the lowest and highest plant biomass P uptake coincided with K-humate (8.14 kg ha⁻¹) and Crop care (13.9 kg ha⁻¹) in 2006/07, Growmax (9.15 kg ha⁻¹) and Promis (11.5 kg ha⁻¹) in 2007/08, and K-humate (12.4 kg ha⁻¹) and Growmax (18.8 kg ha⁻¹) in 2008/09. Significant differences amongst some of the IMBAs were observed in 2006/07 when Gromor, Crop care and Montys resulted in significantly higher plant biomass P uptake than Promis and K-humate. Similar significant increases resulted in 2008/09 when Growmax recorded significant plant biomass P uptake compared to Promis and K-humate. For each season, none of the IMBAs resulted in significantly higher plant biomass P uptake than the NPK treatment. In fact the NPK treatment gave in 2006/07 significantly higher P uptake by plant biomass compared to Promis and K-humate plots. Similar significant increases manifested between the NPK standard and Growmax in 2007/08. Comparing to plant biomass P uptake in the control, none of the IMBAs performed poorer throughout the three seasons. Significant differences between some of the IMBA treatments and the control manifested in all three seasons.

For the IMBA treatments, grain P uptake at harvest ranged from 6.98 kg ha⁻¹ with Gromor to 14.5 kg ha⁻¹ with Gliogrow in 2006/07, 32.0 kg ha⁻¹ from Gromor to 47.3 kg ha⁻¹ with K-humate in 2007/08, and 21.5 kg ha⁻¹ with Gromor to 35.3 kg ha⁻¹ with Crop care in 2008/09. The differences in grain P uptake amongst some of the IMBAs were significant in all three seasons due to poor performance from Gromor plots. The grain P uptake following application of Crop care in 2008/09 was significantly higher when the NPK served as a reference. On the other hand, grain P uptake was with Gromor, Promis and Montys lower than the NPK treatment irrespective of the season. Significant differences were recorded only in 2006/07 for Gromor. In any of the three seasons, grain P uptake between several of the IMBAs and control was significant. This higher uptake of P by grain could be ascribed to the significantly higher grain P content following application of the different IMBAs. Generally, only Gromor in 2006/07 performed poorer than the control.

The stover P uptake amongst the IMBAs at harvest differed significantly from one another and also to the control treatment in every season, while no significant differences were observed between the IMBAs and NPK standard. Despite this insignificance between the IMBAs and NPK check, stover P uptake following application of Promis was consistently lower than in the NPK treated plots, though not significantly. The P uptake by stover was lowest and highest with Promis (1.19 kg ha^{-1}) and Lanbac (4.26 kg ha^{-1}) in 2006/07, Promis (1.61 kg ha^{-1}) and Montys (3.30 kg ha^{-1}) in 2007/08, and Lanbac (1.78 kg ha^{-1}) and Gromor (4.94 kg ha^{-1}) in 2008/09.

9.3.3 Phosphorus agronomic use efficiency

The agronomic use efficiency of applied P (AE_P) in the IMBA treatments across the seasons and localities are given in Table 9.3.

9.3.3.1 Bethlehem

With respect to the IMBA treatments, the values of AE_P was highest with Montys (16.6 kg kg^{-1}) in 2006/07, and Growmax in 2007/08 (44.9 kg kg^{-1}) and 2008/09 (57.0 kg kg^{-1}). Gromor gave for each season the lowest AE_P with values of 2.24, 0.72 and 32.6 kg kg^{-1} in 2006/07, 2007/08 and 2008/09, respectively. The differences amongst some of the IMBAs were significant only in 2007/08. With reference to the NPK treatment, none of the IMBAs resulted in either significantly lower or higher AE_P values. Regardless of the season, a higher AE_P with Growmax and K-humate and a lower AE_P with Gromor were recorded than with the NPK treatment.

9.3.3.2 Bothaville

Concerning AE_P amongst IMBAs, highest values were observed with Crop care (23.8 kg kg^{-1}) in 2006/07, and K-humate in 2007/08 (51.7 kg kg^{-1}) and 2008/09 (47.9 kg kg^{-1}). Like at Bethlehem, Gromor resulted in the lowest AE_P values. These lowest values were 7.49, 9.84 and 8.29 kg kg^{-1} in 2006/07, 2007/08 and 2008/09, respectively. The differences in AE_P amongst the IMBAs were significant in all three seasons. This could be attributed due to the consistently least efficiency of applied P following application with Gromor. The differences in AE_P amongst some of the IMBAs and the NPK treatment were not significant throughout the three seasons. However, plots in which Gliogrow and K-humate were applied gave consistently higher AE_P values than the NPK

check. For each season, lower AE_P values were recorded with Gromor, Promis, Growmax and Lanbac treatments compared to the NPK treatment.

Table 9.3: Effect of IMBAs on phosphorus agronomic use efficiency (kg kg^{-1}) of maize during three production seasons at four sites

IMBAs	Bethlehem				Bothaville				
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean	
Biozone	7.10	30.3ab	35.2	24.2	15.9abcd	51.6a	47.6a	38.4	
Gliogrow	6.80	33.8ab	45.9	28.8	11.0cd	46.9a	43.9a	33.9	
Gromor	2.20	0.72b	32.6	11.8	7.50d	9.80b	8.29b	8.50	
Promis	12.5	28.7ab	54.2	31.8	12.9abcd	35.7a	32.5a	27.0	
Growmax	8.60	44.9a	57.0	36.8	10.1cd	34.3ab	31.8a	25.4	
Crop care	4.50	22.8ab	37.1	21.5	23.8a	37.2a	33.9a	31.6	
K-humate	10.4	37.9ab	42.9	30.4	11.7cd	51.7a	47.9a	37.1	
Lanbac	8.90	26.8ab	45.8	27.2	12.7abcd	35.2a	32.6a	26.8	
Montys	16.6	24.4ab	32.8	24.6	22.9ab	34.2ab	30.9a	29.3	
NPK	7.40	33.7ab	35.0	25.4	19.8abc	44.3a	35.4a	33.2	
Grand Mean	8.50	28.4	41.9	26.2	14.8	38.1	34.5	29.1	
SEM	7.9	10.9	18.2		5.4	12.3	10.7		
$LSD_{T(0.05)}$	16.2	22.3	37.3		11.1	25.2	21.9		
		Ottosdal				Potchefstroom			
Biozone	3.45	47.8a	49.8abcd	33.7	30.7a	129.1a	102.1ab	87.3	
Gliogrow	11.7	32.2ab	55.2abc	33.0	38.8a	105.7a	103.3ab	82.6	
Gromor	11.8	4.02c	25.9d	13.9	-2.50b	42.7b	23.6c	21.3	
Promis	5.20	12.0bc	30.7cd	16.0	36.5a	35.7b	35.1c	35.8	
Growmax	0.86	32.8ab	65.5a	33.1	13.5ab	119.1a	124.9a	85.8	
Crop care	12.5	8.54bc	38.9bcd	20.0	27.4ab	90.7a	117.6ab	78.6	
K-humate	8.45	47.8a	51.2abcd	35.8	30.5a	131.6a	109.5ab	90.5	
Lanbac	10.2	48.0a	57.0abc	38.4	17.2ab	128.5a	110.0ab	85.2	
Montys	21.5	12.3bc	50.3abcd	28.0	36.9a	125.9a	91.4b	84.7	
NPK	9.70	43.8a	54.1ab	35.9	30.5a	116.7a	97.1ab	81.4	
Grand Mean	9.55	28.9	47.9	28.8	26.0	102.6	91.5	73.3	
SEM	12.1	13.0	12.9		12.8	16.1	15.9		
$LSD_{T(0.05)}$	24.9	26.7	26.4		26.2	33.0	32.7		

Means followed by the same letters within a column are not significantly different at 5% probability level; where letters are not shown indicate no significant differences

9.3.3.3 Ottosdal

For each season, the AE_P values amongst IMBA treatments were never significantly higher than the applied P from the NPK standard in any of the three seasons. In fact the Gromor, Promis, Crop care and Montys in 2007/08, and Gromor and Promis recorded significantly lower AE_P values. The lowest AE_P values resulted with Growmax (0.86 kg kg^{-1}) in 2006/07, and Gromor in 2007/08 (4.02 kg kg^{-1}) and 2008/09 (25.9 kg kg^{-1}), while the highest AE_P values coincided with Montys (21.5 kg kg^{-1}) in 2006/07,

Lanbac (48.0 kg kg⁻¹) in 2007/08, and Growmax (65.5 kg kg⁻¹) in 2008/09. These differences were significant in 2007/08 and 2008/09.

9.3.3.4 Potchefstroom

The AE_P values ranged from 2.48 kg kg⁻¹ with Gromor to 38.8 kg kg⁻¹ with Gliogrow in 2006/07, 35.7 kg kg⁻¹ with Promis to 131.6 kg kg⁻¹ with K-humate in 2007/08, and 23.6 kg kg⁻¹ with Gromor to 124.9 kg kg⁻¹ with Growmax in 2008/09. Significant differences in AE_P amongst some of the IMBAs were observed in all the three seasons probably due to consistently low AE_P values following application of Gromor. In most instances, the IMBA treatments that received baseline inorganic NPK fertiliser gave in 2007/08 higher AE_P values than the Gromor and Promis treatments that replaced NPK completely. A similar pattern in AE_P values was found in 2008/09. In comparison with NPK check, plots treated with Gromor and Promis resulted in significantly lower AE_P values in 2008/09. However, treatment with Biozone gave higher AE_P values than the NPK treated plots regardless of the season, though not always significant.

9.4 Summary and conclusions

The study on plant biomass P content and uptake at 9th leaf, silking and harvesting, and also the agronomic efficiency of applied P from the IMBAs was conducted for three seasons at four localities, resulting in 12 response cases per IMBA treatment. The performance of each IMBA for these 12 cases was compared with the relevant NPK treatment to obtain the frequency of significant increases as presented in Table 9.4.

The plant biomass P content and uptake recorded at 9th leaf, silking and harvesting was inconsequential higher than the NPK check. However, P content at 9th leaf stage increased significantly in three to four instances due to the application of Promis, Growmax and Montys. The efficiency of applied P from the IMBAs was not in one case significantly better than the applied P from the NPK check.

Table 9.4: Frequency of occurrence of significant increases in plant biomass P content and uptake at 9th leaf, silking and harvesting, and also the agronomic efficiency of applied P (AE_P) following IMBAs application in comparison with the NPK treatment over the three production seasons at four sites

IMBAs	P content				P uptake				AE _P
	9 th leaf	Silking	Grain	Stover	9 th leaf	Silking	Grain	Stover	
Biozone	1	2	1	0	0	2	1	0	0
Gliogrow	2	2	0	0	0	0	0	1	0
Gromor	2	0	1	0	0	0	0	0	0
Promis	4	0	1	0	0	0	1	0	0
Growmax	4	3	0	1	1	0	1	1	0
Crop care	0	1	2	1	0	1	1	1	0
K-humate	1	1	1	3	0	0	1	2	0
Lanbac	0	1	1	0	0	1	1	0	0
Montys	3	2	0	0	0	0	0	0	0

Typically for maize, the P content in grain was higher than in plant biomass at 9th leaf, silking and harvesting stages (decline in this sequence) due to high demand for P during silking for the formation of cob structures (Zia *et al.*, 1988). The higher plant biomass P content at 9th leaf stage that coincided with Gromor application could be related to its high P content. This high P content emanated from the chicken manure which is the main constituent of Gromor. However, Promis which was also a chicken manure-based IMBA gave lower P content probably due to differences in composting of these two products and the lower P content in Promis. Miles and Manson (2005) showed that much of the N and P in manures is combined with organic substances and only becomes available to plants when these substances decompose. The IMBA treatments had inconsequential effect in plant biomass P content across seasons and localities, except on clayey soils typical of the Potchefstroom ecotope. The consistently high biomass P content recorded at Potchefstroom could be ascribed to the fairly high residual soil P relative to the other sites at the commencement of this study due to recurrent fertiliser input over the seasons. This result concurs with an earlier report from a study by Sahrawat *et al.* (2003) concerning long-term P fertiliser effects on P uptake and efficiency by upland rice.

At 9th leaf stage, plant biomass P uptake was considerably lower at the Bethlehem ecotope than the other three ecotopes. This could be ascribed to the consistently poorer plant growth that could further be related to the lower soil pH observed at Bethlehem than the other ecotopes that could have impaired efficient uptake of nutrients, especially during silking. These results agree with those of Uhart and Andrade (1995) that partitioning of nutrients to reproductive organs is dependent on their availability. The higher biomass P uptake on clayey soil at Potchefstroom ecotope could be attributed to the fairly high nutrient availability, particularly P following cultivation of cowpea on this site which often requires high P fertilisation. However, due to the difference in texture this was not the case for the sandy soil at Ottosdal ecotope where cowpea was also the preceding crop. Van Veen *et al.* (1985) indicated that P uptake is related to residual soil P content.

The IMBAs containing either humates or beneficial microorganisms resulted consistently in higher P content, uptake and agronomic use efficiency by maize than the manure-based IMBAs. Van Averbeke and Yoganathan (2003) asserted that high concentrations of P and K would typically be found in fields where heavy rates of animal and poultry litter have been applied which were not the case in this study. Consequently, Charest *et al.* (2004) indicated that consistent use of humic acid should reduce the need for fertilisation because it will improve the soil's and plant's ability to make better use of applied nutrients. Moreover, humus has the ability to absorb the highly active non-nutrient hydrogen sources present in soil and makes them immediately available as a food source for assimilation and usage by the plant (Charest *et al.*, 2004). Furthermore, humus acts as a buffer and eventually enhances carbon, nitrogen, phosphorus and sulfur availability in soils for usage by microorganisms and plants (Campitelli *et al.*, 2005). Humic acid is especially beneficial in improving the availability of nutrients in soil for plant uptake (Ayuso *et al.*, 1996). For instance, if phosphorus is fixed by aluminum in acid soil, humic acid enhances the release of P into the soil solution for absorption by plant roots. Soil microbes are responsible for solubilising vital nutrients such as P that can then be adsorbed by humic acid and in turn made it available to the plant (Charest *et al.*, 2004).

The variable AE_P values of IMBAs between the four ecotopes may be due to the variation in clay content of their soils. Another contributing factor to the low AE_P values

at Ottosdal may be ascribed to the residual effect of the cropping and P fertiliser history of the field which was previously planted with cowpea. The AE_p levels observed with the IMBAs are not only related to their P content but also to quantities of residual P in soils (van Veen *et al.*, 1985). For example, the AE_p values for the IMBA plots was low at the Bothaville ecotope with low residual soil P and high at the Potchefstroom ecotope with high residual soil P. Usually, build-up of P is fastest in systems where the difference in N: P between crop and manure is greatest, e.g on pasture fertilised with poultry litter (van Averbeke & Yoganathan, 2003). Excess application of P with manure is good for fields with low soil P test, but not for fields with high soil P test since the latter may result in pollution of water resources (Pote *et al.*, 1996).

The results of this study demonstrated that the IMBAs exerted variable but significant effects on P content and uptake while no significant positive effect realised on the agronomic efficiency of applied P. Concerning the significant increase of P content in different plant parts, Biozone, Gliogrow, Gromor, Promis, Growmax, K-humate and Montys showed most potential. More so, significant increases of P uptake in different plant parts could be promoted following application of Biozone and K-humate. The P content and uptake with manure-based IMBAs like Gromor and Promis was in many instances higher than the NPK check at vegetative stage but not at reproductive stage. The agronomic efficiency of applied P from the different IMBA treatments differed not significantly from that of the NPK standard. Nonetheless, Biozone, Gliogrow, K-humate and Lanbac efficiently used the applied P and were least efficiently in Gromor and Promis. The combined use of manure-based IMBAs and inorganic NPK fertiliser like in the Growmax treatment increased P content and uptake compared to the sole use of manure-based IMBAs in the Gromor and Promis treatments. The P content and uptake from IMBA treatments that coincided with either optimum or reduced application rates of inorganic fertiliser were in all cases higher than from the control. Likewise, sole application of manure-based IMBAs in the Gromor and Promis treatments resulted in most instances with higher P content and uptake. These two IMBAs showed however inconsequential effects at sites with better field management and hence higher residual soil P.

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CHAPTER 10

ASSESSMENT OF INDUSTRIALLY MANUFACTURED BIOLOGICAL AMENDMENTS ON PHYSICAL QUALITY OF MAIZE GRAIN UNDER DIFFERENT ECOTOPES

10.1 Introduction

Millions of people in developing countries desire and consume maize for its calorie requirements which accounts for 15 to 56% of the total daily calories (Prasanna *et al.*, 2001). Although many would intend to attain these calorie requirements from animal meat. This is expensive and often unavailable to a vast sector of population, especially in developing countries (Zarkadas *et al.*, 1995). Typically maize has poor nutritional value for humans because of lower essential amino acids content. As the procurement of grain becomes more quality based, grading regulations will probably in future include certain developed quality criteria (ARC-MIG, 2005).

One thousand kernels mass (TKM) is the mass of air-dried undamaged grains and used as one of the parameters for assessing grain quality. Grain with higher TKM have better milling quality and ensure better plant emergence (Protic *et al.*, 2007). An effective translocation of assimilates from leaves and wheat straw into grain is notably for obtaining TKM, although genetic variations might prevail (Sarkar *et al.*, 1988). Application levels of N up to 60 kg ha⁻¹ increased wheat TKM, while higher N application levels decreased TKM (Protic & Jankovic, 1999; Protic *et al.*, 2007).

Mature or immature maize grain is processed by dry milling techniques to give a relatively large number of intermediary products, such as maize grits of different particle sizes, maize meal, flour and flaking grits (SAGL, 2004). In grain production, milling quality is an increasingly important factor determining the income of farmers while at the same time, the market value of grain crops is based to a large extent to its milling quality and yield (Perez *et al.*, 1996). Similarly, the head of rice is the primary factor that determines rice prices in the world rice markets (Brorsen *et al.*, 1984). Nitrogen fertilisation affects grain yield and milling quality (Perez *et al.*, 1996). Applying N fertiliser close to booting enhance photosynthetic capacity during grain-filling period thereby leading to an increase in head rice yield (Wopereis-Pura *et al.*, 2002).

Grain quality depends largely on the grain type and its end uses. These include a range of properties that can be defined in terms of physical properties *inter alia* moisture content, test weight, kernel size, broken kernels, stress cracking, breakage susceptibility, foreign material, pesticide residue and fertiliser (Maier, 1995). Other inherent quality characteristics include milling yield, oil and protein content, hardness, density, starch content, feed value, viability and storability. These grain quality properties are affected by its genetic traits, growing period, timing of harvest, grain harvesting and handling of equipment, storage management practices and transportation procedures (Maier, 1995).

A study of Fox and Manley (2009) showed that determination of maize hardness assists the maize industry to improve efficiency in processing and possibly provide a quality specification for maize growers, which could attract a premium. These authors concluded that one of the simplest methods used to measure hardness is a grinding step followed by a sieving step, using multiple sieve sizes. Accordingly, Izsáki (2007) indicated that hardness is a highly heritable trait, hence when a desirable level of hardness is finally agreed upon, breeders will quickly produce materials with hardness levels required by the industry.

Although genetics usually exerts huge effect on maize grain quality, agronomic practices are also important (Seebauer *et al.*, 2010). A study of Gambin *et al.* (2006) showed that grain composition is a result of the genetic make-up of the endosperm sink, the maternal plant and the environment, but it is not clear how much the amount and form of assimilates provided from the nutrients source supply influences grain composition. Hence, this study was established to assess the effect of industrially manufactured biological amendments (IMBAs) on selected physical quality traits of maize grain under different ecotopes.

10.2 Experimental procedure

The detail description on materials and methods for this study on physical quality of maize grain is thoroughly discussed earlier in Chapter 3, but for convenience, a concise description is given here. In total nine IMBAs were evaluated at rates recommended by either product manufactures or suppliers during three seasons at four sites. Optimum recommended rates of conventional inorganic NPK fertiliser at each site and

unamended control treatments were included as check. Maize grains harvested from the field trials were used to determine effect of IMBAs on physical grain quality traits at the Grain Quality Laboratory of the ARC-Grain Crops Institute, Potchefstroom. Measurements recorded included TKM, milling index and kernel size fraction. These three parameters were subjected to analyses of variance using GenStat Release 14th edition. Differences in treatment means were separated using Tukey's honestly significant difference (HSD) post-hoc test at 5% probability level.

10.3 Results and discussion

10.3.1 Thousand kernel mass

The TKM at harvest under the different IMBA treatments during the three seasons at four localities is given in Table 10.1.

10.3.1.1 Bethlehem

With respect to TKM amongst the IMBA treatments, K-humate coincided with the lowest TKM in each season. These lowest values were 317.8 g in 2006/07, 293.9 g in 2007/08, and 361.9 g in 2008/09. The highest TKM values were recorded with Gromor (342.9 g) in 2006/07, Lanbac (360.0 g) in 2007/08, and Promis (417.3g) in 2008/09. Significant differences in TKM between some of the IMBAs were observed in 2007/08 and 2008/09. With regard to NPK treatment, K-humate gave lower TKM values in all three seasons, but differed significantly only in 2008/09. Similar trends, though not significantly were noted with Gliogrow in 2006/07, Gromor in 2007/08, and Growmax and Lanbac in 2008/09. However, the value of TKM from the Lanbac treatment in 2007/08 was significantly higher than the NPK check. In this particular season, Montys gave a 9% larger TKM than the NPK treatment, though not significantly. In each season, none of the IMBAs gave lower TKM than the unamended control, except for K-humate in every season and Growmax in 2007/08, though not significantly. Significant differences manifested only in 2007/08 and 2008/09.

Table 10.1: Effect of IMBAs on one thousand kernel mass (g) of maize at harvest during three production seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	332.9	335.5ab	410.5ab	359.6	299.9	352.5abc	328.8ab	327.1
Gliogrow	331.0	344.0ab	378.3abc	351.1	308.2	361.0abc	348.4a	339.2
Gromor	342.9	310.0bc	413.4ab	355.4	311.7	322.0cde	301.3bc	311.7
Promis	339.0	340.5ab	417.3a	365.6	291.7	357.5abc	332.9ab	327.4
Growmax	339.7	298.7c	387.4abc	341.9	306.3	315.7de	293.3c	305.1
Crop care	333.8	344.5ab	414.1ab	364.1	306.0	361.5ab	344.8ab	337.4
K-humate	317.8	293.9b	361.9c	324.5	308.0	330.0cde	332.4ab	323.5
Lanbac	338.7	360.0a	394.8abc	364.5	301.1	377.0a	315.7bc	240.9
Montys	342.8	356.5ab	392.2abc	363.8	313.4	373.5ab	286.5c	324.5
NPK	331.8	327.3bc	403.1ab	354.1	305.2	344.3bcd	323.9ab	324.5
Control	324.5	307.9bc	375.4bc	335.9	301.8	310.9e	287.1c	299.9
Mean	334.1	329.0	395.3	352.8	304.8	346.0	317.7	322.8
SEM	13.3	15.4	19.9		11.5	15.3	15.6	
CV (%)	5.6	6.6	7.1		5.4	6.3	6.9	
LSD _{T(0.05)}	27.1	31.4	40.8		23.6	31.3	31.9	
	Ottosdal				Potchefstroom			
Biozone	273.9b	342.5abc	345.8abcd	320.7	309.4b	405.3ab	335.8ab	350.2
Gliogrow	346.6a	351.0abc	365.4a	354.3	365.0a	420.2a	355.4a	380.2
Gromor	280.3b	312.0bc	318.3de	303.5	326.9b	371.5b	308.3bcd	335.6
Promis	304.5ab	347.5abc	349.9abc	334.0	321.1b	424.6a	339.9ab	361.9
Growmax	292.3b	305.7bc	310.3cde	302.8	308.8b	379.1ab	300.3cd	329.4
Crop care	292.6b	351.5ab	361.8abc	335.3	326.8b	399.0ab	351.8a	359.2
K-humate	287.3b	300.9bc	349.4abc	312.5	326.0b	362.3bc	294.1d	327.5
Lanbac	298.6b	367.0a	332.7cde	332.8	319.4b	349.9c	322.7bcd	330.7
Montys	280.6b	363.5ab	296.8cde	313.6	312.2b	384.3abc	294.9d	330.5
NPK	303.3b	334.3bc	340.9abcd	326.2	318.2b	394.6abc	330.9abc	347.9
Control	297.0b	320.0c	304.1e	307.0	314.3b	383.2abc	339.4ab	345.6
Mean	296.1	336.0	334.1	322.1	322.6	388.6	324.9	345.4
SEM	21.0	15.3	14.5		16.1	23.8	15.9	
CV (%)	10.0	6.4	6.1		7.1	8.7	6.9	
LSD _{T(0.05)}	42.9	31.3	29.6		32.9	48.6	32.5	

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

10.3.1.2 Bothaville

Concerning TKM among the IMBA treatments, significant differences were observed in 2007/08 and 2008/09. However, only those of the Biozone, Gliogrow, Promis and Crop care gave consistently higher TKM values in both seasons. Lower TKM resulted with Biozone, Promis and Lanbac in 2006/07 than the NPK treatment. Treatments with Gromor and K-humate in 2007/08, and Growmax and Lanbac in 2008/09 gave similar effects. However in 2007/08, Lanbac (33%) and Montys (29%) treatments resulted in

the highest TKM when the NPK treatment served as a check, but this was only significant for Lanbac. Similarly, Crop care gave a TKM advantage of 17% in 2007/08 and 21% in 2008/09 than the NPK treatment, though not significantly. In comparison with the control, over half of the IMBA treatments resulted in significantly higher TKM in 2007/08 and 2008/09. However, those of the Biozone, Promis and Lanbac in 2006/07 and Montys in 2007/08 resulted in lower TKM.

10.3.1.3 **Ottosdal**

The lowest and highest TKM were recorded with Biozone (273.9 g) and Gliogrow (346.6 g) in 2006/07, K-humate (300.9 g) and Lanbac (367.0 g) in 2007/08, and Montys (296.8 g) and Gliogrow (365.4 g) in 2008/09. These differences were significant in each of the three seasons. However, TKM values amongst the IMBA treatments were in many cases lower in comparison with the NPK treatment. Nevertheless, TKM from treatments with Gliogrow in 2006/07 and Lanbac in 2007/08 were significantly higher. In two of the three seasons, Biozone, Gromor, Growmax and K-humate registered lower TKM values than the control, though not significantly. This phenomenon could be attributed to high residual nutrient in this soil which could have rendered some of the IMBAs ineffective. Despite these lower TKM values, Gliogrow in 2006/07, and Crop care, Lanbac and Montys in 2007/08 resulted in significantly higher TKM than the control.

10.3.1.4 **Potchefstroom**

Amongst the IMBA treatments, Gliogrow in 2006/07 recorded significantly higher TKM than the other IMBAs. However, Gliogrow and Promis in 2007/08, Gliogrow and Crop care in 2008/09 resulted with significantly higher TKM than the other IMBAs. The IMBA treatments gave in many cases lower TKM values than the NPK treatment. Nevertheless, Gliogrow resulted in a TKM advantage of 47% in 2006/07, 26% in 2007/08, and 25% in 2008/09. Similar increases were observed also with Promis (30%) in 2007/08 and Crop care (21%) in 2008/09, though not significantly. The only significant difference in this regard was observed in 2006/07 with Gliogrow. For each season, Growmax recorded lower TKM than the control, though not significantly. The differences in TKM between the IMBAs and control were significant only in 2006/07. Like at the Ottosdal site, in this locality, the lower TKM from some of the IMBA treatments than the control could be attributed to high residual nutrient content in the soil which could have rendered some of the IMBAs ineffective.

10.3.2 Milling index

The values of milling index obtained across seasons and localities with the different IMBA treatments are given in Table 10.2. In this study the milling index values reported is the average of the predicted minimum and maximum values of a white maize hybrid.

Table 10.2: Maize milling index at harvest as influenced by IMBA treatments during three production seasons at four sites

IMBAs	Bethlehem				Bothaville			
	2006/07	2007/08	2008/09	Mean	2006/07	2007/08	2008/09	Mean
Biozone	119.9	121.8b	122.7ab	121.4	127.5ab	130.4ab	127.5bc	128.5
Gliogrow	117.2	123.5ab	122.2ab	121.0	129.7a	130.7a	131.7a	130.7
Gromor	117.8	118.1cd	120.3abc	118.7	127.5ab	127.8abc	130.2ab	128.5
Promis	118.7	120.4c	121.4abc	120.2	123.2bc	119.5cd	130.0ab	124.2
Growmax	116.7	118.5cd	119.0bc	118.1	126.2abc	123.9c	131.5a	127.2
Crop care	119.4	124.9a	124.0a	122.8	128.9a	131.7a	129.2ab	129.9
K-humate	117.6	123.7ab	122.6ab	121.3	123.0bc	123.0bc	125.9c	124.0
Lanbac	117.0	123.5ab	122.1abc	120.9	129.9a	131.1a	131.6a	130.9
Montys	116.2	124.2ab	122.1abc	120.9	125.5abc	125.6bc	128.5b	126.5
NPK	118.5	122.8ab	122.6abc	121.3	125.8abc	128.3abc	126.4bc	126.8
Control	116.2	114.7d	117.4c	116.1	121.4c	117.6d	128.2bc	122.4
Mean	117.7	121.5	121.5	120.2	126.2	126.3	129.2	127.2
SEM	2.24	1.44	2.24		2.77	2.47	1.20	
CV (%)	2.7	1.7	2.6		3.1	2.8	1.3	
LSD _{T(0.05)}	4.58	2.95	4.57		5.66	5.04	2.46	
	Ottosdal				Potchefstroom			
Biozone	122.3abc	128.7ab	127.2abc	126.1	122.1a	119.7ab	119.7bc	120.5
Gliogrow	126.3a	130.4a	130.1a	128.9	119.7a	122.0a	126.6a	122.7
Gromor	122.9abc	125.1b	125.1abc	124.4	117.3ab	117.6ab	120.3bc	118.4
Promis	127.1a	127.0ab	128.8ab	127.6	113.2bc	113.6bc	116.4c	114.4
Growmax	121.7bc	130.3a	126.1abc	126.0	113.9bc	115.1bc	118.6c	115.8
Crop care	126.1a	125.1b	127.3abc	126.2	119.1ab	120.6ab	124.4ab	121.4
K-humate	127.9a	126.2b	128.8ab	127.6	116.5ab	117.9ab	121.9ab	118.8
Lanbac	120.9bc	123.4bc	123.9bc	122.7	119.3ab	120.8ab	124.6ab	121.6
Montys	122.8bc	127.4ab	126.8abc	125.7	121.1a	118.1ab	117.5bc	118.9
NPK	121.0bc	125.7b	125.1abc	123.9	116.8ab	115.3bc	116.2bc	116.1
Control	118.4c	120.1c	123.2c	120.5	110.0c	111.0c	114.3c	111.8
Mean	123.4	126.3	126.6	125.4	117.2	117.4	120.0	118.2
SEM	2.37	1.80	2.72		2.73	3.22	3.04	
CV (%)	2.7	2.0	3.0		3.3	3.9	3.6	
LSD _{T(0.05)}	4.83	3.68	5.56		5.57	6.57	6.20	

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

10.3.2.1 **Bethlehem**

The values of milling index varied between 116.2 with Montys and 119.9 with Biozone in 2006/07, 118.1 with Gromor and 124.9 with Crop care in 2007/08, and 119.0 with Growmax and 122.7 with Biozone in 2008/09. These differences amongst the IMBAs were significant in 2007/08 and 2008/09. For each season, the milling index of the IMBA treatments was in many cases lower than the NPK treatment, though not significantly. Regardless of this insignificance, Crop care gave a higher milling index in each of the three seasons. None of the IMBA treatments resulted in each season with significantly lower milling index than the control. In fact the IMBAs had significantly greater milling index in 2007/08 and 2008/09, but were more frequently in 2007/08.

10.3.2.2 **Bothaville**

Amongst the IMBA treatments, the milling index ranged from 123.0 with K-humate to 129.9 with Lanbac in 2006/07, 123.0 with K-humate to 131.7 with Crop care in 2007/08, and 125.9 with K-humate to 131.7 with Gliogrow in 2008/09. Significant differences were observed between some of the IMBA treatments in every season. However, Gliogrow and Lanbac treatments gave in each season the highest milling index values. The milling index of the IMBA treatments and the NPK check was significant in 2008/09 when Gliogrow, Growmax and Lanbac applications resulted with substantial higher values of milling index. Comparing to the control, the IMBA treatments resulted in significantly higher milling index throughout the three seasons. Nonetheless, in 2008/09 Biozone and K-humate gave lower milling index, though not significantly.

10.3.2.3 **Ottosdal**

Regardless of the season, Lanbac coincided with the lowest milling index. These lowest values were 120.9 in 2006/07, 123.4 in 2007/08, and 123.9 in 2008/09. However, highest milling index resulted from K-humate (127.9) in 2006/07, and Gliogrow in 2007/08 (130.4) and 2008/09 (130.1). Differences between some of the IMBAs were significant in all three seasons. With reference to the NPK treatment, lower values of milling index resulted only with Lanbac throughout the three seasons, and Gromor and Crop care in 2007/08, though not significantly. However, Gliogrow gave significantly higher milling index in 2006/07 and 2007/08. Similar significant differences were observed following application of Promis, Crop care and K-humate in 2006/07, and

Growmax in 2007/08. Compared to the control treatment, some of the IMBA treatments resulted in significantly higher milling index values in each of the three seasons.

10.3.2.4 **Potchefstroom**

Concerning milling index amongst the IMBAs, the lowest and highest values were recorded with Promis (113.2) and Biozone (122.1) in 2006/07, Promis (113.6) and Lanbac (120.8) in 2007/08, and Promis (116.4) and Lanbac (124.6) in 2008/09. For each of the three seasons, Gliogrow, Crop care and Lanbac gave significantly higher milling index than K-humate. The IMBA treatments gave in each season higher milling index than the NPK check, except for Promis and Growmax in 2006/07 and 2007/08, and K-humate in 2006/07. Significant differences in milling index between several of the IMBA treatments and the NPK check were observed in 2007/08 and 2008/09. In none of the three seasons milling index recorded in the control plots were higher than those in the IMBA plots. However, in some instances the IMBAs resulted in significantly higher milling index than the control.

10.3.3 **Kernel size**

The percentage kernels of the various size fractions that realised in the IMBAs across the seasons at Bethlehem, Bothaville, Ottosdal and Potchefstroom are given in Tables 10.3 to 10.6, respectively.

10.3.3.1 **Bethlehem**

The percentage kernels of > 11 mm varied between 0.52% with Biozone and 0.92% with Montys in 2006/07, 1.60% with Crop care and 1.92% with Montys in 2007/08, and 0.40% with K-humate and 0.93% with Lanbac in 2008/09. Some significant differences amongst the IMBAs were observed in 2006/07 (Crop care and Montys) and 2008/09 (K-humate and Lanbac). With regard to the NPK treatment, none of the IMBAs resulted in significantly lower amount of kernels in this size fraction. In fact Lanbac in 2008/09 had significantly more percentage kernels than the NPK check. Comparing to the control, Montys in 2006/07 and 2007/08, Gromor in 2007/08, and Lanbac in 2007/08 and 2008/09 resulted in significantly higher percentage of > 11 mm kernels.

Table 10.3: Percentage kernel size fractions (mm) of maize as affected by the IMBA treatments during three seasons at Bethlehem

IMBAs	2006/07					2007/08					2008/09				
	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8
Biozone	0.51ab	4.10d	34.2bc	43.5ab	9.9	1.66ab	6.40	39.9	42.0ab	9.3	0.53ab	6.10bc	42.7ab	39.1ab	9.7
Gliogrow	0.53ab	9.80ab	41.4ab	36.5b	10.1	1.61ab	10.8	37.5	40.0ab	9.3	0.46ab	12.4a	33.1d	40.1ab	9.9
Gromor	0.65ab	8.50bc	33.7c	43.1ab	10.1	1.79a	7.00	39.8	41.5ab	9.3	0.66ab	8.40abc	42.2ab	38.7ab	8.9
Promis	0.62ab	12.5a	39.0bc	36.8b	8.8	1.68ab	9.20	43.3	37.3ab	7.9	0.47ab	8.70abc	36.9cd	37.3ab	8.4
Growmax	0.62ab	6.30bc	38.4bc	41.9ab	9.8	1.68ab	6.60	41.8	40.4ab	8.9	0.47ab	6.10bc	40.8bc	40.4ab	9.5
Crop care	0.45b	6.40bc	39.3ab	42.1ab	9.0	1.60ab	8.90	40.3	40.4ab	8.2	0.49ab	8.30abc	40.1bc	40.6ab	8.8
K-humate	0.58ab	9.30abc	34.1bc	45.1a	8.6	1.62ab	7.90	37.8	43.5a	8.4	0.40b	7.50abc	36.9cd	43.6a	8.9
Lanbac	0.55ab	6.20c	42.3ab	39.0ab	8.4	1.87a	8.90	43.7	37.6ab	7.6	0.93a	8.40abc	43.8ab	37.6ab	8.3
Montys	0.92a	11.4ab	43.7a	33.9b	8.9	1.92a	10.8	42.0	35.4b	9.3	0.65ab	10.5ab	39.2bc	35.4b	9.7
NPK	0.67ab	9.80ab	39.9bc	38.5ab	8.1	1.69ab	9.70	43.8	37.0ab	7.3	0.45b	9.40ab	45.6a	34.1b	7.9
Control	0.47b	4.60d	43.9a	38.8ab	7.5	1.24b	9.80	44.7	37.2ab	6.7	0.41b	5.00c	43.5ab	37.3ab	7.3
Mean	0.60	8.08	39.1	39.9	9.0	1.67	8.73	41.3	39.3	8.4	0.54	8.25	40.4	38.6	8.9
SEM	0.14	1.65	2.70	3.66	1.89	0.23	2.68	3.74	3.68	1.90	0.13	2.45	2.16	3.67	1.89
CV (%)	33.2	28.9	9.4	12.7	29.2	19.8	43.5	12.8	13.2	31.8	35.2	41.9	7.5	13.2	30.0
LSD _{T(0.05)}	0.29	3.36	5.51	7.48	3.87	0.48	5.48	7.65	7.51	3.85	0.27	4.99	4.42	7.48	3.86

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

Concerning the 10-11 mm kernel size, Biozone had in each season the lowest amount with 4.1, 6.4 and 6.1% in 2006/07, 2007/08 and 2008/09, respectively. The highest amount of 10-11 mm kernels was recorded with Promis (12.5%) in 2006/07, Gliogrow in 2007/08 (10.8%) and 2008/09 (12.4%). Some of the IMBAs differed significantly in 2006/07 and 2008/09. For each season, the amount of 10-11 mm kernels resulted amongst the IMBAs was in many instances lower compared to the NPK check, though not always significantly. However, Montys gave the highest percentage of 10-11 mm kernels regardless of the season. Comparing to the control, lower percentage of 10-11 mm kernels was recorded in many instances following application of IMBAs in 2007/08, except for Gliogrow and Montys. This was not the case in 2008/09 since the highest percentage of 10-11 mm kernels was obtained with the IMBA treatments than the control. Significant differences manifested only in 2006/07 and 2008/09.

For the IMBA treatments, the percentage of 9-10 mm kernels ranged from 33.7% with Gromor to 43.7% with Montys in 2006/07, 37.5% with Gliogrow to 43.7% with Lanbac in 2007/08, and 33.1% with Gliogrow to 45.2% with Gromor in 2008/09. Significant differences were found in 2006/07 and 2008/09. In each of the three seasons, the percentage of 9-10 mm kernels from the IMBA plots was in many instances lower when the NPK treatment served as a check. Nevertheless, the percentage of these sizes of kernels was with Promis in 2006/07 significantly higher, and was with Gromor in 2006/07 and Gliogrow, Promis, Growmax, Crop care, K-humate and Montys in 2008/09 significantly lower. For each season, none of the IMBA plots registered significantly higher percentage of 9-10 mm kernels than the control. In fact the IMBA treatments resulted often in significantly lower percentage of these sizes of kernels, e.g. Biozone, Gromor, and K-humate in 2006/07, and Gliogrow, Promis and K-humate in 2008/09.

Concerning 8-9 mm kernels, there were significant differences amongst the IMBA treatments in all three seasons. The lowest and highest percentage of kernels in this size fraction coincided with Montys and K-humate, respectively. The values ranged from 33.9 to 45.1% in 2006/07, 35.4 to 43.5% in 2007/08, and 35.4 to 43.6% in 2008/09. For each of the three seasons, the IMBAs gave higher percentage of 8-9 mm kernels than either the NPK or the control treatments, though not always significantly. The only exception was Montys.

With regard to the percentage kernels of 7-8 mm, none of the IMBA treatments differed significantly from one another and also between the IMBAs and either the NPK or control treatments in any of the three seasons. Amongst the IMBAs, highest percentage of these size of kernels was recorded with Gliogrow in 2006/07 (10.1%) and 2007/08 (9.9%), and Gromor (9.9%) in 2008/09. Lanbac gave in the three seasons the lowest values, viz. 8.4% in 2006/07, 7.6% in 2007/08, and 8.3% in 2008/09. In any of the three seasons, some of the IMBA treatments resulted in higher percentage of 7-8 mm kernels than the NPK and control treatments.

10.3.3.2 **Bothaville**

Concerning the percentage of kernels > 11 mm, the differences amongst the IMBA treatments were not significant. Despite non-significant differences between the IMBA treatments and the NPK check, Gliogrow, Crop care, K-humate, Lanbac and Montys in 2006/07, Promis, Growmax and Montys in 2007/08, and K-humate in 2008/09 tended to give a higher percentage of kernels > than 11 mm. For each of the three seasons, none of the IMBA treatments gave a lower percentage of kernels in this size fraction than the control. In fact some of the IMBA treatments gave in 2006/07 and 2008/09 a significantly larger percentage of > 11 mm kernels than the control.

The amount of 10-11 mm kernels ranged from 1.8% with Lanbac to 3.6% with Crop care in 2006/07, 1.7% with Gromor to 3.8% with Crop care in 2007/08, and 1.9% with Lanbac to 3.6% with Montys in 2008/09. No significant differences amongst the IMBAs were observed. This applies also for differences between the IMBAs and NPK check. Nonetheless, Biozone, Crop care, K-humate and Montys gave in each season the largest percentages of 10-11 mm kernels, but was in many cases lower with the other IMBAs, though not significantly. For each season, the IMBA treatments had a higher percentage of 10-11 mm kernels than the control. The only significant difference in this regard was observed in 2007/08 with Crop care and Montys.

Table 10.4: Percentage kernel size fractions (mm) of maize as affected by the IMBA treatments during three seasons at Bothaville

IMBAs	2006/07					2007/08					2008/09				
	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8
Biozone	0.06	3.19	30.1ab	47.2	16.3d	1.51a	2.96	30.8ab	45.7	15.5	0.56ab	3.21ab	29.6ab	46.0	15.8cd
Gliogrow	0.02	2.73	30.8ab	47.3	18.0cd	1.52a	2.28	31.3ab	45.9	15.8	0.58a	2.76ab	30.3ab	46.0	14.8d
Gromor	0.05	2.25	26.2ab	49.3	17.9cd	1.46a	1.73	26.9ab	47.8	18.8	0.55ab	2.29ab	25.7ab	48.1	20.7bc
Promis	0.05	2.62	27.3ab	47.1	21.7ab	1.29a	2.56	28.2ab	45.5	18.4	0.56ab	2.64ab	26.8ab	45.8	16.2bcd
Growmax	0.06	2.66	23.2b	49.2	22.5a	1.36a	2.88	24.0b	47.8	20.2	0.56ab	2.70ab	22.7b	48.0	19.1bc
Crop care	0.04	3.59	26.2ab	47.9	18.0cd	1.52a	3.83	27.0ab	46.3	18.3	0.54ab	3.61a	25.7ab	46.7	19.7cd
K-humate	0.02	3.60	31.7a	44.0	20.0abc	1.58a	2.85	32.4a	42.5	17.3	0.51ab	3.61a	31.2a	42.8	15.7cd
Lanbac	0.04	1.84	24.2ab	48.9	22.8a	1.54a	3.12	24.8ab	47.4	20.3	0.54ab	1.88ab	23.6ab	47.7	18.9bc
Montys	0.04	3.60	29.4ab	44.1	18.8b	1.43a	3.74	29.9ab	42.8	19.4	0.55ab	3.62a	29.0ab	42.8	21.0b
NPK	0.05	4.38	33.4a	43.0	18.0cd	1.45a	2.73	34.1a	41.5	15.9	0.54ab	4.39a	32.8a	41.8	14.9d
Control	0.00	1.60	26.5ab	46.7	18.0cd	0.42b	1.12	27.2ab	46.3	20.2	0.48b	1.64b	21.6b	45.9	27.6a
Mean	0.04	2.91	28.1	46.8	18.9	1.37	2.71	28.8	45.4	18.2	0.54	2.94	27.2	45.6	18.6
SEM	0.04	1.15	3.82	4.12	1.72	0.15	1.06	3.87	4.06	3.12	0.05	1.14	3.76	4.07	2.57
CV (%)	16.5	55.7	19.2	12.5	12.9	15.5	55.4	19	12.7	24.3	12.0	54.7	19.3	12.6	19.6
LSD _{T(0.05)}	0.09	2.34	7.80	8.42	3.51	0.31	2.17	7.91	8.30	6.37	0.09	2.32	7.67	8.31	5.25

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

Amongst the IMBAs, Growmax in each season coincided with the lowest percentage of 9-10 mm kernels. These values were 23.2% in 2006/07, 24.0% in 2007/08, and 22.7% in 2008/09. However, K-humate resulted in the highest values which were 31.7% in 2006/07, 32.4% in 2007/08, and 31.2% in 2008/09. The differences amongst the IMBAs were significant in any of the three seasons on account of the poor performance of Growmax. For each season, the IMBA treatments resulted in the lower percentage of 9-10 mm kernels than the NPK treatment. The only significant difference in this respect was observed in each season with Growmax. Significant differences between some of the IMBAs and control was obtained in 2008/09 on the percentage of 9-10 mm kernels.

In two of the three seasons, the lowest and highest percentage of 8-9 mm kernels amongst the IMBA treatments were recorded with K-humate and Gromor application, respectively. These values varied between 44.0% and 49.3% in 2006/07, and 42.5% and 47.8% in 2007/08. In 2008/09, the lowest and highest percentage kernels were obtained with Montys (42.8%) and Gromor (48.1%). The differences amongst the IMBAs were not significant in any of the three seasons and also between the IMBAs and either the NPK or control treatments. However, the IMBA treatments resulted in the three seasons with higher percentage of 8-9 mm kernels than the NPK treatment. On the other hand, K-humate and Montys gave in 2006/07 lower percentage of these sizes of kernels than the control. Similar trends were noted with Promis, K-humate and Montys in 2007/08 and 2008/09, and with Biozone and Gliogrow in 2007/08.

The lowest and highest percentage of 7-8 mm kernels coincided with Biozone and Lanbac application in 2006/07 (16.3% and 22.8%) and 2007/08 (15.5% and 20.3%), respectively in two of the three seasons. In 2008/09, the lowest and highest percentage of these sizes of kernels amongst the IMBAs was recorded with Gliogrow (14.8%) and Montys (21.0%). Significant differences amongst the IMBAs were observed in 2006/07 and 2008/09. With reference to the NPK treatment, only Biozone and Gromor in 2006/07 gave lower percentage of 7-8 mm kernels, though not significantly. Treatments with Biozone in 2007/08, and Gliogrow in 2007/08 and 2008/09 demonstrated a similar trend. However, the percentage of kernels realised in the 7-8 mm sieve fraction with the NPK check was significantly lower than with Growmax in 2006/07, and with Gromor and Montys in 2008/09. For each season, the percentage of 7-8 mm kernels from the IMBA treatments was in many cases lower than the control. However, in 2006/07, Promis,

Growmax and Lanbac treatments registered significantly higher percentage kernels in this size fraction.

10.3.3.3 **Ottosdal**

The only significant difference amongst the IMBA treatments was observed in 2007/08 when Gliogrow resulted in a higher percentage of > 11 mm kernels than Gromor and Crop care. In comparison with the NPK treatment, the IMBA treatments resulted in many instances during 2006/07 and 2008/09 with a lower percentage of > 11 mm kernels. This was not the case in 2007/08. In this season (2007/08), Gliogrow resulted in significantly higher percentage of > 11 mm kernels than the NPK check. For each of the three seasons, the percentage of > 11 mm kernels amongst the IMBA treatments was consistently greater than the control, but differed significantly only in 2007/08.

The lowest amount of 10-11 mm kernels resulted from Gromor with values of 1.7, 2.4 and 2.1% in 2006/07, 2007/08 and 2008/09, respectively. Gliogrow resulted in the largest amount of 10-11 mm kernels with values of 8.8, 9.6 and 9.2% in 2006/07, 2007/08 and 2008/09, respectively. Significant differences were observed in each of the three seasons since Gliogrow performed better than Biozone and Gromor. The percentage of 10-11 mm kernels amongst the IMBA plots and NPK check differed not significantly in the three seasons. In fact the percentage of 10-11 mm kernels from the IMBA treatments was in many instances lower, except for Gliogrow, Growmax and Lanbac throughout the three seasons. In comparison with the control, Biozone, Gromor and Crop care resulted in each season with a lower percentage of 10-11 mm kernels, though not always significantly.

With respect to the 9-10 mm kernels, Growmax in 2006/07 (25.4%) and 2008/09 (24.8%), and Gromor (25.5%) in 2007/08 gave the lowest values. The highest values were recorded consistently with Gliogrow in 2006/07 (37.5%), 2007/08 (38.5%), and 2008/09 (37.0%). Significant differences amongst some of the IMBAs were observed only in 2007/08. For each of the three seasons, the percentage of 9-10 mm kernels amongst the IMBAs was in many cases lower than the NPK check, though not always significantly. However, the percentage of kernels in this size fraction with the Growmax and Gliogrow treatments was higher than the NPK treatment. Concerning the control

treatment, in every season none of the IMBA treatments gave higher percentage of 9-10 mm kernels, except for Gliogrow and K-humate, though not significantly.

In any of the three seasons, the percentage of 8-9 mm kernels from Gliogrow was significantly lower than Gromor. For each of the three seasons, none of the IMBA treatments registered in this size fraction lower percentage of kernels than the NPK treatment, except for Gliogrow in 2007/08 and 2008/09. The only significant difference in this regard was observed in each of the three seasons with Gromor. In comparison with the control, only Gliogrow and Lanbac resulted in every season in lower percentage of 8-9 mm kernels, though not significantly. Significant differences between some of the IMBA treatments and control was observed in 2006/07 and 2008/09.

For each of the three seasons, Gliogrow coincided with the lowest percentage of 7-8 mm kernels with values of 10.5% in 2006/07, 9.2% in 2007/08, and 11.0% in 2008/09. The highest values were recorded consistently with K-humate, viz. 21.2% in 2006/07 and 2007/08, and 22.2% in 2008/09. Significant differences were observed amongst some of the IMBAs in all the three seasons on account of the consistently low percentage of 7-8 mm kernels with Gliogrow. For each season, Gliogrow, Promis and Crop care recorded lower percentage of these sizes of kernels than the NPK treatment, though not always significantly. The IMBA treatments gave compared to the control lower percentage of 7-8 mm kernels, except for K-humate in every season. The only significant difference in this respect was obtained in each of the three seasons with Gliogrow.

Table 10.5: Percentage kernel size fractions (mm) of maize as affected by the IMBA treatments during three seasons at Ottosdal

IMBAs	2006/07					2007/08					2008/09				
	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8
Biozone	0.09	2.80b	28.9	47.6ab	17.9ab	1.51ab	3.45b	28.9ab	46.6ab	17.4ab	0.59	3.23b	28.4	47.2ab	18.4ab
Gliogrow	0.35	8.76a	37.5	41.9b	10.5b	1.97a	9.55a	38.5a	40.3b	9.2b	0.85	9.18a	37.0	41.3b	11.0b
Gromor	0.02	1.71b	25.9	52.0a	17.8ab	1.50b	2.42b	25.5b	50.4a	17.8ab	0.52	2.13b	25.2	51.5a	18.3ab
Promis	0.18	3.86ab	31.5	48.2ab	14.3ab	1.60ab	4.51ab	31.9ab	47.3ab	13.3ab	0.68	4.29ab	31.0	47.8ab	14.8ab
Growmax	0.33	5.62ab	26.5	45.3ab	18.8ab	1.81ab	5.80ab	27.9ab	43.8ab	17.9ab	0.86	5.93ab	26.0	44.8ab	19.3ab
Crop care	0.00	3.34ab	34.3	44.7ab	15.6ab	1.46b	3.77b	35.3b	43.4ab	14.6ab	0.50	3.77ab	33.8	44.3ab	16.1ab
K-humate	0.07	4.13ab	27.1	44.0ab	21.2a	1.58ab	4.42ab	26.9ab	43.0ab	21.2a	0.54	4.04ab	26.6	43.4ab	22.2a
Lanbac	0.26	6.24ab	31.0	42.2b	17.5ab	1.67ab	6.82ab	32.0ab	40.7b	16.5ab	0.80	6.66ab	30.4	41.7b	17.9ab
Montys	0.24	5.02ab	25.4	46.7ab	19.0ab	1.63ab	5.61ab	26.1ab	45.4ab	18.2ab	0.72	5.44ab	24.8	46.3ab	19.3ab
NPK	0.34	5.34ab	32.5	41.9b	16.6ab	1.50b	5.75ab	33.6ab	40.7b	15.8ab	0.86	5.74ab	32.0	41.5b	16.8ab
Control	0.00	3.56ab	31.8	42.7b	19.0a	0.64c	4.41ab	31.2ab	41.9ab	18.4a	0.40	3.99ab	31.2	42.3b	19.3a
Mean	0.17	4.58	30.2	45.2	17.1	1.53	5.14	30.7	44.0	16.4	0.67	4.94	29.7	44.7	17.6
SEM	0.24	2.82	6.30	4.45	4.27	0.23	2.69	6.25	4.38	4.16	0.23	2.79	6.31	4.44	4.24
CV (%)	196.9	87.0	29.5	13.9	35.3	21.0	74.0	28.8	14.1	35.9	49.6	79.7	30.1	14.0	34.1
LSD _{T(0.05)}	0.48	5.76	12.9	9.10	8.71	0.46	5.49	12.8	8.94	8.50	0.48	5.69	12.9	9.06	8.66

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented indicate no significant differences

10.3.3.4 Potchefstroom

Amongst the IMBAs, plots in which Montys was applied gave significantly more kernels > 11 mm than K-humate in 2007/08. These two IMBAs gave in 2007/08 significantly lower percentage of > 11 mm kernels than Gliogrow. Similarly in 2008/09, the percentage of kernels (> 11 mm) recorded with Crop care was lower than with Growmax and Lanbac. These three IMBA treatments gave also significantly lower percentage of kernels than Gliogrow. For each season, the amount of kernels > 11 mm differed significantly between some of the IMBAs and NPK check. Significant differences in the percentage of > 11 mm kernels were observed between the IMBAs and control in every season, but more frequently in 2007/08 and 2008/09 than in 2006/07.

In any of the three seasons, the lowest and highest percentage of 10-11 mm kernels was recorded with Gromor and Gliogrow, respectively. The percentage kernel sizes between Gromor and Gliogrow ranged from 2.7 to 13.6% in 2006/07, 3.2 to 14.1% in 2007/08, and 3.7 to 15.3% in 2008/09. In comparison with the NPK treatment, some of the IMBA treatments resulted with lower percentage of 10-11 mm kernels. Nevertheless, Gliogrow gave significantly higher percentage of these sizes of kernels irrespective of the season. Similar trends were observed with Montys, though not significantly. In not any of the three seasons the percentage of 10-11 mm kernels in the control plots was higher than those in the IMBA plots, except for Gromor, though not significantly. The only significant differences between the IMBAs and the control observed in any of the three seasons were with Gliogrow.

The lowest and highest percentage of 9-10 mm kernels were recorded from the Growmax and Gliogrow treatments in every season. The values ranged from 30.3 to 44.1% in 2006/07, 30.4 to 44.0% in 2007/08, and 28.6 to 41.5% in 2008/09. The significant differences observed amongst the IMBAs in any of the three seasons were on account of poor performance of either Gromor or Growmax. With reference to the NPK treatment, none of the IMBAs gave in each season either significantly lower or higher percentages of 9-10 mm kernels. For each of the three seasons, the IMBA treatments resulted in higher percentage kernels in the 9-10 mm size fraction than the control, except for Gromor and Growmax.

Table 10.6: Percentage kernel size fractions (mm) of maize as affected by the IMBA treatments across the seasons at Potchefstroom

IMBAs	2006/07					2007/08					2008/09				
	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8	> 11	10-11	9-10	8-9	7-8
Biozone	0.10b	4.44b	35.8ab	46.7a	11.5b	1.18bc	4.87b	35.8ab	45.2a	11.9b	1.11bc	6.20b	33.5ab	45.0a	12.4b
Gliogrow	1.09a	13.6a	44.1a	34.2b	6.1c	2.29a	14.1a	44.0a	32.7b	6.5c	1.89a	15.3a	41.5a	33.0b	7.2c
Gromor	0.12b	2.71b	34.0b	48.2a	13.5ab	1.22bc	3.22b	33.9b	46.8a	14.0ab	1.02bc	3.73b	32.9b	46.4a	14.4ab
Promis	0.11b	5.04b	37.2ab	47.1a	9.5bc	1.24bc	5.47b	37.1ab	45.8a	9.9bc	0.96bc	6.59b	34.2ab	46.2a	10.8bc
Growmax	0.04c	3.27b	30.3b	47.1a	17.0a	1.14bc	3.82b	30.4b	45.5a	17.4a	0.94bc	4.80b	28.6b	45.1a	18.3a
Crop care	0.11b	5.22b	38.5ab	44.7a	10.2bc	1.04bc	5.65b	38.7ab	43.3a	10.5bc	1.36b	6.77b	35.9ab	43.5a	11.4b
K-humate	0.24b	7.00b	36.5ab	42.9ab	12.0b	1.44b	7.57b	36.4ab	41.4ab	12.3b	1.04bc	8.55b	35.5ab	40.6ab	12.8b
Lanbac	0.13b	4.21b	38.5ab	43.2ab	12.4bc	1.33bc	4.64b	38.3ab	41.8ab	12.8b	0.93c	5.22b	36.2ab	42.3ab	13.7b
Montys	0.10b	5.58b	30.3ab	48.4a	13.4ab	1.00c	6.01b	30.5b	46.9a	13.8ab	1.01bc	7.38b	28.9b	46.2a	14.1ab
NPK	0.11b	6.51b	37.5ab	42.3ab	12.0b	1.13b	6.94b	37.5ab	40.8ab	12.5b	1.00bc	7.64b	36.1ab	40.6ab	12.9b
Control	0.03c	2.79b	32.9b	49.2a	13.4ab	0.21c	3.42b	32.7b	48.0a	14.1ab	0.28d	4.60b	31.5a	47.1a	14.0ab
Mean	0.20	5.49	36.0	44.9	11.9	1.20	5.97	35.9	43.5	12.3	1.05	6.98	34.1	43.3	12.9
SEM	0.17	2.67	4.31	4.67	1.99	0.21	2.65	4.31	4.64	1.97	0.20	2.75	4.10	4.50	1.94
CV (%)	121.9	68.9	16.9	14.7	23.6	24.4	62.7	17.0	15.1	22.6	27.3	55.7	17.0	14.7	21.2
LSD _{T(0.05)}	0.35	5.46	8.80	9.54	4.06	0.42	5.40	8.80	9.48	4.03	0.41	5.61	8.38	9.20	3.96

Means followed by the same letter within a column are not significantly different at 5% probability level: where letters are not presented

indicate no significant differences

Amongst the IMBA treatments, Gliogrow gave lowest percentage of 8-9 mm kernels in every season. Significant differences were observed amongst some of the IMBAs. For each of the three seasons, the IMBA treatments recorded higher percentages of 8-9 mm kernels than the NPK treatment, though not significantly. In this regard, Gliogrow was the only exception. While Gromor registered significantly larger percentage sizes of 8-9 mm kernels than those in the NPK treatment in all three seasons. With regard to the control, in not any of the three seasons the IMBA treatments gave higher percentage kernels in the 8-9 mm size fraction. Likewise, Gliogrow resulted in each of the three seasons in significantly lower percentage kernels of these sizes.

The percentage of 7-8 mm kernels recorded with Gliogrow was significantly lower in every season than with the other IMBAs, except from Promis (in each season) and Crop care (in 2006/07 and 2007/08). In any of the three seasons, the percentage of these sizes of kernels amongst the IMBA treatments was in many cases lower than with the NPK check. However, Growmax gave in each season significantly higher percentage of 7-8 mm kernels. In comparison with the control, a higher percentage of 7-8 mm kernels coincided with Growmax in every season, Gromor in 2006/07, and Montys in 2008/09. However, only Gliogrow resulted in each season with significantly lower percentage kernels in this size fraction.

The 6.35-7 mm and <6.35 mm size fraction comprised of a substantial amount of either broken or damaged kernels. Therefore results on them will not be presented and discussed as with the larger size fractions. However, on average, the percentage kernels in the 6.35-7mm ranged across the seasons and localities from 0.13 to 3.92% and that in <6.35 mm fraction from 0.07% and 0.50%. The IMBA treatments consistently recorded higher percentage of these sizes of kernels at Bethlehem and Bothaville than the NPK check.

10.7 Summary and conclusions

The study on physical traits of maize grain was conducted over three seasons at four localities, resulting in 12 response cases per IMBA treatment. The performance of each IMBA for these 12 cases was compared with the relevant NPK treatment to obtain the frequency of significant increases as presented in Table 10.7.

In comparison with the NPK check, Gliogrow, Crop care and Lanbac significantly increased TKM in two to three cases, and milling index in two to seven cases. The performance of the other IMBAs in relation to the NPK check was inconsistent concerning these two physical traits of maize grain.

Table 10.7: Frequency of occurrence of significant increases in physical traits of maize grain following IMBAs applications in comparison with the NPK treatment over the three production seasons at four sites

IMBAs	Size fractions						
	TKM	Milling index	>11	10-11	9-10	8-9	7-8
Biozone	0	0	0	0	0	0	0
Gliogrow	2	7	4	3	0	0	0
Gromor	0	1	0	0	0	3	1
Promis	0	3	0	0	0	0	0
Growmax	0	2	0	0	0	0	4
Crop care	2	1	0	0	0	0	2
K-humate	0	1	0	0	0	1	0
Lanbac	3	2	0	0	0	0	2
Montys	0	0	0	0	1	0	2

The comparable trend in TKM recorded in 2007/08 and 2008/09 could be ascribed to favourable climatic conditions. However, lower TKM in 2006/07 could be attributed to higher temperatures and erratic rainfall that possibly exerted negative effects on maize phenological growth, which consequently hampered grain filling. Steduto *et al.* (2009) indicated that extreme temperature affects crop phenology. Application of Gliogrow resulted in many instances with significantly higher TKM than the NPK treatment at Ottosdal and Potchefstroom which was not always the case with the other IMBA treatments. Moreover, this IMBA gave lower TKM values in many instances at Bethlehem and Bothaville. This could be related to the fact that these ecotopes are from the same soil family group regardless of the difference in soil texture at the ecotopes and the previous production practices of each site (van Veen *et al.*, 1985).

In comparison to 2006/07, the IMBA treatments resulted in 2007/08 with 11.3% and in 2008/09 with 9.2% higher TKM. A study of Dordas *et al.* (2008) concur with findings of this study who indicated that TKM was not affected in the first two years of the study, but improved by an average of 9% in the third year from the combination of manure and nitrogen treatments. Although, fertilisation was reduced by 30% with Crop care, it however gave higher TKM than the NPK check in two out of the potential 12 cases. Most of the IMBAs that coincided with optimum applications of inorganic fertiliser showed depressive effects. An increase in applications of N up to 60 kg ha⁻¹ increased TKM, while further increase of N application decreased TKM (Protic & Jankovic, 1999; Protic *et al.*, 2007).

The values of milling index recorded in this study concur with values reported by Southern African Grain Laboratories on white maize (SAGL, 2004). Maize kernels from Bothaville and Ottosdal ecotopes showed higher milling index than those from the other two ecotopes at Bethlehem and Potchefstroom. A report from SAGL (2008) suggests that milling index is not only an indication of the milling abilities but also the milling quality of maize kernels. A higher milling index indicates a higher extraction of the high-grade and most profitable products like samp, maize rice and grits. The Gliogrow, Promis, Growmax and Lanbac treatments gave significantly higher milling index across the localities. Hence, the results of this study supported observations from an earlier study by Protic *et al.* (2007) who indicated that grain with higher TKM have better milling quality and ensure better emergence. The lower milling index values at Bethlehem and Potchefstroom could be related to the similar climatic conditions of the two sites (Steduto *et al.*, 2009).

A study of SAGL (2008) indicated that the most acceptable kernels for the milling industry ranged between 8 mm and 10 mm in size. Most of the kernels from the IMBA treatments were within the 8 mm and greater size fraction. Kernel size is important to the starch manufacturing industry, hence kernels that are too small hamper the separation of kernel fractions in the wet milling process, and the result is a lower starch yield (SAGL, 2004). On the other hand a mixture of small and large kernels cause additional problems, as homogeneous steeping cannot be achieved. However, very large kernels can also cause problems since the ratio between volume and mass is

unfavourable to proper steeping. Thus, a uniform kernel size is of particular importance to this industry (SAGL, 2008).

Application of some of the IMBA treatments gave a profound significant positive effect on TKM, milling index and kernel size of maize across the seasons and localities. With respect to TKM and milling index, Gliogrow, Promis, Growmax, Crop care and Lanbac applications exerted a more positive profound effect than the NPK and control treatments regardless of the ecotopes. The IMBA treatments promoted higher TKM more frequently at the Bethlehem and Potchefstroom ecotopes, and milling index at the Bothaville and Ottosdal ecotopes. Higher TKM values were consistently recorded from treatments with Gliogrow, Crop care and Lanbac irrespective of the ecotope. However, the performance of Gliogrow at Bethlehem ecotope was poor. There is a tendency that the IMBAs coincided with higher TKM also improved milling index and hence the milling potential. Like with TKM, maize kernels with bigger grading sizes were recorded amongst the IMBAs at Bethlehem and Potchefstroom ecotopes. Except at Bethlehem ecotope, Gliogrow resulted across the localities explicitly with significantly more cases of bigger kernels (>10 mm) compared to the NPK standard which are better for the grain and milling industry. Across localities and seasons, the IMBA treatments resulted in a high percentage of kernels ranging between 8 mm and 10 mm size fraction which are preferred in the milling industry. The IMBA treatments gave higher TKM than the unfertilised plots at Bethlehem and Bothaville ecotopes with low residual nutrient contents in soil but not at the Ottosdal and Potchefstroom ecotopes with high residual nutrient contents in soil. However, the IMBAs resulted with higher milling index than the control regardless of differences in soil fertility. Kernels of 9 mm and greater were recorded with the IMBAs while kernels in the unamended control were predominantly 9 mm and less in size.

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CHAPTER 11

SYNOPSIS AND RECOMMENDATIONS

The major maize producing regions of South Africa has soil characteristics that are often highly deficient in major plant nutrients. This had forced producers to apply higher rates of inorganic fertiliser to meet optimal crop yields, which is often impracticable for many resource-poor farmers. The steadily yearly hike in prices of conventional NPK fertiliser among other reasons has inspired many companies in South Africa to commence the manufacturing of biological-enriched amendments herein refers as industrially manufactured biological amendments (IMBAs). Most of the IMBAs are supplements of conventional NPK fertiliser rather than total replacements and therefore would mean an extra cost to producers. The usage of ineffective and uneconomic materials as crop growth and yield promoters either as soil or foliar amendments could therefore negatively affect producers that are already under financial constraint.

A glasshouse pot trial was conducted during 2008/09 season to assess the effects of graded rates of nine locally produced IMBAs on maize seedlings establishment and growth over a six weeks period. These IMBAs were Biozone, Gliogrow, Gromor, Promis, Growmax, Crop care, K-humate, Lanbac and Montys. All nine IMBAs were assessed at 50, 75 and 100% of the recommended rates together with the optimum rates for conventional inorganic NPK fertiliser and a control that received neither inorganic fertiliser nor any of the IMBAs. The treatments in the trial were arranged in a completely randomised design (CRD) and replicated four times. The results of this study revealed that the IMBA treatments exerted in many instances a deleterious effect on the percent maize seedling emergences when applied at 100% rate; being generally higher at 50 and 75% rates. More so, application rates of 50 and 75% appeared sufficient amongst several of the IMBAs for encouraging better growth and phenological development of maize, the most appropriate rate is however dependent on the IMBA type.

In order to address the effects associated with the use of IMBAs on maize performance, grain yield and quality, and on soil chemical and microbial properties rainfed field experiments were conducted during 2006/07 to 2008/09 at four sites

namely; Bethlehem, Bothaville, Ottosdal and Potchefstroom. The same nine IMBAs used in the glasshouse pot trial were evaluated along with optimum conventional inorganic NPK rate and the unamended control as standard check at each site. The IMBAs were applied based on either the product manufacturers or supplier recommendation rates. The conventional NPK was applied using limestone ammonium nitrate, superphosphate and potassium chloride, respectively. The experiments were laid-out in a randomised complete block design (RCBD) with each treatment replicated four times. All trial sites were planted to one maize cultivar PAN 6479 at 0.3 and 1.5 m intra- and inter-row spacing, respectively. All agronomic practices were kept normal and uniform for all treatments and fields throughout the study period. Every season, observations on phenological growth traits of maize, grain yield and yield components, nitrogen and phosphorus content, uptake, and agronomic use efficiency, chemical and microbial properties of soil and on physical grain quality traits were recorded. Recorded data were analysed using GenStat Release 14.

With regard to soil chemical and microbiological properties, application of the manure-based IMBAs (total replacement of inorganic NPK fertiliser) generally raised pH to between 6.0 and 7.0 which was not always the case with the other IMBAs that coincided with inorganic NPK fertiliser. However, application of nearly all the IMBA treatments resulted in significant pH increases compared to the NPK standard. These significant increases were mainly obtained on the sandy soil of Bothaville ecotope and the clayey soil of Potchefstroom ecotope, while no significant increases manifested in the sandy soils of Ottosdal ecotope. Generally, Gromor and Gliogrow recorded most cases of significant pH increases when the NPK treatment serves as reference, namely in five and seven cases, respectively. In relation to the NPK check, the frequency of significant increases in organic C, mineral N and extractable P were only four instances and less. The most cases of significant organic C increase resulted from Gliogrow and Crop care. These significant increases were observed under sandy soil of the Bothaville and Ottosdal ecotopes. Virtually all the manure-based IMBAs like Gromor, Promis and Growmax resulted in no cases of significantly higher mineral N and extractable P than the NPK check. However, Growmax gave only one case of significant increase on mineral N at Ottosdal ecotope while Promis showed two cases of significant extractable P increases at the Bothaville and Potchefstroom ecotopes.

The IMBAs promoted higher microbial biomass-C immobilisation at 4-weeks after planting while biomass-C mineralisation was predominant at flowering and crop harvest, although it tended to decline at crop harvest. The different IMBAs exerted in many instances no significant effect on biomass-C and -P in relation to the NPK plots in all three samplings. However, the IMBAs that responded positively gave only one case of significant increase in either biomass-C or-P than the recommended NPK standard in any of the three samplings. Also, no positive significant effect resulted on these parameters under sandy soil at Bethlehem ecotope. With regard to biomass-P, the IMBAs augmented mineralisation regardless of the season and sampling time, although it was in many instances less than that in the NPK check. These cases of significant increase resulted respectively during 4-weeks after planting and flowering at Potchefstroom ecotope, and also at Ottosdal ecotope during crop harvest. Generally, the IMBAs had consistently the highest degree of immobilisation for biomass-C and -P compared to the unfertilised plots, probably due to lower C inputs from root residue in the later.

Results on growth and phenological characteristics of maize revealed that, the different IMBAs had no positive effect in comparison with the NPK treatment. More so, the frequency of significant increases in biomass yield (Gliogrow and Lanbac) and leaf area index (Biozone and Lanbac) were only in one instance at silking stage. Despite this insignificance, it was noted that application of Gliogrow resulted with constant reduction in plant phenological growth at the 9th leaf and silking growth stages due to poor emergence, particularly from soils with higher clay content. Application of the manure-based IMBAs like Gromor and Promis gave consistently better maize growth during vegetative stage but not at reproductive stage, possibly due to their slowly nutrient releasing potential.

Results on grain yield and yield components demonstrated that the manure-based IMBAs like Gromor and Promis exerted no significant positive effect compared to the NPK check. However, Promis resulted with significant increase in total biomass yield only in one case. Nonetheless, Growmax (manure-based IMBAs coincided with conventional inorganic NPK fertiliser) resulted in few instances with significantly higher yield and yield components than the NPK standard, except for harvest index and cob

length. More of these significant increases manifested in inherently fertile soil due to recurring fertiliser application at the Ottosdal and Potchefstroom ecotopes. Application of Gliogrow had in comparison with the other IMBAs a deleterious effect on maize plant stand count throughout the three seasons of assessment, but gave comparative yield which could be attributed possibly to its prolific effects on cob length and kernel mass. Plots from treatment with K-humate gave the highest number of cases of significant grain yield increase followed by Biozone and Growmax applications, respectively. The different IMBAs gave positive effects on grain and stover yields at Bothaville and Potchefstroom ecotopes, and total biomass yield and the number of cobs at Bethlehem and Potchefstroom ecotopes. Concerning harvest index, the different IMBAs resulted also in few cases with significant increases compared to the NPK check. These were concomitant with the sites' soil characteristics since higher harvest index were recorded more frequently in clayey than sandy soil. The IMBAs did not have a positive significant effect on cob length in relation to the NPK treatment.

The results on plant biomass N content and uptake recorded at 9th leaf, silking and harvesting revealed that these parameters were rarely significantly higher than those in the NPK standard. The following IMBAs showed potential in increasing N content at various growth stages: Biozone, Gliogrow and Promis at 9th leaf stage, Gliogrow and K-humate at silking, and Biozone and K-humate at harvesting. The manure-based IMBAs like Gromor and Promis gave only sporadic a significant increase in N content and uptake at various growth stages. However, Growmax which is also a manure-based IMBA but coincided with conventional inorganic NPK fertiliser gave more cases of significant increases. The different IMBAs showed more cases of significant N content increase in plant biomass at 9th leaf stage on the Bothaville ecotope, and at silking and harvesting on the Ottosdal and Potchefstroom ecotopes. None of the IMBAs exerted a significant effect on the agronomic use of the applied N compared to the applied N from the NPK check, except for the only one chance of significant increase with Promis.

The results on plant biomass P content and uptake recorded at 9th leaf, silking and harvesting demonstrated that, these parameters were infrequently significantly higher than those in the NPK check. However, P content at 9th leaf stage increased significantly in three to four instances due to the application of Promis, Growmax and

Montys. The efficiency of applied P from the IMBAs was not in one case significantly better than the applied P from the NPK check.

Results of physical grain quality traits of maize revealed that, Gliogrow, Crop care and Lanbac significantly increased TKM in two to three cases, and milling index in two to seven cases in comparison with the NPK check. The performance of the other IMBAs in relation to the NPK check varied considerably concerning these two physical traits of maize grain. Except at Bethlehem ecotope, Gliogrow gave bigger kernel sizes across the other three localities which is a better attribute for maize grain and the milling industry. Likewise, this IMBA solely gave significantly higher percentage of >11 mm, and 10-11 mm kernels than the NPK plots. Equally, Gromor gave significantly higher percentage of 8-9 mm kernels, and Growmax of 7-8 mm kernels. Across the seasons and localities, the IMBAs tended to give higher percentage of kernels that ranged between 8 mm and 10 mm in size.

Considering the results that emanated from this study it is apparent that:

- Despite inconsequentiality, farmers could be encouraged to use the IMBAs Gliogrow, Growmax, Crop care, K-humate, Lanbac and Montys as growth boosters since they could improve maize productivity in both clayey and sandy soil.
- Producers could be encouraged to adapt to use manure-based IMBAs like Gromor at 2000 kg ha⁻¹ and Promis at 2000 and 1000 kg ha⁻¹ for soil nutrient restoration.
- The positive response of the manure-based IMBA like Gromor will be achieved when this product is applied at recommendation rate (2000 kg ha⁻¹) in combination with the recommended conventional NPK fertiliser, but Promis (manure-base IMBA) will show promising potential on maize growth and yield when applied at 750 kg ha⁻¹ other than the recommended rate of 1000 kg ha⁻¹.
- Application of the different active ingredients of IMBAs exerted greater response when applied in fields succeeding legumes. It will therefore paramount that producers take heed to rotate non-leguminous crops with leguminous crops when considering using any of the IMBA treatment evaluated in the research.

- The IMBAs could also enhance maize performance when applied at either 50 or 75% of the recommended rate given by either product manufacturers or suppliers other than at 100% recommended application rate.

Further studies are warranted to:

- Detail investigation need to be undertaken in a wide range of soil to assess the suitability of Gliogrow to achieve the intended purpose. Such investigation will include detail characterisation of the product for isolation of compounds that is responsible for the deleterious effect on plant emergence observed in the current study in order to develop a resilient product that will be adaptable in a wide range of soils and environmental conditions.
- There is need to undertake further research work that establishes the optimum application rate for each IMBAs independent of the manufacturer's or supplier's recommendation rates under varying ecological zones and soil conditions for a wide range of crops.
- The cost-benefit analyses of each IMBA treatment used need further detail assessment comparative to the use of the conventional NPK fertiliser in order for them to be regarded as the feasible and cost-effective alternative soil/plant ameliorants.
- Finally, long-term studies will have to be carried out to assess the potential effect of these IMBAs on soil nutrient balances, carbon sequestration, their contribution to greenhouse gases as well their potential impact on underground water sources.