Fertiliser effectiveness of poultry manure and n-fertiliser value of cattle kraal manure under field conditions.

FERTILISER EFFECTIVENESS OF POULTRY MANURE AND N-FERTILISER VALUE OF CATTLE KRAAL MANURE UNDER FIELD CONDITIONS

By

Justice MAHOPE

Submitted in partial fulfilment of the requirements for the degree

MAGISTER TECHNOLOGIAE: AGRICULTURE

in the

Department of Crop Sciences

FACULTY OF SCIENCE

TSHWANE UNIVERSITY OF TECHNOLOGY

Supervisor: Prof W Van Averbeke

Co-supervisor: Prof P Soundy

November 2019

DECLARATION

"I hereby declare that the dissertation submitted for the degree M Tech: Agriculture, at the Tshwane University of Technology, is my own original work and has not previously been submitted to any other institution of higher education. I further declare that all sources cited or quoted are indicated and acknowledged by means of a comprehensive list of references".

J Mahope
Student number: 214000474

DEDICATION

I dedicate this dissertation to my dear parents (Mr & Mrs Mahope), with overflowing love, admiration and appreciation. You are so wonderful.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Almighty God for giving me the strength and ability to start and complete this study. Indeed with God everything is possible.

I wish to express my sincere and deepest gratitude to my supervisor Professor W Van Averbeke, for his valuable time, encouragement and excellent advice throughout the entire period of my study. I am sincerely indebted to your constructive criticism, professional guidance and all the assistance and financial support you provided me with during the course of my study without which this dissertation might never have materialised. For what I am now and what I will be in future I largely owe it to you Professor. I also gratefully acknowledge my co-supervisor Professor P Soundy for being supportive throughout the entire study and Ms L Morey for her assistance with the statistical analysis of my data.

My sincere appreciation goes to Mrs. Mawera and Mr Mulaudzi for allowing me to conduct my field experiments in their home gardens. To all the field assistants that helped me during the entire experimental period, big thank you. Special thanks to Mr Adebisi LO for his advice and my fellow post graduate students, Thapelo, Ntokozo, Zanele, Sithembiso, Wandile, Christopher, Boitshepo, Ayanda and Cecelia for their support.

To the entire Christian family who supported me in varied ways, thank you very much. I would also like to thank my friend Blessing for all the love and moral support throughout the study. To my parents and my siblings, who were so generous with their encouragement and prayers throughout the study, big thank you. I am thankful to staff members of the Department of Crop Sciences for all their support. Lastly, I am also indebted to the Tshwane University of Technology and VLIR-OUS (in collaboration with Gent University) for their financial support.

ABSTRACT

A study was carried out to determine the residual and application rate effects on the nitrogen fertiliser value (NFV) of cattle kraal manure, to explore the potential of chicken litter to rapidly restore the fertility of nutrient-depleted garden soils in Thulamela, and to find out whether the use of banding or spot placement of chicken litter is a beneficial strategy for use when access to chicken litter is restricted. In a field experiment conducted over two consecutive growing seasons using maize as test crop, nitrogen was applied at 30, 60, 90 and 120 kg N ha^{-1} both as cattle kraal manure and as urea. This arrangement provided four estimates of the residual effect of the first application on the NFV of cattle kraal manure. To pursue the potential of chicken litter to rapidly restore the fertility of home garden soils, an irrigated field experiment involving a winter and summer crop was conducted in which N, P and K were applied at a high and a low rate in the form of chicken litter and chemical fertilisers. Fertiliser placement effects were investigated at the low rate of nutrient application. The key findings of the study were that cattle kraal manure applied during the first year had a considerable positive effect on the NFV of the cattle manure applied during the second year. This is important, because it confirms that the strategy of applying cattle kraal manure annually to the same parcel of land, which is used by a minority of home gardeners in Thulamela is useful in raising the supply of N to crops. Application rate affected the second-season NFV of cattle kraal manure, which ranged between 20 and 22% when manure was applied at rates of 60 kg N ha^{-1} and higher and dropped to 14.5% when manure application rate was reduced to 30 kg N ha^{-1}. Applying chicken litter at the rate of 90 kg N ha^{-1} provided crop productivity levels that were slightly below those of chemical fertiliser for the first crop and slightly above those of chemical fertiliser for the second crop, indicating that chicken litter is a ‘complete fertiliser’, able to supply not only plant available N but also P and K. and able to rapidly restore the fertility of soil that has been depleted of nutrients as a result of nutrient mining. However, the risk of raising soil P to supra-optimal levels, by the continuous application of chicken litter at high rates, was identified. At low rates of application (15 kg N ha^{-1}) band or spot placing instead of broadcasting chicken litter was found to be superior.

INDEX

CHAPTER 3

CHAPTER 4

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDICES (CD-ROM)

ABBREVIATIONS

^oC	Degree Celsius
%	Percentage
ANOVA	Analysis of variance
ARC	Agricultural Research Council
ARNFV	Apparent relative nitrogen fertiliser value
DAP	Days after planting
FSARNFV	First-season apparent relative nitrogen fertiliser value
G	Gram
g m^{-2}	Gram per square metre
ha	Hectare
K	Potassium
kg	Kilogramme
kg ha^{-1}	Kilogramme per hectare
ℓ	Litre
LSD	Least Significant Difference
mg	Milligrams
mg N kg $soil^{-1}$	Milligram Nitrogen per kilogram soil
mg P kg $soil^{-1}$	Milligram Phosphorus per kilogram soil
mℓ	Millilitre
mm	Millimetre
mS m^{-1}	MilliSiemens per metre
N	Nitrogen
NO_3^--N	Nitrate nitrogen
NASAWC	Non Affiliated Soil Analysis Work Committee
NH_4^+-N	Ammonium nitrogen
NFV	Nitrogen fertiliser value
P	Phosphorus

CHAPTER 1

1. GENERAL INTRODUCTION

The aim of the current study was to contribute to knowledge on the use of animal manure as a fertiliser in crop production with specific reference to home garden cultivation in Thulamela Municipality, Vhembe District, Limpopo Province. The specific objective of the study was to field-test two strategies to raise the fertility of home garden soils. The first strategy involved successive applications of cattle kraal manure, which is the most commonly available type of animal manure in the study area. Previous research by Ngwenya (2017:54) demonstrated that cattle kraal manure from Thulamela had a very limited ability to make available nitrogen to crops following its first-time application, casting doubt on its value as a nitrogen fertiliser. The second strategy involved the use of chicken manure to rapidly restore the fertility of depleted home garden soils.

The large majority of rural households in the communal areas of South Africa only grow crops in their home gardens and engage in this activity for the purpose of obtaining an additional source of food (Shackleton, Shackleton & Cousins, 2001:590; Lehohla, 2016:5). Denison *et al*. (2016:174) demonstrated that this general description also applied to Thulamela. Their survey results showed very high levels of participation in home garden cultivation among rural households and confirmed the dominance of the home consumption purpose of this activity. Home gardens in Thulamela tend to be fairly small, typically of the order of 1000 m^2 (Denison *et al*., 2016:130) but still contribute, on average, about one month's worth of food to the households of home gardeners (Mpyana, 2017:140). Water deficit is a primary constraint to crop growth and yield in home gardens (Moeletsi, Mpandeli & Mellaart, 2011:485; Moswetsi, Fanadzo & Ncube, 2017:54) but indications are that the fertility of the majority of these gardens is also very low, to the extent that crop production is expected to be affected (Ramphisa, 2015a:44).

There are several ways of raising soil fertility. The most obvious is to apply the required inorganic fertilisers (Sanchez, 2002:2019), but Mkhabela (2006:1160) pointed out that for reasons of affordability and lack of access, the rates of inorganic fertiliser applied by South African smallholders are well below recommended levels. Unaffordability of chemical fertilisers among smallholders was confirmed by Odhiambo and Magandini (2008:359) for the Vhembe District of Limpopo Province. They reported that three out of four of the smallholders they interviewed could not afford the required quantities of inorganic fertiliser.

Besides purchase and application of chemical fertilisers, other practices exist to raise the fertility of cultivated soils. These include application of organic sources of nutrients, such as animal manure, crop rotations involving legumes, and agro-forestry (Kumwenda *et al.,* 1996:10; Mkhabela, 2002:30). All of these practices employ on-farm or local resources and put less strain on the limited financial capital at the disposal of smallholders than buying chemical fertilisers (Kumwenda *et al.,* 1997:159; Nhamo, Kintche & Chikoye, 2017:60).

The use of animal manure as a source of plant nutrients is a well-established practice in South African smallholder farming and gardening systems (Mkhabela, 2002:30; Materechera, 2010:420). Fertilising soil with animal manure is appropriate for smallholders, because many of them practise mixed farming (Mkhabela, 2006:1162), whilst people without livestock can access manure at little or no cost in their neighbourhood (Mkhabela & Materechera, 2003:155; Mkhabela, 2006:1162). Ruminant manure is the main type of manure used as fertiliser on cropped land (Mkhabela, 2002:30; Materechera & Modiakgotla, 2006:21), but poultry manure is gaining in importance as well (Mkhabela, 2006:1162). Apart from supplying nutrients for uptake by plants, application of manure also contributes positively to soil quality by improving physical, chemical and biological soil properties (Fageria & Baligar, 2005:140; Morris *et al.,* 2007:21).

In most South African soils, N is the nutrient that limits plant growth most (Du Toit & Du Preez, 1995:74; Barnard & du Preez, 2004:305; Laker, 2008:332). Accordingly, the ability to provide plants with N is of primary interest when using manure as a fertiliser. The N in manure is usually present in both inorganic and organic forms (Crohn, 2004:1). Inorganic forms of N consist primarily of ammonium (NH_4^+) and nitrate (NO_3^-) and these two forms of N are immediately available to the plant (Sanchez *et al*, 1997:8; Brady & Weil, 2008:534). Organically bound N needs to be mineralised to become plant-available (Balkcom, Blackmer & Hansen, 2009:1074), even though certain plants are able to take up dissolved, N-containing, organic molecules with low molecular weight (Näsholm, Huss-danell & Hogberg, 2000:1155; Näsholm, Kielland & Ganeteg, 2009:35). Mineralisation of N is the microbially mediated transformation of organically bound N into inorganic N compounds (Zech *et al.,* 1997:139), whilst immobilisation of N is the conversion of mineral N into organic forms (Watts & Torbert, 2014:86). Both mineralisation and immobilisation of N are biochemical processes that occur simultaneously (Murugan & Swarnam, 2013:175). Organic N added to the soil is only plant-available during periods of net mineralisation (Murugan & Swarnam, 2013:175). Whether or not net mineralisation of manure N occurs depends on manure and soil type (van Fassen & van Dijk, 1987:36). The rate of N mineralisation in manure is controlled by a range of soil and manure factors. Soil factors include temperature, water content, particle size distribution, and pH (Murwira, Swift & Frost, 1995:134). Among the manure factors, C:N ratio and lignin and polyphenol content of manure appear to be most important (Murwira, Swift & Frost, 1995:134; Kumar & Goh, 2003:2441).

The proportion of N in applied manure that is taken up by the crop is referred to as the nitrogen fertiliser value (NFV) of manure (Hijbeek *et al.,* 2018:105). The NFV of manure depends on a wide range of factors, including manure composition, rate, time and method of application, type of crop and its growing period, soil type and fertility status, history of the field, and climatic conditions, particularly the soil water and temperature regime (Agehara & Warncke, 2005:1844; Bannink & Bos, 2005:126; Nevens & Reheul, 2005:350; Schröder, Jansen & Hilhorst, 2005:196; Ruiz Diaz, Sawyer & Mallarino, 2011:730; Adebisi, 2015:43). This partly explains why the NFV of animal manure reported in the literature varies so widely. Comparison of the NFV of different types of manure becomes more meaningful when conditions of measurement are standardised, which was the purpose of the development of the apparent relative nitrogen fertiliser value assay (ARNFV) (Ngwenya, 2017:27-28; Mthimkulu, 2019:32-34). This assay is a pot-based method in which the first-season nitrogen fertiliser value (NFV) of manure is measured using maize as the test crop. The maize is grown for a period of six weeks (42 days) from planting in a standard low-fertility soil. Making use of this assay, Ngwenya (2017:54) found that the first-season NFV of cattle kraal manure from Thulamela Municipality was very low, ranging between -0.8% and 4.9%.

Several studies have demonstrated that manure with low first-year NFV partly compensates for the initial low plant-availability of the N it contains by showing a greater residual effect, which increases the N fertiliser value of the manure of subsequent applications (Schröder, Jansen & Hilhorst, 2005:196; Schröder, Uenk & Hilhorst, 2007:97). However, all of these studies used manure from cattle that were reared in intensive livestock production systems in Europe. These production systems differ considerably from communal cattle rearing systems in Africa, where animals rely heavily on the natural vegetation for their sustenance (Mkhabela, 2006:1161-1162). Hence, there is a need to investigate the residual N effect of manure derived from cattle that were reared in the communal areas of Africa. Accordingly, the first objective of the current study was to determine the magnitude of the residual N effect on the relative nitrogen fertiliser value of cattle kraal manure under field conditions.

The second objective of the study was to assess the potential of chicken manure to rapidly restore the fertility of nutrient-depleted garden soils using chicken manure. Chicken manure contains particularly high amounts of N, P and other plant nutrients (Sims & Wolf, 1994:18-19), and is known to rapidly release these nutrients in plant-available forms (Pratt, Broadbent & Martin, 1973:12; Wilkinson, 1979:122-123). These properties make chicken manure potentially suitable for rapid restoration of the fertility of soils that have been depleted of plant nutrients, particularly N and P (Maerere, Kimbi & Nonga, 2001:17-21). The availability of chicken manure in rural and peri-urban South Africa has increased due to the establishment of small-scale broiler and layer units in many locations since 1994 (Materechera & Morutse, 2009:262). Ralivhesa *et al.* (2013:285) reported that the majority of smallholders in Vhembe District purchased poultry manure for use as fertiliser from small and medium poultry production units operating in their neighbourhoods.

Rearing of scavenger chickens is also common in the rural areas of Thulamela (Norris *et al.*, 2007:22; Mtileni *et al.*, 2011:209-211). Often the birds are housed at night (Halima *et al.*, 2007:194) creating the opportunity for the collection of chicken excrements and their use as fertiliser. Ngwenya (2017:72) found that the first-season NFV of chicken manure from Thulamela Municipality ranged between 24% and 64%, making chicken manure a promising and useful resource in raising the fertility of home garden soils, but this needs verification.

This manuscript documents the study that was conducted. It contains four chapters, two of which are empirical, one for each of the two study objectives. These empirical chapters were compiled using the IMRAD[1] structure of a scientific article. It is the intention to submit these two chapters for publication in appropriate scientific journals. The other two chapters consist of a general introduction, which provides the background to the study, and a general conclusion, which contextualises the findings of the study.

[1] IMRAD is the acronym for Introduction, Materials and method, Results And Discussion.

CHAPTER 2

2 RESIDUAL AND APPLICATION RATE EFFECTS ON THE APPARENT RELATIVE NITROGEN FERTILISER VALUE OF CATTLE KRAAL MANURE

2.1. Introduction

Cattle kraal manure, which is defined as 'the organic material that consists mainly of the excretions of cattle and plant residues that have accumulated on the floor of the livestock enclosure' (Archer, 1988:124; Van Averbeke & Yoganathan, 2003:2), is commonly used as a fertiliser in South African smallholder cropping systems (Yoganathan *et al*., 1998:362; Mkile, 2001:47; Mkhabela & Materechera, 2003:152; Materechera, 2010:420). Ramphisa (2015a:39) reported cattle kraal manure as the most commonly applied fertiliser in home garden cropping systems of Thulamela Municipality. However, Ngwenya (2017:54) found that cattle kraal manure from Thulamela had a very low first-season nitrogen fertiliser value (NFV). She recorded NFVs that ranged between -1.7% and 4.9% for the four cattle kraal manure samples she investigated. The first-season NFV of manure is the proportion of the total N present in manure that is taken up by the crop planted immediately after application of manure to the soil for the first time (Hijbeek *et al.*, 2018:105).

Assessment of the value of manure as a source of plant-available N should not only consider its first-season contribution but also the contributions it makes during subsequent seasons. After the first season of application, manure leaves behind appreciable amounts of N that have not been mineralised. These can become plant-available in subsequent seasons (Schröder, Jansen & Hilhorst*,* 2005:201). The contribution of historical manure applications to plant-available N in soil is referred to as the residual N effect of manure (Silva *et al*., 2006:166; Suthamathy & Seran, 2013:2). In cropping systems where manure is applied regularly, the residual N effect of manure tends to raise the N-fertiliser value of a particular manure as time goes by (Schröder, Jansen & Hilhorst*,* 2005:201).

Both first-season NFV and long-term NFV of manure have been the subject of research in western farming systems. An example of such an investigation was the comparison of the short and long term NFV of dairy cattle slurry and farm yard (cattle) manure by Schröder, Uenk and Hilhorst (2007:94) in the Netherlands. They found that undigested dairy cattle slurry that was injected into soil had a first-season NFV of 52%, whilst that of Dutch farmyard manure was 31%. Schröder, Uenk and Hilhorst (2007:94) predicted that it would take 7 to 10 yearly injections of undigested dairy cattle slurry to raise the NFV of this slurry to 70%. They also predicted that the NFV of farmyard manure would only attain the 70% level after 20 to 40 annual applications. This example demonstrates that the NFV of manure varies greatly, both in the short and in the long term.

A range of factors affect the N-fertiliser value of manure. These include the chemical composition of manure, rate, time and method of application, type and growing period of the crop being cultivated, the history of the field, the soil type, and the climatic characteristics of the area, with particular reference to temperature and soil water regime (Agehara & Warncke, 2005:1844; Nevens & Reheul, 2005:350; Schröder, Jansen & Hilhorst, 2005:196; Ruiz Diaz, Sawyer & Mallarino, 2011:730; Adebisi, 2015:43). The chemical composition of manure is influenced by livestock species, diet, materials added to the excrements, such as bedding material, chemical transformations during storage, and the partitioning of urine and faeces into solid and liquid manure fractions (Webb *et al.,* 2013:376; Shah *et al.,* 2015:2). The wide range of livestock farming systems practised by farmers in different parts of the world makes it necessary to characterise the manure being generated in these systems. Based on their very low first-season NFV, Ngwenya (2017:54) categorised the cattle manure accumulating in the enclosures of Thulamela farmers as a poor source of plant-available N. However, before dismissing Thulamela cattle kraal manure as a possible N fertiliser for there is a need to investigate the magnitude of its residual N effect. For this reason, the first objective of the current cattle kraal manure study was to determine the residual N effect on the NFV of cattle kraal manure from Thulamela.

Selecting the appropriate fertiliser application rate is the main way in which farmers manage the supply of N to their crops. Applying fertiliser at rates that are too high or too low is known to negatively affect crop production and farm income, and may even reduce soil health (Zingore *et al.,* 2014:49). To assist crop producers with selecting appropriate fertiliser application rates, researchers have developed nutrient response curves for different crops. These response curves enable farmers to optimize application of fertilisers, usually on the basis of the nutrient content of the soil and the target yield of the crop to be grown. Locally, the Fertiliser Society of South Africa has been an important provider of fertiliser recommendations for different crops and target yields but its recommendations assume application of chemical fertilisers. When organic fertilisers are used, such as cattle kraal manure, knowledge of the fertiliser value of these sources is critical, as this enables use of fertiliser recommendations that were developed for use with chemical fertilisers. One of the unknowns, however, is whether the fertiliser value of organic nutrient sources is affected by application rate. With reference to nitrogen, several studies have reported a reduction in the NFV of manure as application rate is raised (Muñoz *et al.,* 2004:723; Cusick *et al.,* 2006:2175-2176). For example, Myint *et al.* (2011:470) found that the NFV of fermented cow manure was 26% when applied at the rate of 5 t ha^{-1}, 15% when applied at the rate of 10 t ha^{-1}, and 11% when applied at the rate 15 t ha^{-1}. Beah *et al.* (2015:269) reported a similar trend using dried grass clover as the source of N. On the other hand, in an incubation study of cattle kraal manure from Makhado Municipality, which neighbours Thulamela, Ramphisa (2015b:49) found that the quantity of mineral N released from the manure was directly proportional to manure application rate. These contradicting reports highlight the need to empirically investigate the relationship between the NFV and application rate for organic sources of nutrients that are used by farmers. Accordingly, the second objective of the cattle kraal manure study was to examine the effect of application rate of cattle kraal manure from Thulamela on the apparent relative NFV of this manure.

2.2 Materials and methods

2.2.1 Description of the study site

The field experiment was conducted in the home garden of Mr Mulaudzi, in Tshivhuyuni village, Thulamela Municipality, Vhembe District, Limpopo Province, South Africa. The home garden is situated at an altitude of 562 m above sea level. Its coordinates are 23º 01' 08'' S and 30º 26' 43'' E.

The land at the experimental site sloped gently in a north-east-north direction with a gradient of 3%. The soil in the garden was classified as being of the Avalon form and Blackmoor family (Soil Classification Working Group, 1991:114-115). The soil was 1.3 m deep and somewhat poorly drained. A complete description of the soil profile is presented in Appendix 2.1. The physical and chemical properties of the soil were determined by Nvirotek Laboratories. The results of the analyses appear in Appendix 2.2.

Van Averbeke (2008:44) described the climate of Dzindi irrigation scheme, which neighbours Tshivhuyuni village, as semi-arid and subtropical, with a mean annual rainfall of about 700 mm and no frost. De Mey (2002:88) reported that the mean annual rainfall at Thohoyandou, located about 8 km ENE of Tshivhuyuni was 697 mm, with most of the rain (79.5%) falling during summer, between October and March. The monthly mean daily minimum temperature (T_{min}) during the year ranged between 9.8 ^{o}C and 19.9 ^{o}C, and the monthly mean daily maximum temperature (T_{max}) between 23.6 ^{o}C and 30.8 ^{o}C (De Mey, 2002:88). Important variables describing the climate of Thohoyandou are shown in Table 2.1.

2.2.2 Experimental design

The field experiment was aimed at determining the first and second season apparent relative N-fertiliser value of cattle kraal manure. For that purpose, nine treatments were laid out in a randomised complete block design (RCBD). A summary of these nine treatments are presented in Table 2.2.

TABLE 2.1: Summary of climatic variables recorded for Thohoyandou over a period of ten years (De Mey, 2002:88)

Month	Rainfall (mm)	Mean daily T_{max} (°C)	Mean daily T_{min} (°C)	Mean daily T_{mean} (°C)	R.H. (%)	Sunshine (hr day^{-1})	Radiation ($MJm^2.day^{-1}$)	Eto (mm day^{-1})	Days $Month^{-1}$	Eto (mm $month^{-1}$)
Jan	74	30.8	19.9	25.4	60.5	6.0	13.4	4.02	31	124.6
Feb	108	30.0	19.7	24.9	62.0	5.4	14.4	4.17	28	116.8
Mar	75	29.6	18.9	24.3	60.0	5.9	16.9	4.56	31	141.4
Apr	47	27.6	16.4	22.0	58.5	6.5	19.2	4.79	30	143.7
May	15	26.2	12.7	19.5	54.0	8.6	22.9	5.26	31	163.1
Jun	17	23.6	9.9	16.8	53.0	8.7	23.0	4.95	30	148.5
Jul	14	23.7	9.8	16.8	53.5	9.1	23.6	4.99	31	154.7
Aug	11	25.4	11.7	18.6	52.0	9.1	23.2	5.23	31	162.1
Sep	39	27.2	14.2	20.7	50.5	8.9	21.6	5.41	30	162.3
Oct	93	27.5	16.3	21.9	53.5	7.1	17.1	4.64	31	143.8
Nov	76	28.9	17.6	23.3	57.5	6.4	14.2	4.16	30	124.8
Dec	128	30.0	19.4	24.7	58.0	6.1	13.0	3.97	31	123.1
Year	697								365	1708.8

T_{max}=Maximum temperature; T_{min}=Minimum temperature; T_{mean}= Mean temperature R.H= Relative humidity; Eto=Potential evapotranspiration

TABLE 2.2: Summary of the treatments used in the experiment aimed at determining the residual N effect on the nitrogen fertiliser value (NFV) of cattle kraal manure from Thulamela

Treatment	N-fertiliser applied	Rate of elemental nutrient applied			Mass of fertiliser applied			
		N	P*	K*	CKM	Urea	SSP	KCl
		…………($kg\ ha^{-1}$)………			….……………($kg\ ha^{-1}$)…..……….			
Control P+K	None	0	30	40	0	0	361	78
CF1	Urea	30	30	40	0	65	361	78
CF2	Urea	60	30	40	0	130	361	78
CF3	Urea	90	30	40	0	195	361	78
CF4	Urea	120	30	40	0	260	361	78
CKM1	CKM	30	30	40	1852	0	361	78
CKM2	CKM	60	30	40	3704	0	361	78
CKM3	CKM	90	30	40	5556	0	361	78
CKM4	CKM	120	30	40	7407	0	361	78

* The rate of P and K added in the cattle kraal manure (CKM) treatments excludes the P and K contained in the manure; CF: Chemical fertiliser; CKM: Cattle kraal manure; SSP: Single superphosphate; KCl: Potassium chloride

All treatments were replicated three times, resulting in an arrangement that comprised 27 field plots. Eight of the nine treatments consisted of four rates of N application namely, 30 kg N ha^{-1}, 60 kg N ha^{-1}, 90 kg N ha^{-1}, 120 kg N ha^{-1}, which were applied as urea (CF1-4) and as cattle kraal manure (CKM1-4). The range of N application rates (30-120 kg N ha^{-1}) was selected to more or less embrace the N removal by the maize test crop for a target grain yield of 5 ton ha^{-1}, which is a realistic target yield for maize grown at a planting density of 28 571 plants ha^{-1} (Du Plessis, 2003:20) used in the current experiment. Maize producing a grain yield of 5 ton ha^{-1} is expected to remove 75 kg N ha^{-1}, 15 kg P ha^{-1} and 17.5 kg K ha^{-1}, whereas nutrient removal by the whole maize plant is expected to be 135 kg N ha^{-1}, 22.5 kg P ha^{-1} and 100 kg K ha^{-1} per ton of grain (FSSA, 2007:179). In the eight aforementioned treatments, phosphorus (P) was applied in the form of superphosphate (8.3% P) at the rate of 30 kg P ha^{-1}, and potassium (K) in the form of potassium chloride (50% K) at the rate of 40 kg K ha^{-1}. P and K were applied at these rates to avoid any plant growth limitations due to deficiencies in these two plant nutrients. The last treatment was the control

(control P+K), in which P and K were applied at the same rate as in the eight N treatments.

Maize, which is the most prevalent crop grown in home gardens of Thulamela (Ramphisa, 2015a:39; Denison *et al*., 2016:177), was used as the test crop in the experiment. To enable estimation of the residual effect on the N-fertiliser value of cattle kraal manure, the experiment was conducted over two consecutive growing seasons, with each field plot receiving the same treatment twice. The first run of the experiment occurred during the summer of 2014-15, and the second during the summer season of 2015-16.

2.2.3 Materials

The home garden in which the experiment was conducted had been under a weedy fallow for two years prior to laying out the experiment. No fertilisers had been applied in the garden during the previous four years.

A plastic rain gauge, purchased from the Noord Transvaal Koöperasie (NTK) (PTY) Ltd branch at Muledane, was mounted in the garden with the rim of the gauge at a height of 1.2 m above the soil surface. This rain gauge was used to record the rainfall during the growing period of the test crop. Rainfall was recorded daily at 8 am. The test crop was the PAN 67 maize cultivar (*Zea mays* var. *indentata*). Seed of this cultivar was obtained from Pannar in Greytown. Urea (46% N), single superphosphate (8.3% P) and potassium chloride (50% K) were the chemical fertilisers that were applied. They were all manufactured by SASOL® and purchased from the Noord Transvaal Koöperasie (NTK) (PTY) Ltd branch at Muledane. The cattle kraal manure that was applied was sourced from Mrs Mantsha of Manamani village in Thulamela Municipality (Limpopo Province). Selected chemical and physical properties of this cattle kraal manure are shown in Table 2.3.

TABLE 2.3: Chemical and physical properties of cattle kraal manure used in the nitrogen fertiliser value experiment

Property	**Unit**	**Cattle kraal manure**
pH[2]		8.80
Moisture[3]	%	5.99
Total solids[1]	%	94.01
Ash	%	29.6
Organic matter content	%	64.4
Total organic carbon[1]	%	30.9
Total nitrogen content	%	1.62
Carbon: Nitrogen ratio	%	19.1
Polyphenol content	%	0.17
Polyphenol: Nitrogen ratio	%	0.11
Lignin	%	9.7
Lignin: Nitrogen ratio	%	5.99
Calcium (Ca)[1]	%	2.16
Magnesium (Mg)[1]	%	0.89
Phosphorus (P)[1]	%	0.312
Potassium (K)[1]	%	2.79
Aluminium (Al)[1]	$g\ kg^{-1}$	5.8
Iron (Fe)[1]	$g\ kg^{-1}$	6.9
Zinc (Zn)[1]	$mg\ kg^{-1}$	<10
Copper (Cu)[1]	$mg\ kg^{-1}$	10.3
Manganese (Mn)[1]	$mg\ kg^{-1}$	264
Sodium (Na)[1]	$mg\ kg^{-1}$	826
Electrical conductivity[4]	$mS\ m^{-1}$	326

[1] The manure to water ratio used for pH measurement was 1 g manure: 5 mL water.

[2] All values in the table are reported on an air dry basis and are based on the dried and milled samples provided to the Institute of Soil, Climate and Water - Agricultural Research Council, South Africa, 2008.

[3] The manure to water ratio used for electrical conductivity was 1 g manure: 10 mL water

Gross plot size was 2.8 m x 3.5 m = 9.8 m^2. Weighing out the chemical fertilisers to be applied to the plots was done using a Scout Pro SPU123 portable electronic scale with a capacity of 120 g and an accuracy of 0.001 g, which was manufactured by Ohaus and supplied by Scientific United in Randburg. Weighing of cattle kraal manure and biomass produced by the test crop was done using an Adam® electronic scale with a capacity of 30 kg and an accuracy of 10 g. This scale was manufactured and supplied by Adam® equipment Co Ltd in Kempton Park.

2.2.4 Methods

To prepare the land for planting in the summer cropping season of 2014-15 and incorporate the weeds covering the garden, the soil of the garden was ploughed with a disk plough to a depth of 220mm. On the ploughed land, the 27 plots were demarcated by means of galvanised steel pegs and chemical fertilisers and cattle kraal manure were broadcast and incorporated into the soil with a garden fork to a depth of 150 mm depth (Plate 2.1 and 2.2).

PLATE 2.1: Broadcasting of cattle kraal manure on marked plot

PLATE 2.2: Incorporating fertilisers into the soil with a garden fork

After incorporation of the fertilisers, the plots were planted to maize using a row spacing of 0.70 m and an intra-row spacing of 0.50 m, resulting in a planting density of 2.8571 plants m^{-2}. Planting involved opening of 8 cm deep planting furrows with a hand hoe followed by the application of 10 litre of water into the furrows using a bucket. After the water in the furrows had infiltrated, a marked planting chain was placed in the furrow and three maize seeds were pressed into the wet soil at each planting station. This was followed by covering the seeds with dry soil using a rake. Two weeks after the maize seedlings had emerged the stands were thinned to one plant per hill and Kombat cutworm bait, with *sodium fluosilicate* as the active ingredient, was spread in a band of about 20 cm wide covering the planting rows at the rate of 2 g per meter row-length.

All plants in the two outer rows and the first and last plant in the two inner rows served as guard plants. The resulting net plot was 2.5 m x 1.4 m in size and contained 10 plants that qualified for the measurements that formed part of the experiment. Table 2.4 shows the dates of planting, harvesting and the duration of the growing period of the test crop for the two seasons. A view of the 2015-16 experiment is shown in Plate 2.3.

TABLE 2.4: Dates of planting and harvest and duration of the growing period of the maize crop in the relative nitrogen fertiliser value experiment

Crop	Planting date	Final harvest date	Growing period (days)
Maize	15-Dec-2014	22-Apr-2015	121
Maize	20-Nov-2015	20-Mar-2016	121

PLATE 2.3: View of the apparent relative N-fertiliser value 2015-16 experiment with maize 40 days after planting

Weeds were controlled as they emerged using hoeing and uprooting. Plants were scouted twice per week for insects or insect damage using the zigzag method described by Fishel *et al.* (2001:10), which ensures that all parts of the plots are covered. Pests identified on maize included aphids (*Rhopalosiphum maidis*) and maize stalk borer (*Busseola fusca*). Aphids were controlled by means of the knapsack spray application on the foliage of the maize, with *pirimicarb* as the active ingredient, at the rate of 5 g per 10 L water. To protect the maize crop against top grub and stalk borer, a few granules of Dipterex were applied in the whorl of each maize plant when the crop was about 30 cm high. Both of these plant protection measures are recommended by the Directorate: Food Safety and Quality Assurance (2007:72). All agro-chemicals used were purchased from the Noord Transvaal Koöperasie (NTK) (PTY) Ltd branch at Muledane.

The 2014-15 experiment was planned as a rainfed experiment in line with the practices of the majority of home gardeners in Thulamela (Denison *et al*., 2016:177). However, the growing season turned out to be exceptionally dry. The lack of rain caused visible water stress in the maize stand, necessitating the introduction of irrigation, which was first applied on the 14th of February 2015 and continued until 31st March 2015. However, by the time irrigation was applied, plant growth and development had been adversely affected by water stress.

From the results obtained during the 2014-15 season it was evident that plant water availability needed to be eliminated as a factor affecting growth of maize on the experimental site. For this reason, the 2015-16 experiment was irrigated. Using a system of ridges and tied furrows constructed along the maize rows of each plot, specified quantities of irrigation water were applied in the furrows by means of calibrated buckets. Before planting, 80 mm of water was applied to all plots to charge the upper 800 mm of the soil profile to field capacity. Following emergence of the maize plants, all plots received 20 mm of irrigation water per week for the duration of the growing period. In this irrigation schedule rainfall was only taken into account when the rain event exceeded 10 mm. The irrigation schedule used ensured that all plots received the same amount of water and was effective to the extent that no visible stress was ever observed. When first tried out on the irrigation scheme nearby, Van Averbeke *et al*. (2013:199) reported that this particular irrigation schedule produced biomass and grain yields that were not materially different from those obtained under full irrigation. Information on rainfall and irrigation received by the maize crop in the 2014-15 and 2015-16 experiments is presented in Table 2.5.

TABLE 2.5: Rainfall and irrigation water applied during the growing period of maize in the 2014-15 and 2015-16 relative nitrogen fertiliser value experiments

Period	**Rainfall** (mm)	**Irrigation** (mm)	**Total water supplied** (mm)
01-31 December 2014	128		
01-31 January 2015	33		
01-28 February 2015	14	80	
01-31 March 2015	20	60	
Total 2014/15 growing season	**195**	**140**	**335**
01-30 November 2015	25	80	
01-31 December 2015	90	40	
01-31 January 2016	60	80	
01-29 February 2016	45	80	
01-31 March 2016	10		
Total 2015/16 growing season	**230**	**280**	**510**

2.2.5 Data collection

All data collection was done on the 10 plants contained in the net plot area. Figure 2.1 shows the spacing of the maize plants in each of the plots and the 10 plants in the net plot area.

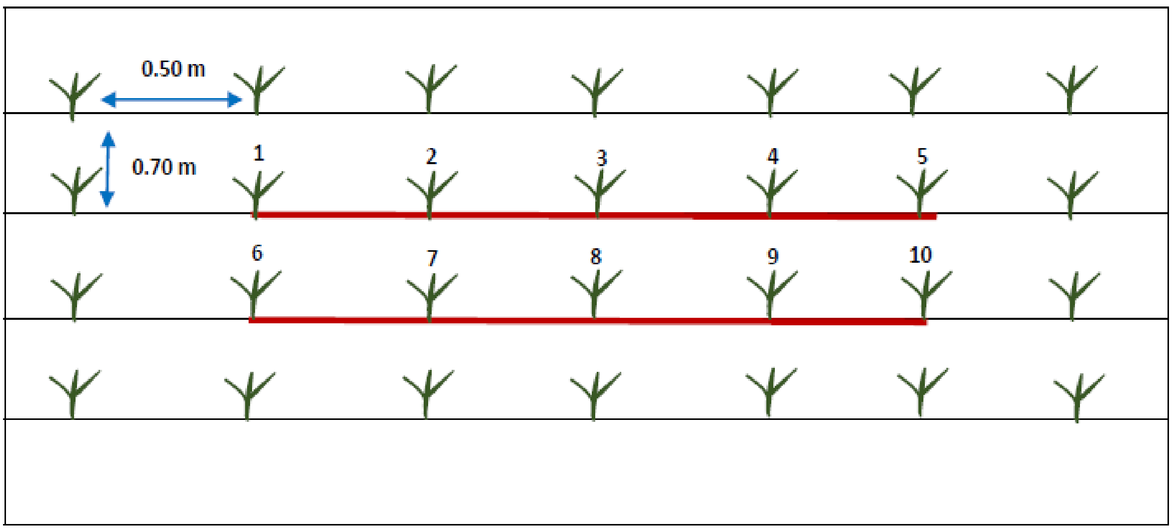

Figure 2:1: Arrangement of the maize plants in each of the experimental plots with the 10 numbered plants along the red lines representing net plot area

Leaf area, being an indicator of the vegetative development of the maize plants (Sezer, Oner & Mut, 2009:785; Mananze, Pôças & Cunha, 2018:202), was monitored weekly throughout the growing season on three randomly selected plants in the net plot area of all plots. Leaf area development of maize plants depends on many factors, including nitrogen availability (Biemond, Vos & Struik, 1995:217; Loustau, Hungate & Drake, 2001:127-129; Zhao *et al.,* 2005:395). By keeping constant all other factors that could affect leaf area development, monitoring of leaf area held the promise of providing insight into the dynamics of treatment effects. The expectation was that differences in N availability would gradually become evident as the plants in the different treatments proceeded through their growth stages. On each day of measurement, the length and width of the leaves, which had developed fully during the seven-day period preceding the day of measurement, were determined. Maize leaves were considered fully developed when the ligule at the base of the leaf was clearly visible (Jordan-Meille & Pellerin, 2004:76). The length of the fully opened leaf lamina was measured from the ligule to the tip of the leaf using a tape measure. The width of the leaf blade was measured using a ruler at the position where the blade was at its widest. The area of each leaf was taken as the product of length and width multiplied by a correction factor to account for the shape of the leaves. The correction factors proposed by Van Averbeke (1991:116-117) were used for this purpose.

On each measurement day, leaf senescence was also recorded. A leaf was considered senesced when 60% of the surface of the leaf had turned brown and lifeless. At that stage, the date of senescence was recorded, and the leaf was carefully removed from the plant and stored in a labelled paper packet that was unique to the plot from which it was collected. Collection of senesced leaves was done to obtain accurate measurement of total above-ground biomass in the net plots. Removal of senesced leaves occurred weekly on all 10 plants in the net plot.

The 10 maize plants in the net plots were harvested at physiological maturity. The stems of these plants were cut just above the soil surface using hand hoe. Next, the cobs were removed from the plants and the husks covering the ears were peeled off. For each plot, the ears were placed in a labelled paper bag, whilst the husks and the remainder of the plants were cut into small pieces (about 5 cm long) and placed in another labelled bag. The bags and their content were dried at 65° C in a forced draught oven to constant mass, which took 14 days. Once oven-dry, ears were shelled by hand to separate grain from rachis. The mass of the rachis was added to the mass of the husks and remainder of the plant to make up the stover yield. The mass of grain was used to obtain grain yield. Both yield of grain and of stover are reported on an oven-dry basis.

To monitor the dynamics of the mineral N concentration in the topsoil of the various treatments during the two-year experimental period, soil samples were collected on five occasions. Prior to application of fertilisers and planting of the 2014-15 experiment, soil samples representative of the experimental site were taken from the upper 200 mm of the soil on the 13th December 2014 using a core sampler. All soil cores were placed together in a clean bucket and mixed thoroughly before taking three sub-samples for analysis of nitrate-N and ammonium-N. Subsequently, the soil in the net plot area of each plot was sampled on four more occasions. The first was immediately after harvesting the 2014-15 maize crop (19th April 2015); the second before treatment application in the 2015-16 experiment (18th November 2015); the third after harvesting the 2015-16 maize crop (24th March 2016); and the fourth and last after the winter fallow period following the second growing season (20th October 2016). Each plot sample consisted of four soil cores (0-200 mm) taken from within the net plot area, with the sampling positions selected in relation to plants 3 and 9, as shown in Figure 2.2.

For each plot, the four soil cores were placed in a clean bucket and mixed thoroughly by hand before taking a sub-sample of about 300 g, which was placed in a labelled zip lock bag and placed in cool box containing icepacks. At completion of the sampling, the samples were transferred to a freezer in Thulamela, where they were stored at a temperature of -10 °C. The frozen samples were later transported in a cool box containing icepacks from Thulamela to the Tshwane University of Technology in Pretoria, where they were once more stored in a freezer at -10^{o}C. The evening before extraction of the mineral N, the soil samples were removed from the freezer and left to thaw overnight. Freezing of the samples was done to prevent N mineralisation during storage.

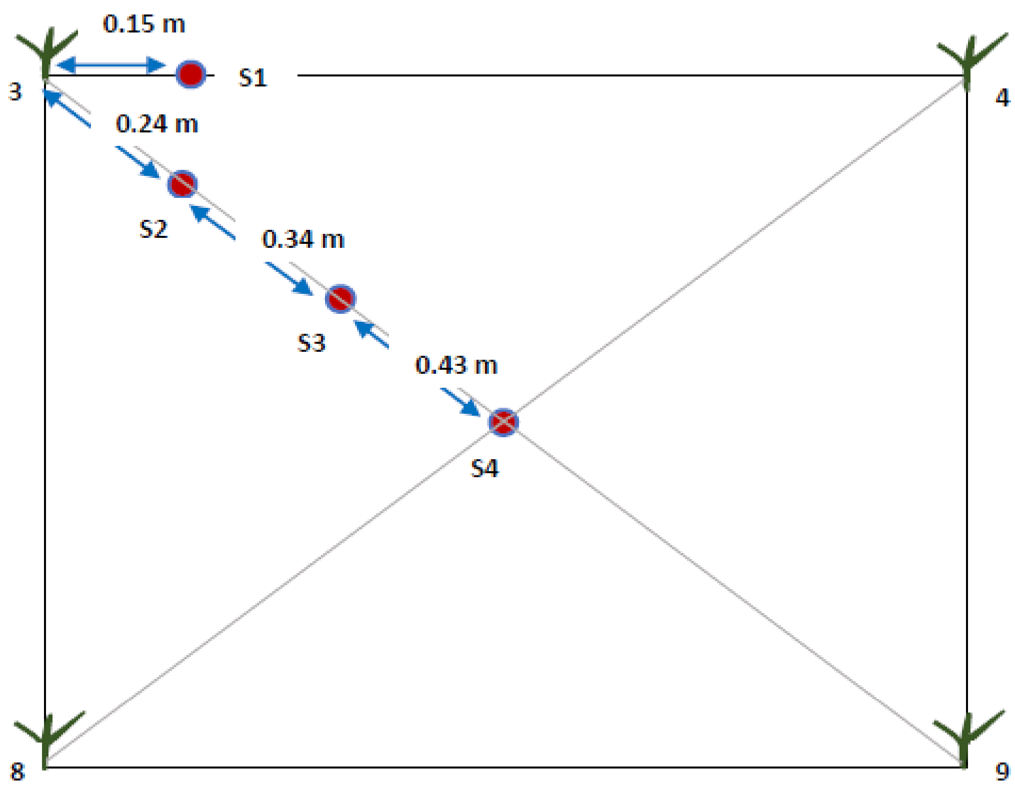

Figure 2:2: The locations where soil cores were collected in each net plot area for the measurement of mineral N concentration

Extraction of nitrate and ammonium from the soil samples with 0.5 M potassium sulphate (K_2SO_4) was done on 7.5 ml samples taken from the bags. The 7.5 mL soil sample was placed in a 100 mL extraction bottle to which 20 mL of 0.5 M K_2SO_4 was added. This mixture was shaken for 30 minutes on a Labcon Micro-processor Controlled Platform Shaker® set for 160 oscillations per minute. Shaking was followed by filtration of the mixture through Whatman No 1 filter paper. The filtrate was then analysed colorimetrically for both nitrate and exchangeable ammonium using the procedures described by Anderson & Ingram (1993:73-74) in Appendix 2.3. A Jenway 7300 spectrophotometer® procured from Lasec SA, (Pty) Ltd set at a wavelength 410 nm and 655 nm was used to read sample absorbance for nitrate and exchangeable ammonium, respectively. For each batch of samples, readings were also taken for standards containing 0, 2, 4, 6, 8, 10 mg NO_3^--N ℓ^{-1} and 0, 2, 5, 10, 15 and 20 mg NH_4^+-N ℓ^{-1}, enabling conversion of the readings to concentration of nitrate and ammonium in the soil. Nitrate and ammonium standards were prepared using potassium nitrate (KNO_3) and ammonium sulphate ($(NH_4)_2SO_4$), respectively. To express mineral N concentration in the soil on a mass basis, the oven-dry weight of a 7.5 ml scoop of soil was determined separately using 20 replicates. The oven-dry weight of a 7.5 ml scoop of soil was 8.9 g ± 0.4 g.

2.2.6 Data capture, transformation and analysis

Total oven-dry above-ground biomass data obtained in the two cropping summer seasons were captured separately on a Microsoft Office Excel® spread sheet for analysis of variance using the Genstat Statistical Software Version 19 to test for treatment effects. When these effects were statistically significant ($p \leq 0.05$), the Fisher's Protected Least Significant Difference (LSD) test ($p=0.05$) was used to separate treatment means (Baird *et al.,* 2017).

Measurements of leaf area growth of maize performed on the three monitored net plants were captured on a Microsoft Office Excel® spread sheet and averaged per plot. The means obtained for each plot were then subjected to analysis of variance using the Genstat Statistical Software Version 19 to test for treatment effects, and when these effects were statistically significant ($p \leq 0.05$), the Fisher's Protected Least Significant Difference (LSD) test ($p=0.05$) was used to separate treatment means (Baird *et al.,* 2017).

In order to obtain the mineral N concentration of the soil in the different treatments, calibration curves were constructed, using Microsoft Office Excel®, to relate the absorbance values of the standards to their nitrate-N and ammonium-N concentrations expressed in mg ℓ^{-1}. Equation 2.1, taken from Anderson and Ingram (1993:74), was then used to convert the nitrate-N and ammonium-N concentration in the extractants to mg nitrate-N kg soil $^{-1}$ and mg ammonium-N kg soil $^{-1}$.

Concentration in mg kg soil^{-1} = (C.V) ÷ W **Equation 2.1**

whereby:

C = concentration of nitrate, ammonium or phosphorus in solution (mg ℓ^{-1});

V = volume of extractant used (ℓ); and

W = Mass of oven-dry soil (g)

The nitrate-N and ammonium concentrations in the soil were captured on spread sheets, using Microsoft Office Excel® (2013), and the concentration of total mineral N in soil was calculated as the sum of the ammonium-N and nitrate-N concentrations. The mineral-N concentration data were subjected to analysis of variance (ANOVA) using the Genstat Statistical Software Version 19 to test for treatment effects. When these effects were statistically significant ($p \leq 0.05$), the Fisher's Protected Least Significant Difference (LSD) test ($p=0.05$) was used to separate treatment means.

Calculation of the apparent relative N-fertiliser value of manure (ARNFV) was done using Equation 2.2, which involved subtracting the above-ground biomass data obtained in the control treatment from those obtained in the treatments amended with manure or chemical fertiliser to remove the contribution of N present in the seed and unamended soil to the growth and biomass production of the crops.

$$\text{ARNFV (\%)} = \frac{(Y_{tmi} - Y_{co})}{(Y_{tc} - Y_{co})} \times 100\% \qquad \textbf{Equation 2.2}$$

whereby

ARNFV (%) = apparent relative N-fertiliser value of manure

$[Y_{tmi}]$ = above-ground biomass of test crop obtained in manure treatment i.

$[Y_{tc}]$ = above-ground biomass of test crop obtained in chemical fertiliser treatment.

$[Y_{co}]$ = above-ground biomass of test crop obtained in the control treatment

The apparent relative N-fertiliser values were subjected to analysis of variance (ANOVA) using the ANOVA Procedure of Genstat Version 19 to test for treatment effects, and when these effects were statistically significant ($p \leq 0.05$), the Fisher's Protected Least Significant Difference (LSD) test ($p=0.05$) was used to separate treatment means.

2.3 Results

2.3.1 The 2014/15 experiment

The biomass of maize obtained in the different treatments of 2014/15 experiment are shown in Table 2.6. The statistical analysis of the biomass data, which is presented in Appendix 2.4, shows that the biomass of maize was not significantly ($p>0.05$) affected by source and application rate of N.

TABLE 2.6: Effect of source and application rate of N on the oven-dry above-ground biomass of maize (Tshivhuyuni, 2014/15)

Application rate	**Source of N**	
	Urea	Cattle kraal manure
(kg N ha^{-1})	Stover (g m^{-2})	
0	343.2	343.2
30	457.2	456.1
60	416.8	438.6
90	394.2	437.1
120	453.3	392.2
Mean	**412.9**	**413.5**
	Grain (g m^{-2})	
0	342.9	342.9
30	336.2	383.8
60	281.9	360.0
90	234.3	314.3
120	405.7	417.1
Mean	**320.2**	**363.6**
	Total (g m^{-2})	
0	686.1	686.1
30	793.4	839.9
60	698.7	798.6
90	628.5	751.1
120	859.0	809.6
Mean	**733.0**	**777.0**

The 2014-15 season was characterised by severe drought, with no irrigation applied to the plots until the maize had reached the flowering stage. Generally, water stress affected the growth of maize as evidenced by visible water stress in all plots, but some plots or parts of plots were less severely affected than others. This caused within treatment variability, which was most likely due to within-garden differences in soil depth and possibly other factors that influenced soil water availability. Within treatment variability masked possible treatment effects on the biomass of maize (Table 2.6), and made computation of the first-season N-fertiliser value of the cattle kraal manure meaningless.

2.3.2 The 2015/16 experiment

The biomass of maize obtained in the different treatments of the 2015/16 experiment are presented in Table 2.7 and the analysis of variance in Appendix 2.5. The two main treatments (source of N and application rate of N) both had a highly significant effect ($p<0.001$) on biomass production of maize, and the interaction effect (source of N x application rate was highly significant ($p<0.001$) as well.

Table 2.7 shows that at comparable rates of N application, biomass of maize was consistently higher when urea was the source of N than when cattle kraal manure was used. For both sources of N, there was a significant increase in biomass as rate of application was increased from zero to 120 kg N ha^{-1} (Table 2.7). When urea was the applied source of N, total oven-dry above-ground biomass increased dramatically (by 263 g m^{-2}) when N application rate was raised from zero to 30 kg N ha^{-1} but the biomass response to subsequent increases in N application rate was more gradual. When cattle kraal manure was used as the source of N, biomass response to rising application rate of N was more subdued than in the case of urea and also tended to increase more proportional to the rate at which N was applied (Table 2.7).

TABLE 2.7: Effect of source and application rate of N on the oven-dry above-ground biomass of maize at physiological maturity (Tshivhuyuni, 2015/16)

Application rate	Source of N		All
	Urea	Cattle kraal manure	
(kg N ha^{-1})	Stover (g m^{-2})		
0	472.4	472.4	472.4
30	581.0	470.0	525.5
60	631.9	496.2	564.0
90	664.0	504.3	584.1
120	703.8	503.8	603.8
Mean	**610.6**	**489.3**	**550.0**
LSD (p=0.05) source of N = 3.6 g m^{-2}			
LSD (p=0.05) rate of N = 5.1 g m^{-2}			
LSD (p=0.05) source of N x rate of N = 7.3 g m^{-2}			
	Grain (g m^{-2})		
0	418.1	418.1	418.1
30	572.5	458.6	515.5
60	583.8	466.6	525.2
90	604.8	461.9	533.3
120	605.7	476.7	541.2
Mean	**557.0**	**456.4**	**506.6**
LSD (p=0.05) source of N = 6.4 g m^{-2}			
LSD (p=0.05) rate of N = 9.0 g m^{-2}			
LSD (p=0.05) source of N x rate of N = 12.7 g m^{-2}			
	Total (g m^{-2})		
0	890.4	890.4	890.4
30	1153.5	928.6	1041.0
60	1215.7	962.8	1089.0
90	1268.8	966.2	1117.0
120	1309.5	980.5	1145.0
Mean	**1167.6**	**945.7**	**1056.4**
LSD (p=0.05) source of N = 6.9 g m^{-2}			
LSD (p=0.05) rate of N = 9.8 g m^{-2}			
LSD (p=0.05) source of N x rate of N = 13.8 g m^{-2}			

The effect of source and application rate of N on leaf area per plant for the 2015/16 season at 21, 28, 35, 42, 49, 56, 63, 70, 77, 82, 89, 96, 103 and 110 days after planting (DAP) appear in Appendix tables 2.8, 2.9, 2.10, 2.11, 2.12, 2.13, 2.14, 2.15, 2.16, 2.17, 2.18, 2.19, 2.20 and 2.21, respectively. A summary of the main effect of source of N on leaf area per plant over the entire growing season of maize is presented in Figure 2.3.

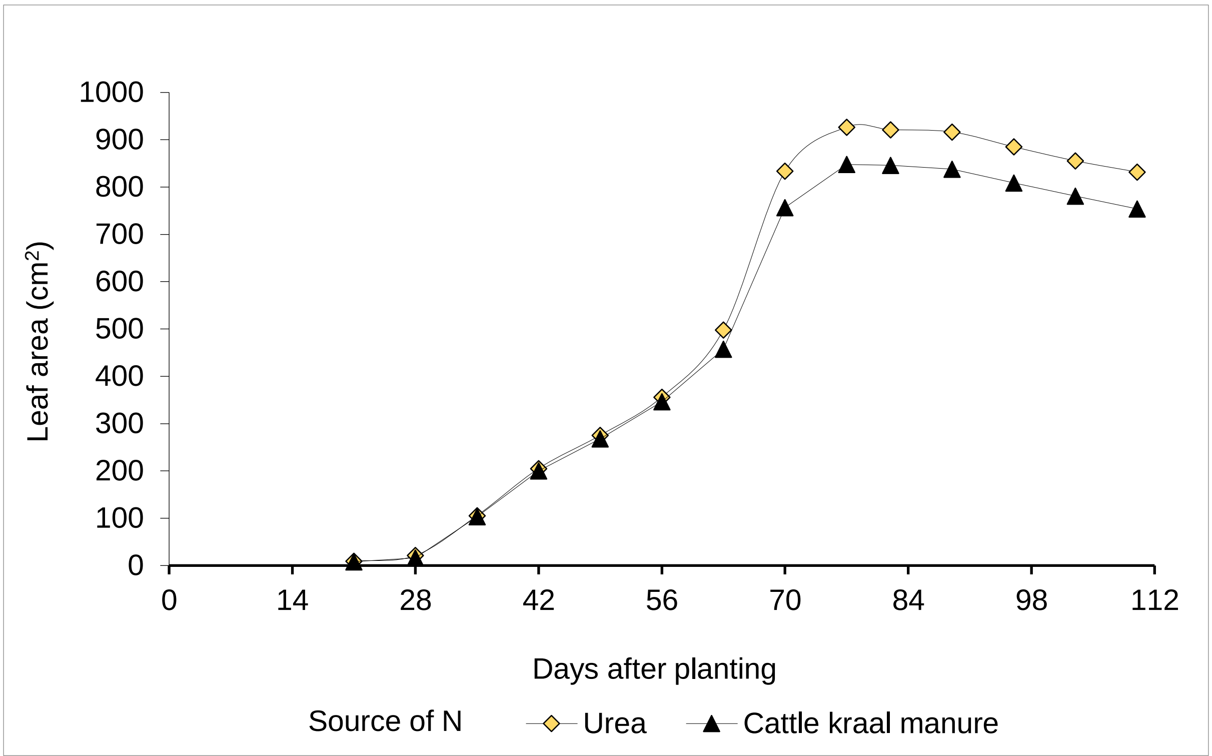

FIGURE 2.3: Main effect of source of N on leaf area per maize plant

The statistical analysis of the data, which appears in Appendix 2.6, shows that the effect of source of N on leaf area per plant was highly significant ($p<0.001$) for each of the 14 dates of measurement. Leaf area per plant was consistently higher ($p\leq0.05$) in soil amended with urea than in soil that received cattle kraal manure as the source of N.

The effect of N-application rate on leaf area per plant, illustrated in Figure 2.4, was also highly significant ($p<0.001$) for each of the 14 dates of measurement (Appendix 2.6). Leaf area per plant was consistently highest ($p\leq0.05$) in the 120 kg N ha^{-1} and consistently lowest ($p\leq0.05$) in the control treatment.

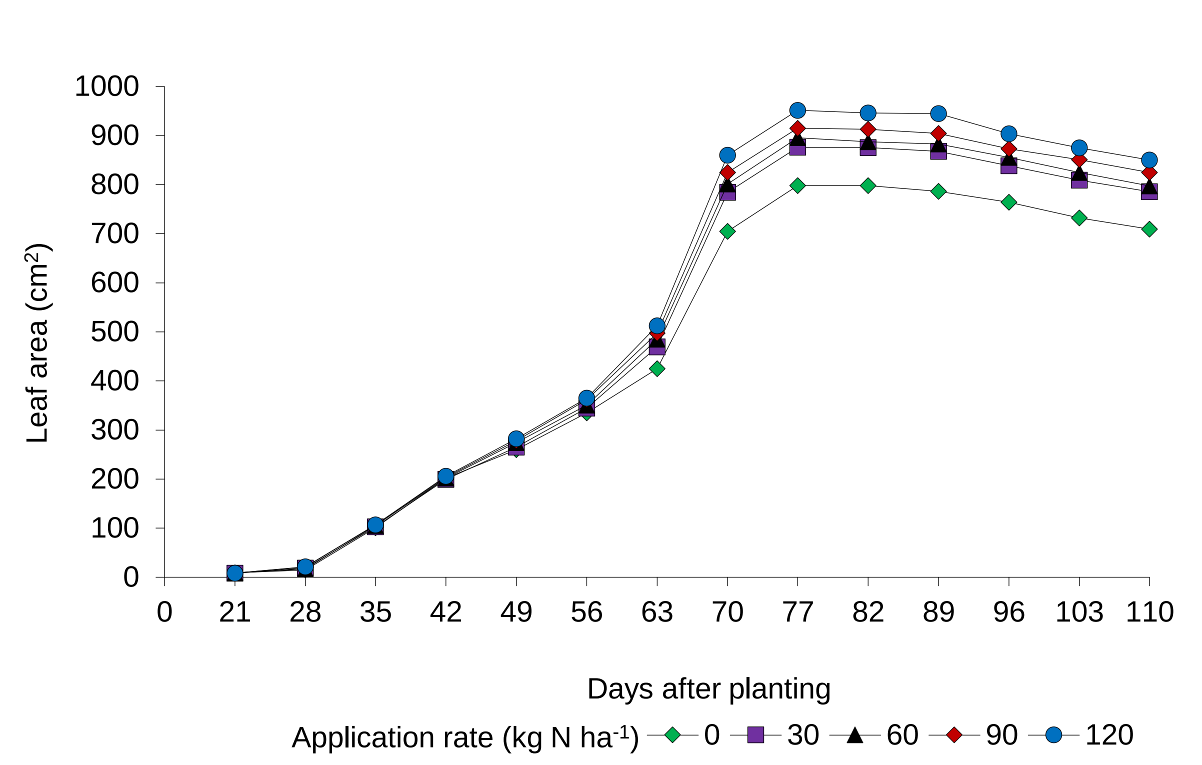

FIGURE 2.4: Main effect of application rate of N on leaf area per maize plant

The interaction effect of source x rate of N was also highly significant ($p<0.001$) with the exception of measuring day 21, 35, 42, 49 and 56 after planting. The difference in the leaf area response pattern of maize to rising application rate is illustrated in Figure 2.5 for urea and Figure 2.6 for cattle kraal manure. In the case of urea, the largest increase in leaf area occurred when N application rate was raised from zero to 30 kg N ha^{-1}, with smaller increases being recorded for subsequent increases in application rate (Fig. 2.5). When cattle kraal manure was used, the leaf area per plant tended to increase incrementally as N application rate was raised. This difference in response pattern between the two sources of N resembled that observed for oven-dry biomass (Table 2.7).

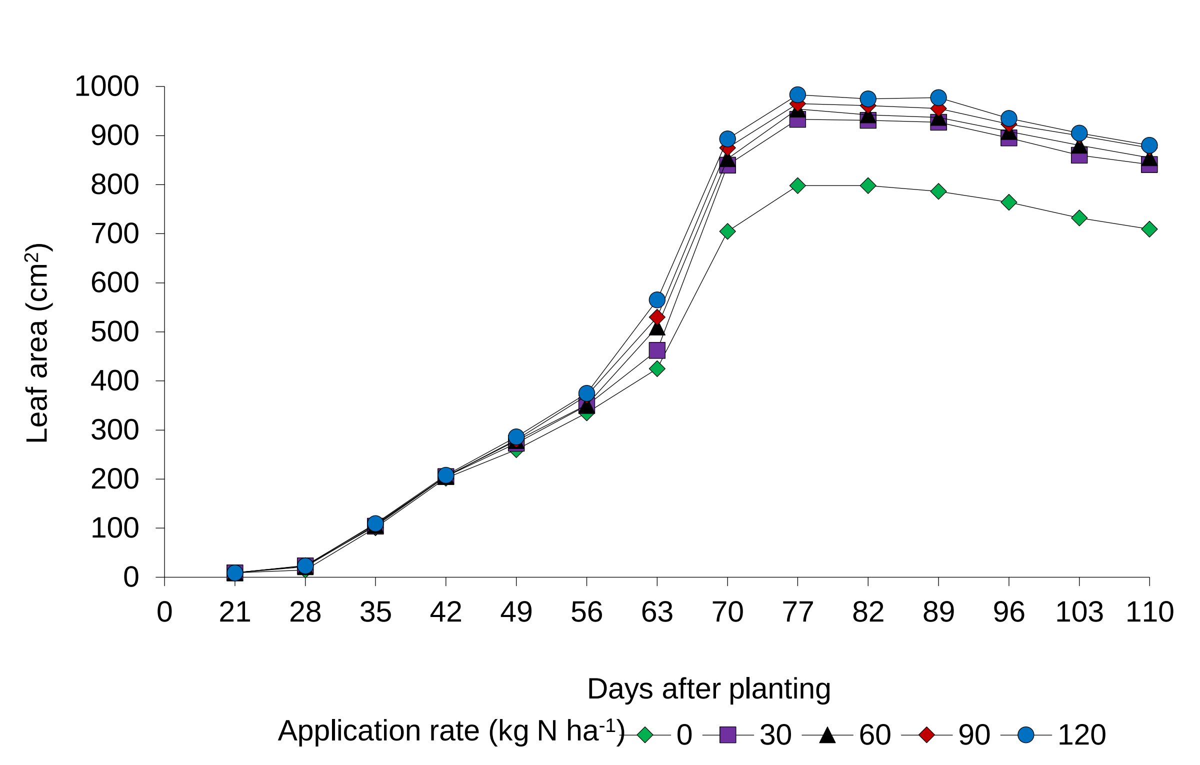

FIGURE 2.5: Effect of urea application rate of N on leaf area per maize plant

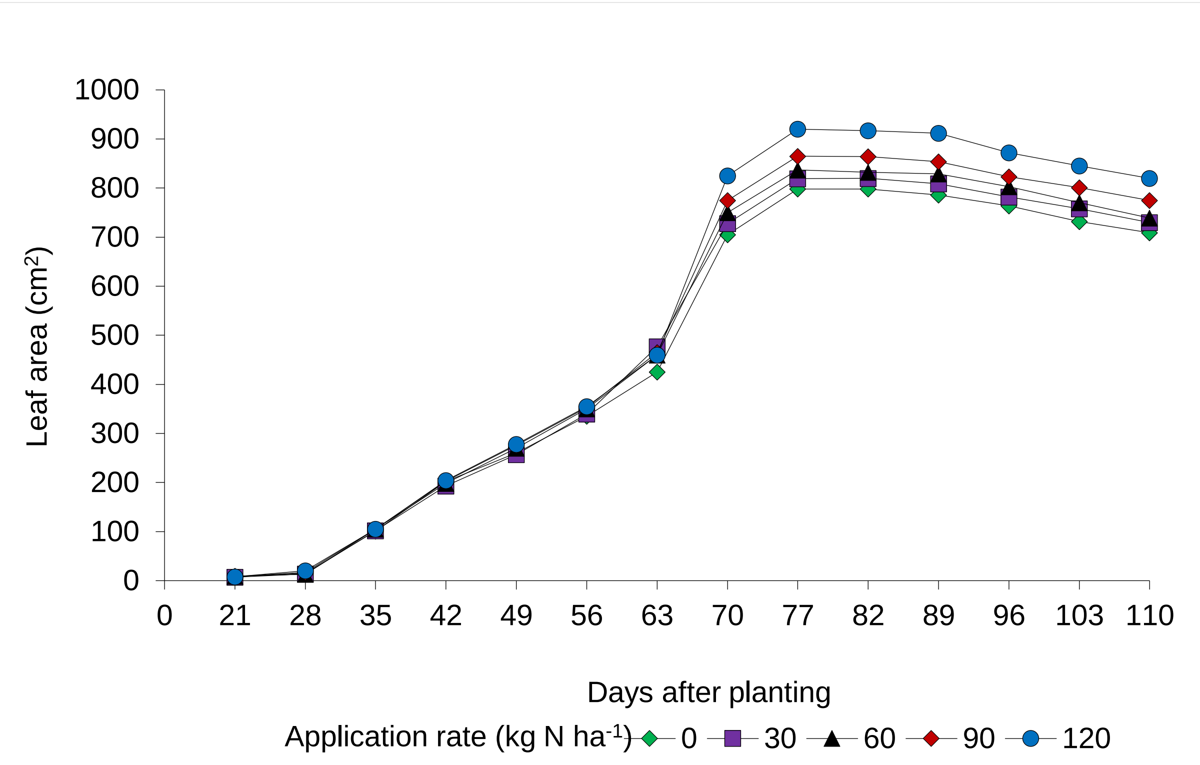

FIGURE 2.6: Effect of cattle kraal manure application rate of N on leaf area development of maize

The effects of source of N and application rate of N, as well as their interaction effects on the mineral N concentration in the soil are shown in Tables 2.22, 2.23, 2.24 and 2.25 for the four dates of measurement. Figures 2.7 and 2.8 summarise the effects for the two sources of N used. The statistical analysis of the data appears in Appendix 2.7

TABLE 2.22: Effects of source and application rate of N on the mineral-N concentration in the topsoil (0-200 mm) at harvest of first-season crop (Tshivhuyuni, 19 April 2015)

Application rate	**Source of N**		**All**
	Urea	Cattle kraal manure	
(kg N ha^{-1})	(mg mineral N kg $soil^{-1}$)		
0	13.6	13.6	13.6
30	14.0	15.8	14.9
60	13.5	17.7	15.6
90	13.3	19.5	16.4
120	13.3	21.5	17.4
Mean	**13.5**	**17.6**	**15.6**
LSD (p=0.05) source of N = 0.68			
LSD (p=0.05) rate of N = 0.96			
LSD (p=0.05) source of N x rate of N = 1.35			

TABLE 2.23: Effects of source and application rate of N on the mineral-N concentration in the topsoil (0-200 mm) before planting second-season crop (Tshivhuyuni, 18 November 2015)

Application rate	**Source of N**		**All**
	Urea	Cattle kraal manure	
(kg N ha^{-1})	(mg mineral N kg $soil^{-1}$)		
0	10.3	10.3	10.3
30	10.9	18.6	14.8
60	10.6	20.1	15.3
90	10.1	22.0	16.1
120	10.5	24.1	17.3
Mean	**10.8**	**19.0**	**14.8**

LSD (p=0.05) source of N = 0.63
LSD (p=0.05) rate of N = 0.89
LSD (p=0.05) source of N x rate of N = 1.25

TABLE 2.24: Effects of source and application rate of N on the mineral-N concentration in the topsoil (0-200 mm) at harvest of second-season crop (Tshivhuyuni, 24 March 2016)

Application rate	**Source of N**		**All**
	Urea	Cattle kraal manure	
(kg N ha^{-1})	(mg mineral N kg $soil^{-1}$)		
0	9.5	9.5	9.5
30	9.6	10.4	10.0
60	9.0	11.8	10.4
90	9.4	13.2	11.3
120	9.4	14.1	11.8
Mean	**9.4**	**11.8**	**10.6**

LSD (p=0.05) source of N = 0.33
LSD (p=0.05) rate of N = 0.47
LSD (p=0.05) source of N x rate of N = 0.67

TABLE 2.25: Effects of source and application rate of N on the mineral-N concentration in the topsoil (0-200 mm) at end of fallow period following second-season crop (Tshivhuyuni, 20 October 2016)

Application rate	**Source of N**		**All**
	Urea	Cattle kraal manure	
(kg N ha^{-1})	(mg mineral N kg soil^{-1})		
0	7.2	7.2	7.2
30	7.4	11.8	9.6
60	7.3	13.7	10.5
90	7.6	16.2	11.9
120	7.5	17.4	12.4
Mean	**7.4**	**13.2**	**10.3**
LSD (p=0.05) source of N = 0.46			
LSD (p=0.05) rate of N = 0.65			
LSD (p=0.05) source of N x rate of N = 0.92			

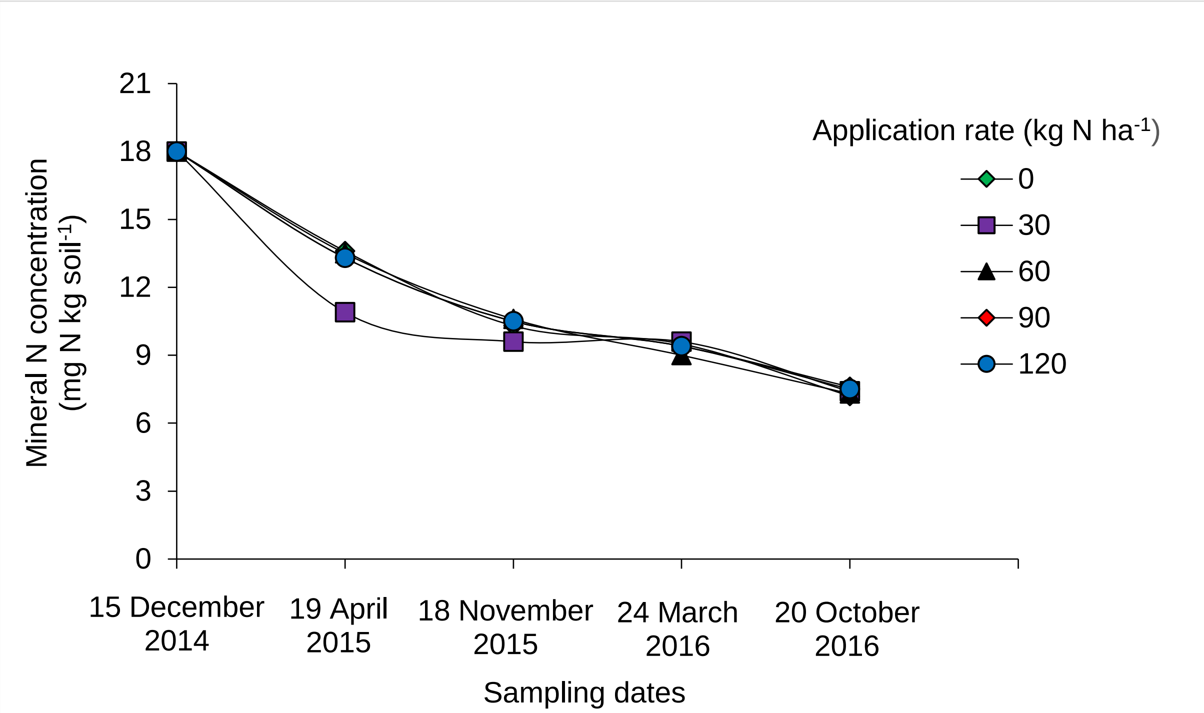

FIGURE 2.7: Effect of urea application rate on the concentration of mineral-N in the soil on five different sampling dates

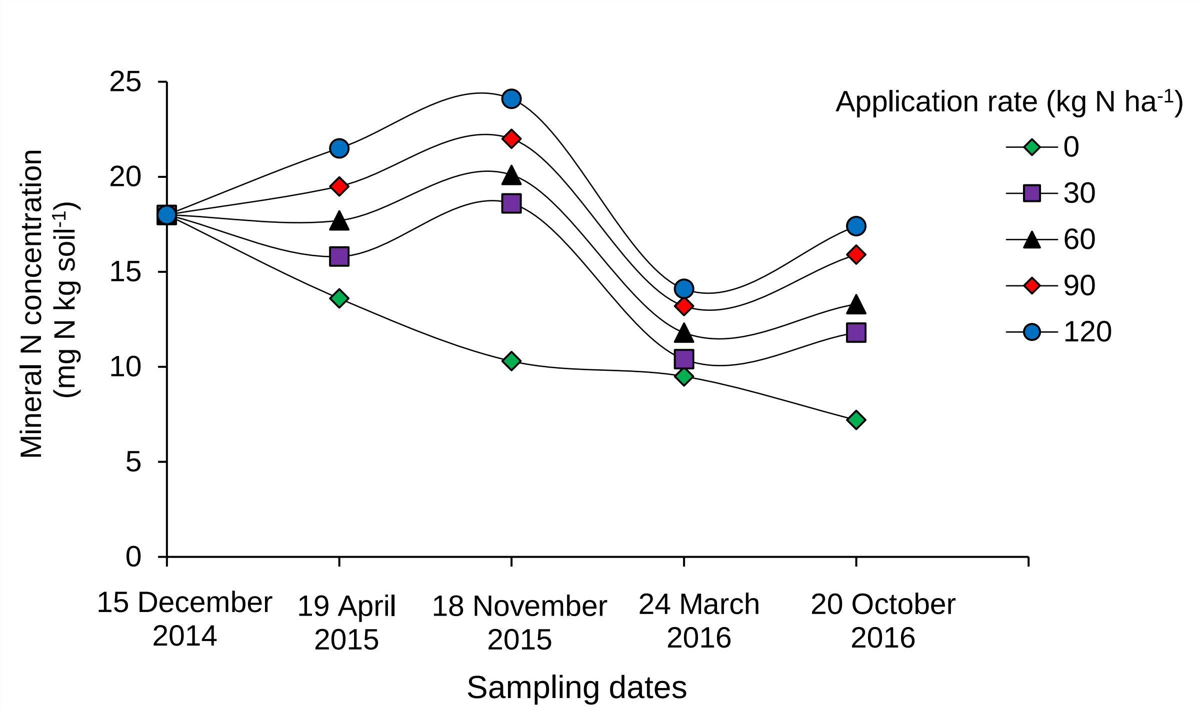

FIGURE 2.8: Effect of cattle kraal manure application rate on the concentration of mineral-N in the soil on five different sampling dates

The effect of source of N on the mineral N concentration in the soil was highly significant ($p<0.001$) on each of the four dates of measurement. The results presented in Tables 2.22 to 2.25 show that the mineral N concentration in the soil was consistently higher ($p\leq0.05$) in soil amended with cattle kraal manure than in soil that received urea as the source of N. The results also indicate that the mineral N concentration in the soil tended to decline during the two-year period, indicating that mineral N mining took place in all treatments. The drop in mineral N concentration over the two-year period was particularly severe in the urea treatments, as shown in Figure 2.7. In the cattle manure treatments (Figure 2.8), mineral N concentration in the soil was partially restored during the two fallow periods, indicating that net mineralisation of organically bound N occurred during these periods. As a result, after the two-year period, the mineral N concentration in all cattle kraal manure treatments was higher ($p\leq0.05$) than in the control and urea treatments.

Whilst the effect of N application rate was highly significant ($p<0.001$), Tables 2.22 to 2.25 and Figures 2.7 and 2.8 show that this effect was only significant in the cattle kraal manure treatments. In these treatments, mineral N concentration was positively associated with rate of N application.

The effect of application rate of nitrogen on the second-season apparent relative nitrogen fertiliser value of cattle kraal manure is presented in Table 2.26. The statistical analysis of the data is presented in Appendix 2.8.

TABLE 2.26: Effect of application rate on the second-season apparent relative nitrogen fertiliser value (ARNFV) of cattle kraal manure

Application rate	**Source**
	Cattle kraal manure
	Second-season ARNFV
(kg N ha^{-1})	………………………………(%)………………………………
30	14.5
60	22.3
90	20.0
120	21.5
Mean	**19.6**
LSD (p=0.05) = 1.7% LSD (p=0.01) = 2.4%	

The overall mean second-season ARNFV of the cattle kraal manure was 19.6% but rate of application had a highly significant effect ($p \leq 0.001$) on values (Appendix 2.8). The main difference among the four application rate treatments was that the ARNFV at the rate of 30 kg N ha^{-1} (14.5%) was more than 5% lower than in the other application rate treatments, which all recorded values of 20% or more. Even though the ARNFV recorded in the 60 kg N ha^{-1} treatment differed significantly from that recorded in the 90 kg N ha^{-1} treatment at p=0.05 but not at p=0.01, the results suggest that when the cattle kraal manure is applied at rates of 60 kg N ha^{-1} or higher, the second season ARNFV of the manure is a more or less 20 to 22%. However, when application rate is reduced below 60 kg N ha^{-1}, the second season ARNFV declines, and reaches a value less than 15% at the application rate of 30 kg N ha^{-1}.

2.4 Discussion

2.4.1 Residual effect on the apparent relative nitrogen fertiliser value of cattle kraal manure from Thulamela

Ngwenya (2017:54) reported that the first-season apparent relative nitrogen value (ARNFV) of cattle kraal manure from Thulamela was very low, with the ARNFV of the four samples that were investigated ranging between a low of -1.7% and a high of 4.9%. The very low ARNFVs of all four cattle kraal manure samples were confirmed in an incubation experiment, which provided no evidence of net mineral N release from these samples after incubation over a 42-day period. Accordingly, Ngwenya (2017:54-62) concluded that cattle kraal manure from Thulamela had characteristics similar to those of East African cattle kraal manure, which is widely considered as a very poor source of plant-available N (Murwira, Swift & Frost, 1995:134; Okalebo *et al.,* 2006:157-158; Waithaka *et al.*, 2007:213). However, the nitrogen fertiliser values of cattle kraal manure from East Africa were obtained in short-term (first-season) investigations, in residual effects were not determined. The objective of the current study was to investigate the extent to which the nitrogen fertiliser value of cattle kraal manure from Thulamela was affected by the residual effect of the previous application.

Whilst circumstances prevented measurement of the first-season ARNFV of the cattle kraal manure sample under field conditions, using the ARNFV assay, Ngwenya (2017:54) reported the first-season ARNFV of the same manure sample as used in the current study to be -0.9%. The results of the current field experiment showed that across the application rate treatments, the ARNFV of the manure was 19.6% in the second season of application, indicating that there was a substantial residual effect on the ARNFV of this cattle kraal manure. The existence of this residual effect was confirmed by the substantial increase in the mineral N content of the soil treated with cattle kraal manure during the fallow between the first and second maize growing season, and again during the fallow that followed harvest of the second season maize, relative to the control and chemically fertilised treatments (Figure 2.8). The findings of the study support the work of Schröder, Jansen and Hilhorst (2005:201), who indicated that manure leaves behind appreciable amounts of N that have not been mineralised after the first season of application, and that parts of these N reserves can become plant-available in subsequent seasons.

The observed second-season mean apparent relative NFV of Thulamela cattle kraal manure of 19.6% is comparable with the NFV of dairy slurry of 19% recorded after three applications by Paul and Beauchamp (1993:822) in Canada. However, as shown in Table 2.27, other studies in the Netherlands and the USA all recorded higher NFVs for cattle manure, irrespective of whether measurements were done after the first season of application or over a longer time span, allowing for residual effects to come into play. It is known that the NFV of manure depends on a range of factors, including diet, materials added to the excrements, losses and chemical transformations during storage and handling, and climatic conditions after land application (Snapp, Mafongoya & Waddington, 1998:196; Webb *et al.,* 2013:376). The findings of Ngwenya (2017:54) and those reported here indicate that some or all of the factors that affect the NFV of cattle manure are less than optimal in the Thulamela free-ranging cattle farming system. This does not mean that application of local cattle kraal manure on cropped land in Thulamela is without merit to the nitrogen economy of soils. On the contrary, the findings in the current study clearly show that when applied successively, this type of manure can play a significant role in maintaining the fertility of cropped land. This conclusion is supported by the findings of Ramphisa (2015a:42), who investigated the effects of fertiliser practices on the mineral N content of garden soils. She reported that garden soils that were amended with manure, mostly cattle kraal manure, contained on average 3 mg mineral N kg soil^{-1} more than garden soils that received no fertilisers or had been fertilised chemically, even though these differences were not significant (p>0/05).

TABLE 2.27: Relative nitrogen fertiliser values of cattle manure reported in various studies (after Ngwenya, 2017:80)

Country	Manure type	Method of application	Test crop	Method used to measure the N-fertiliser value of manure	Relative N-fertiliser Value	Number of seasons	Source
Canada	Dairy slurry	Broadcast and worked into the soil	Maize	Difference method[2]	19%	3	Paul and Beauchamp (1993:256)
The Netherlands	Dairy slurry	Broadcast and worked into the soil	Ryegrass	Difference method	31%	1	Schröder, Uenk and Hilhorst, (2007:83)
The Netherlands	Dairy slurry	Injected	Maize	Difference method	55%-60%	1	Schröder, Jansen and Hilhorst, (2005:201)
Canada	Dairy slurry	Injected	Maize	Fertiliser equivalence method	52%-89%	2	Paul and Beauchamp (1995:38)
Nebraska, USA	Beef feedlot	Broadcast and worked into the soil	Maize	Difference method	40%	5	Eghball and Power (1999:898)
Wisconsin USA	Solid dairy	Broadcast and worked into the soil	Maize	Fertiliser equivalence method	26%-32%	3	Muñoz *et al*. (2004:723)
Canada	Solid beef	Broadcast and worked into the soil	Maize	Difference method	30%	3	Paul and Beauchamp (1993:256)

[2] The nitrogen fertiliser value obtained with the difference method is also called the "apparent recovery of manure" (Paul & Beauchamp, 1993:256) and the "apparent N use efficiency" (Eghball & Power, 1999:897).

2.4.2 Application rate effect on the second-season NFV of cattle kraal manure from Thulamela

The results of the current study showed that the second-season apparent relative NFV was affected by N application rate. Amongst the four application rate treatments, the main differences observed was that the second-season apparent relative NFV at the rate of 30 kg N ha^{-1} was lower than in the other rate treatments, which all recorded values of 20% or more. For the cattle kraal manure used, the application rate of 30 kg N ha^{-1} was achieved by applying 1 852 kg cattle kraal manure per hectare, which is a modest application rate that is well below the 5 tons per hectare that is commonly recommended. Be that as it may, the results of the current study do not resolve the controversy surrounding the effect of application rate of the nitrogen fertiliser value of cattle manure. Whilst Schröder (1998:162) reported an increase in the apparent nitrogen recovery with increasing N application rates of cattle slurry, other investigators reported a decrease as application rate of manure-N was increased (Myint *et al.,* 2011:470; Cusick *et al.,* 2006:2175-2176), and Ramphisa (2015b:49) found that the quantity of mineral N released from cattle kraal manure was directly proportional to manure application rate.

2.4.3 Applying cattle kraal manure to maintain optimum levels of plant available N in soil

Monitoring the mineral N content of the soil at the experimental site demonstrated that applying cattle kraal manure alone was insufficient to prevent a decline during the two-year period of observation. Whilst the rate of this decline was less in the plots that received cattle kraal manure than in the control and the plots that received urea, the results indicated that some ‘mining’ of N also occurred in all the plots that received manure. This finding is in line with the results obtained by Ramphisa (2015a:44), who reported that garden top soils (200 mm) in the village of Manamani (Thulamela) contained less mineral N than the upper threshold of 13.7 mg kg soil^{-1} and the biological optimum of 60 mg kg^{-1} for maize production in South Africa (Van Biljon, Fouché & Botha, 2008:10). Ramphisa (2015a:44) reported that soils that received animal manure contained, on average, 10.3 mg mineral N kg $soil^{-1}$, whilst soils that received either no nutrient application or chemical fertilisers only contained 7.9 mg mineral N kg $soil^{-1}$.

2.5 Conclusion

The overall objective of this study was to determine the extent to which cattle manure application, which is a common practice among smallholder farmers and home gardeners in Thulamela, can make a contribution to the plant available N content of soil. The specific objective of this study was to determine the residual and application rate effects on the apparent relative nitrogen fertiliser value (ARNFV) of local cattle kraal manure under field conditions. For that reason, a field experiment was conducted over two consecutive growing seasons. In this experiment N was applied at four different rates both as cattle kraal manure and as urea. This design provided four estimates of the residual effect on the NFV of cattle kraal manure.

It was found that the second-season apparent relative NFV cattle kraal manure from Thulamela was affected positively by the previous application, and attained a value of about 20%. This indicates that the strategy of applying cattle kraal manure annually to the same parcel of land, as used by some gardeners in Thulamela, is useful in raising the supply of N to crops. However, the two annual applications of cattle kraal manure did not prevent a progressive decline in the mineral N content of the soil, irrespective of application rate. Accordingly, if optimum availability of N is to be maintained in an intensive (irrigated) cropping system, the practice of annually applying cattle kraal manure has to be combined with other practices that enhance the N content of soils. One of the options is to augment the application of cattle kraal manure by adding chemical N to satisfy the crop requirements but this is costly. Another option is to use a crop rotation that has a leguminous green manure crop as one of the entries. The use of a crop rotation involving a leguminous green manure has the disadvantage of reducing the land available for the production of food crops but its advantage is that it is a low external input farming practice. It is recommended that further work aimed at improving the soil fertility of home gardens in Thulamela assesses social acceptability, impact on the nitrogen economy of garden soils, and economic aspects of these two proposed options.

CHAPTER 3

3 RESTORING CHEMICAL SOIL FERTILITY IN HOMEGARDENS OF THULAMELA MUNICIPALITY USING CHICKEN LITTER

3.1. Introduction

The objectives of the study were to investigate the potential of chicken litter to rapidly restore the fertility of home garden soils in Thulamela, and to assess whether the use of banding or spot placement, also called micro-dosing, of chicken litter was a beneficial strategy for use when access to chicken litter was restricted. Both objectives addressed the major constraint of low soil fertility, which limits crop production in the home gardens and fields of large numbers of smallholders in South Africa (Mandiringana *et al.,* 2005:2432; Odhiambo & Magandini, 2008:357).

Soils in the smallholder farming areas of Limpopo Province have been described as low in organic matter and deficient in nitrogen (N) and phosphorus (P) (Ramaru, Mamabolo & Lekgoro, 2000:6; Odhiambo & Magandini, 2008:257; Nethononda, Odhiambo & Paterson, 2012:5440). When using the strategy of applying nutrients to restore the fertility of their field and garden soils, the main options available to rural households are the application of chemical fertilisers and/or animal manure. Application of chemical fertilisers has the advantage of being of immediate benefit to crops, because the nutrients are added to the soil in plant available forms. The main disadvantage of chemical fertilisers is their high cost, which, according to Odhiambo and Magandini (2008:359), makes this type of fertilisers unaffordable for most smallholder farmers. As a result, many of the smallholders who do apply chemical fertilisers tend to use application rates that are below the recommended (Mkhabela & Materechera, 2003:152; Odhiambo & Magandini, 2008:360). Furthermore, applying chemical fertilisers appears to produce short-lived positive effects only. Investigating the effect of various nutrient management practices used by home gardeners in Manamani on the mineral N and P status of garden soils, Ramphisa (2015a:44) found that there was no significant difference between gardens that received no fertiliser application at all and those in which nutrients were added in the form of chemical fertilisers. This finding is notable, because the average application rate at which gardeners in the study applied chemical fertilisers was 291 kg ha^{-1}. This application rate is in line with the 200 to 300 kg chemical fertiliser ha^{-1} which is commonly recommended to smallholders in Southern Africa (Bembridge, 1984:320; Connor, van Rees & Carberry, 2015:4). The other option, namely that of applying animal manure, has the advantage that manure is an on-farm resource for rural South Africans who keep livestock, and locally accessible for those who do not keep animals. Ramphisa (2015a:44) reported that in gardens where soil fertility was managed by applying animal manure, either solely or in combination with chemical fertilisers, the P status of the soil was, on average, more than three times higher (9.8 mg P kg $soil^{-1}$) than in soils that received no nutrient application (3.3 mg P kg $soil^{-1}$), or in soils where nutrient application consisted solely of chemical fertilisers (2.3 mg P kg $soil^{-1}$). Fertility management practices also tended to affect mineral N content of garden soils but the effect was not significant ($P>0.05$). Ramphisa (2015a:44) reported that soils which received animal manure contained, on average, 10.3 mg mineral N kg $soil^{-1}$, whilst soils that received no nutrient application or only received chemical fertilisers contained 7.9 mg mineral N kg $soil^{-1}$. These findings indicated that application of animal manure had the advantage over chemical fertilisers of bringing about a more sustained improvement in the nutrient status of soils.

In Thulamela, as in many parts of Africa, cattle manure is the main type of animal manure available (Odhiambo & Magandini, 2008:360; Mpyana, 2017:149,151). Ngwenya (2017:54) discovered that cattle kraal manure from Thulamela had little value as an immediate source of N but the study reported on in Chapter 2 of this manuscript demonstrated that part of the N applied as cattle manure does become plant available over time. This suggests that applying local cattle manure to soils in Thulamela is can be part of a viable strategy of building soil fertility over the medium to long term but it has limited use when immediate improvement is required, especially when it concerns the plant available N content of soils.

When an immediate rise in soil fertility and crop production is required, chicken litter has the potential to deliver desirable results. Several studies have shown that the use of chicken litter can produce immediate positive crop responses (Maerere, Kimbi & Nonga, 2001:17-21; Tewolde & Sistani, 2014:363). Vitale *et al.* (2011:154) reported that the response of sorghum and Bermuda grass to applied chicken litter was similar to that of chemical fertilisers when applied at commensurate rates.

Poultry manure is a rich source of N, P and other plant nutrients, and is known to rapidly release these nutrients in plant-available forms (Sims & Wolf, 1994:18-19; Wilkinson, 1979:122). For example, in a pot experiment with maize, Ngwenya (2017:72) found that between 39% and 64% of the total N contained in chicken manure became plant available during the first 42 days after application. Adebisi (2015:96) reported that 69% of the total P contained in chicken manure became plant-available during the first 35 days after application, and Ramphisa (2015b:118) reported that 94% of the K in chicken manure was plant available. This information confirms that chicken litter has the potential to rapidly raise the fertility of soil.

Rural people in Thulamela have access to poultry manure. Ralivhesa *et al.* (2013:285) reported that local smallholders purchased poultry manure for use as fertiliser from the multitude of small and medium poultry production units operating in their neighbourhoods. Furthermore, keeping scavenger chickens is common practice among rural households in Thulamela (Denison *et al*., 2016:175). Ngwenya (2017:54) reported that the nitrogen fertiliser value of manure produced by scavenger chickens was as high as the litter of broiler chickens raised in commercial production units. At this stage, the potential of chicken litter to rapidly raise soil fertility of soils in Thulamela has not been investigated, explaining why this was one of the two objectives of the current study.

The second objective of the study addresses concerns about the affordability of chicken litter in quantities that are sufficient to achieve rapid soil fertility restoration. Whilst this concern is usually raised in relation to chemical fertilisers, in Thulamela it also applies to chicken litter, where in 2015, a 50 kg grain bag filled with broiler litter was selling for

R20.00. In recent years, micro-dosing of chemical fertilisers in response to their high cost has received considerable research attention. Okebalama *et al*. (2015:1170) defined fertiliser micro-dosing or micro-fertilisation as 'the application of a small quantity of mineral fertiliser together with seeds of the target crop in the planting hole at sowing or 2-4 weeks after sowing.' Micro-dosing cuts the rate of application of chemical fertilisers from the recommended 200 to 300 kg ha^{-1} to between 20 and 50 kg ha^{-1} in the case of di-ammonium phosphate (Okebalama *et al*., 2015:1170; Connor, van Rees & Carberry, 2015:4). This represents a five to ten-fold reduction compared to the recommended rate. Reports from various African countries indicate that this strategy can raise crop yields by 30% to 100% compared to when no fertilisers are applied (Okebalama *et al*., 2015:1171). Indications are that concentrating manure application in the planting furrow, or spot-placed below the seed, could yield similar benefits. For example, in KwaZulu-Natal, Mkhabela (2003:14) reported that at constant rate of application spot placement of cattle manure raised crop yields more than band placement, which, in turn, gave superior yields to broadcast application.

3.2 Materials and methods

3.2.1 Description of the study site

The field experiment was conducted in a home garden of Mrs Mawera located in the same village as described in section 2.2.1 of this dissertation. The home garden is situated at an altitude of 568 m above sea level. Its coordinates are 23º 01' 07" S and 30º 26' 36" E. The land at the experimental site sloped gently in a west north-west direction with a gradient of 2%. The soil in the garden was classified as being of the Hutton form and Suurbekom family (Soil Classification Working Group, 1991:138-139). The soil was 1.3 m deep and well drained. A complete description of the soil profile is presented in Appendix 3.1. The physical and chemical properties of the soil were determined by Nvirotek Laboratories. The results of the analyses appear in Appendix 3.2. The climatic information is the same as described in section 2.2.1 of this manuscript.

3.2.2 Experimental design

Twelve treatments were laid out in a randomised complete block design. All treatments were replicated three times, resulting in an arrangement of 36 field plots. In the first treatment, designated CLbr1 (chicken litter broadcast), chicken litter was applied at the rate of 5 228 kg ha^{-1} or 90 kg N ha^{-1}. In the second treatment designated CFbr1 (chemical fertiliser broadcast), N, P and K were applied at the same rates as in CLbr1 but in chemical form. This treatment was entered in the design to compare the effectiveness of chicken manure relative to chemical fertiliser in restoring the fertility of home garden soils in Thulamela during the growing season following application. To these two treatments, three additional chemical fertiliser treatments CFbr1-P, CFbr1-K and CFbr1-PK were added. These treatments were aimed at assessing the contributions of the P and K contained in the chicken litter to the growth and yield of the test crops when N was applied as urea at the rate of 90 kg N ha^{-1}.

The effect of fertiliser placement method at low rate of N, P and K application was assessed by means of six treatments, namely three chicken litter treatments (CLbr2, CLba2, CLsp2), as well as three chemical fertiliser treatments (CFbr2, CFba2 and CFsp2). Fertiliser placement treatments included broadcasting before planting (br), banding at planting (ba), and spot placing at planting (sp). In the CL2 treatments, chicken litter was applied at the rate of 15 kg N ha^{-1} or 871 kg chicken litter ha^{-1}. In the three chemical fertiliser treatments (CF2), N, P and K were applied at the same rates as in the CL2 treatment. The twelfth treatment (C) was the control treatment, in which no fertiliser was applied at all (negative control).

TABLE 3.1: Summary of the treatments used in the field experiment aimed at determining the potential of using chicken litter to rapidly restore the fertility of home garden soils in Thulamela with Chinese cabbage

Treatment	**Application rate**			**Application method**	**Mass of fertiliser applied**			
	N	**P**	**K**		**Chicken litter**	**Urea**	**superphosphate**	**Potassium chloride**
	………..(kg ha^{-1})…….							
C	00	0.0	0.0		0.00 g plot $^{-1}$	0.00 g plot $^{-1}$	0.0 g plot $^{-1}$	0.0 g plot $^{-1}$
CLbr1	90	22.3	76.7	Broadcast	5 123.40 g plot $^{-1}$	0.00 g plot $^{-1}$	0.0 g plot $^{-1}$	0.0 g plot $^{-1}$
CFbr1	90	22.3	76.7	Broadcast	0.00 g plot $^{-1}$	191.74 g plot $^{-1}$	156.1 g plot $^{-1}$	150.3 g plot $^{-1}$
CFbr1-P	90	0.0	76.7	Broadcast	0.00 g plot $^{-1}$	191.74 g plot $^{-1}$	0.0 g plot $^{-1}$	150.3 g plot $^{-1}$
CFbr1-K	90	22.3	0.0	Broadcast	0.00 g plot $^{-1}$	191.74 g plot $^{-1}$	156.1 g plot $^{-1}$	0.0 g plot $^{-1}$
CFbr1-PK	90	0.0	0.0	Broadcast	0.00 g plot $^{-1}$	191.74 g plot $^{-1}$	0.0 g plot $^{-1}$	0.0 g plot $^{-1}$
CFbr2	15	3.7	12.8	Broadcast	0.00 g plot $^{-1}$	31.96 g plot $^{-1}$	25.9 g plot $^{-1}$	25.1 g plot $^{-1}$
CFba2	15	3.7	12.8	Band placed	0.00 g row $^{-1}$	7.99 g row $^{-1}$	6.5 g row $^{-1}$	6.3 g row $^{-1}$
CFsp2	15	3.7	12.8	Spot placed	0.00 g plant $^{-1}$	0.571 g plant $^{-1}$	0.46 g plant $^{-1}$	0.45 g plant $^{-1}$
CLbr2	15	3.7	12.8	Broadcast	853.60 g plot $^{-1}$	0.00 g plot $^{-1}$	0.0 g plot $^{-1}$	0.0 g plot $^{-1}$
CLba2	15	3.7	12.8	Band placed	213.50 g row $^{-1}$	0.00 g row $^{-1}$	0.0 g row $^{-1}$	0.0 g plot $^{-1}$
CLsp2	15	3.7	12.8	Spot placed	15.25 g plant $^{-1}$	0.00 g plant $^{-1}$	0.0 g plant $^{-1}$	0.0 g plot $^{-1}$

*C: control, CF: chemical fertiliser, CL: chicken litter, The first run of the experiment was done during the winter cropping season of 2015 with Chinese cabbage. This was followed by the second run, in which maize was used as the test crop. The second run was done during the summer cropping season of 2015 to 2016. Maize is the most commonly grown summer crop in home gardens of Thulamela whilst Chinese cabbage is the most commonly grown winter crop (Denison *et al*., 2016:177).

3.2.3 Materials

The home garden in which the experiment was conducted had been under maize cultivation for three years prior to the establishment of the experiment. No fertilisers had been applied in the garden during the previous three years.

The same plastic rain gauge, maize cultivar, chemical fertilisers and electronic scales as described in section 2.2.3 of this manuscript were used in the conduct of this field experiment. The other test crop was Chinese cabbage. Seed of Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*) was of the *dabadaba* land race, and was produced at the Skills Centre at TUT. The chicken litter that was applied was sourced from Mr Mathoni of Tshivhuyuni village in Thulamela Municipality (Limpopo Province). Selected chemical and physical properties of this chicken manure is presented in Table 3.2.

TABLE 3.2: Chemical and physical properties of chicken litter used in the field experiment determining the potential of using chicken manure to rapidly restore the fertility of home garden soils in Thulamela

Property	**Unit**	**Chicken litter**
pH[2]		7.5
Moisture[1]	%	4.1
Solids[1]	%	95.9
Organic matter content	%	56.3
Total organic carbon	%	15.8
C/N ratio	%	5.9
Total Nitrogen content	%	2.69
Calcium (Ca)	%	2.3
Magnesium (Mg)	%	0.7
Phosphorus (P)	%	0.62
Potassium (K)	%	1.6
Sodium (Na)	%	0.315
Electrical conductivity[3]	dS m^{1}	0.341

[1] All values in the table are reported on an air dry basis and are based on the dried and milled samples provided to the Institute of Soil, Climate and Water - Agricultural Research Council, South Africa, 2008.

[2] The manure to water ratio used for pH measurement was 1 g manure: 5 mL water.

[3] The manure to water ratio used for electrical conductivity was 1 g manure: 10 mL water

3.2.4 Methods

To prepare the land for planting in the winter cropping season of 2015 and summer cropping season of 2015-16 and incorporate weeds and crop residues covering the garden, the soil of the garden was tilled to a depth of about 170 mm using hand hoes. Subsequent layout procedures of plots were precisely the same as used and described in section 2.2.4 of this manuscript. Gross plot size was 2.8 m x 3.5 m = 9.8 m^2. Weighing of the different fertiliser materials as per treatment requirements was done exactly in the same way as described in section 2.2.4 of this manuscript. In all treatments that required broadcasting of fertilisers, the chemical fertilisers and chicken litter were spread evenly over the entire surface of the plot and then incorporated into the soil with a garden fork before ridging and planting. Banding and spot placement of fertilisers was done at planting after the construction of ridges. The fertiliser was incorporated into the soil with a stick, after which the plots were planted to Chinese cabbage using a row spacing of 0.70 m and an intra-row spacing of 0.25 m, resulting in a planting density of 5.7142 plants m^{-2}. Plant spacing for maize was the same as described in section 2.2.4 of this dissertation.

At planting, a narrow planting furrow approximately of 0.05 m deep was opened using a hand hoe along the shoulders of each ridge. In band-placed treatments, the required fertiliser was then evenly spread in this furrow and mixed with soil by dragging a stick along the bottom of the furrow. Spot placement was achieved by making holes of about 0.05 m deep in the bottom of the planting furrow at each planting station. The designated quantity of fertiliser was then placed at the bottom of each hole, where after the hole was filled with soil. Before planting, 10 litre water was applied in each furrow, and after this water had infiltrated, a marked planting chain was placed in the furrow and six Chinese cabbage seeds were pressed into the wet soil at each planting station. The seeds were then covered with soil by closing the planting furrow with a rake. Two weeks after the Chinese cabbage seedlings had emerged the stands were thinned to one plant per hill. Procedures for planting maize were the same as described in section 2.2.4 of this manuscript.

The plants in the two outer rows and the first and last plant in the two inner rows served as guard plants. In the case of Chinese cabbage, the net plot was 3.0 m x 1.4 m in size and contained 24 plants. For maize, the net plot was 2 m x 1.4 m and contained 10 plants. Table 3.3 shows the date of planting and harvest of the two crops and their growing periods.

TABLE 3.3: Dates of planting and harvest and duration of the growing period of Chinese cabbage and maize crop in the field experiment determining the potential of using chicken manure to rapidly restore the fertility of home garden soils in Thulamela

Crop	Planting date	Final harvest date	Growing period (days)
Chinese cabbage	28-June-2015	4-Sept-2015	69
Maize	23-Nov-2015	21-Mar-2016	121

Plate 3.1 shows an overview of the 2015 experiment with Chinese cabbage 28 days after planting. Plate 3.2 provides an overview of the 2015-16 experiment with maize 40 days after planting.

PLATE 3.1: View of the 2015 field experiment aimed at determining the potential of using chicken litter to rapidly restore the fertility of home garden soils

PLATE 3.2: View of the 2015-16 field experiment with maize 40 days after planting that was aimed at determining the potential of using chicken litter to rapidly restore the fertility of home garden soils

Weeds were controlled as they emerged using hoeing and uprooting. Pests identified on non-heading Chinese cabbage included aphids *(Aphididae spp)*, cutworms *(Agrotis segentum)* and the bagrada bug (*Bagrada hilaris*). In the 2015 winter experiment and 2015-16 summer experiments weed control and plant protection measures were applied in the same way as described in section 2.2.4 of this manuscript.

The 2015 winter experiment and 2015-16 summer experiment were conducted under irrigated conditions. Using the system of ridges and tied furrows constructed along the Chinese cabbage rows of each plot, specified quantities of irrigation water were applied in the furrows by means of calibrated buckets. Before planting, 80 mm of water was applied to all plots to charge the top 500 mm of the soil profile to field capacity. Following emergence of the Chinese cabbage plants, all plots received 10 mm of irrigation water every second day for the duration of the growing period as recommended by Van Averbeke and Netshithuthuni (2010:326). Irrigation of maize was done in accordance with the procedures described in section 2.2.4 of this manuscript. In the 2015 winter experiment, the amount of rainfall (15 mm) and irrigation water (280 mm) was received during the growing period resulting in the total amount of 295 mm being applied. Irrigation details for the 2015-16 summer cropping season were exactly the same as presented in section 2.2.4 of this manuscript. Information on rainfall and irrigation water that was applied to the Chinese cabbage in the 2015 winter experiment is presented in Table 3.4.

TABLE 3.4: Rainfall and irrigation water applied during the growing period of Chinese cabbage in the field experiment determining the potential of using chicken litter to rapidly restore the fertility of home garden soils

Period	Rainfall (mm)	Irrigation (mm)	Total water supplied (mm)
01-31 July 2015	0	120	120
01-31 August 2015	0	160	160
01-04 September 2015	15	0	15
Total 2015 growing season	**15**	**280**	**295**

3.2.5 Data collection

Chinese cabbage was harvested in accordance with the procedures described by Van Averbeke and Netshithuthuni (2010:323). In each plot, the leaves of twenty four representative plants were harvested using the staged harvesting procedure. This involved harvest of the fifth leaf when the plants reached the eight-leaf stage, harvest of the sixth leaf and seventh leaf one week later and harvest of the remaining leaves when the peduncle elongation was observed in 50% of the plants. The first four leaves of each net plant were kept in a labelled bag and added to the remainder of the plant to make up the total oven-dry above-ground biomass yield. The total oven-dry above-ground biomass of the plants was the sum of the oven-dry mass of all the plant material that was removed from the net plot, and this was used as the main indicator of crop response to fertiliser treatment. Maize was harvested from the net plots at physiological maturity in accordance with the procedures described in section 2.2.5 of this manuscript. All the biomass measurements were done using the same scales presented in section 2.2.3 of this manuscript.

Soil samples were collected to monitor the dynamics of the mineral N concentration in the topsoil of the various treatments during the 10 months experimental period. Prior to planting the 2015 winter experiment, three soil samples representative of the experimental site were taken from the upper 200 mm of the soil on the 28th June 2015 using a core sampler. All cores were placed together in a clean bucket and mixed thoroughly before taking three sub-samples for analysis of nitrate-N and ammonium-N. Subsequently, the soil in the net area of each plot was sampled on three more occasions. The first of these was immediately after harvesting the 2015 Chinese cabbage crop (5th September 2015); the second before treatment application in the 2015-16 experiment (18th November 2015); and the third and last after harvesting the 2015-16 maize crop (18th March 2016). Each plot sample consisted of four soil cores (0-200 mm) taken from within the net plot area. The procedures used in the collection of this samples and the extraction of nitrate and ammonium were the same as those described in section 2.2.5 of this manuscript.

To monitor the dynamics of the Olson P concentration in the topsoil of the various treatments during the 10 month experimental period, the same soil samples that were collected to monitor the dynamics of the mineral N concentration were used. Sub-samples were air-dried inside the laboratory before crushing the soil with a pestle and mortar and then analysed for Olson P concentration.

Extraction of Olson phosphorus was done using 0.5 M sodium bicarbonate ($NaHCO_3$), at pH 8.5 (NASAWC, 1990:24/1). For this purpose, 2.5 g of air-dried soil was shaken in 50 mℓ of 0.5 M $NaHCO_3$ in a 100 mℓ plastic bottle with screw cap for 30 minutes on a Labcon Micro-processor Controlled Platform Shaker® set to 180 oscillations per minute. Thereafter, the mixture was filtered using double Whatman No 1 filter paper, followed by the preparation of the Murphy-Riley colour-developing solution using 1% ascorbic acid and molybdate reagent, as described by Anderson and Ingram (1993:87) in Appendix

3.3. The analysis was done colorimetrically using the Lasec Cecil 1000 series, CE1021 diode array spectrophotometer® procured from Lasec SA, (Pty) Ltd, which was set at a wavelength of 880 nm. For each batch of samples, readings were also taken for standards containing 0, 1, 2, 3, 4, and 5 ppm P, enabling conversions of the readings to concentration of Olson P in the soil. Standards of phosphorus were prepared using potassium di-hydrogen phosphate (KH_2PO_4).

3.2.6 Data capture, transformation and analysis

Total oven-dry above-ground biomass data of Chinese cabbage obtained in the 2015 winter cropping season and oven-dry above-ground biomass data of maize for the 2015-16 summer cropping seasons were captured separately on a Microsoft Office Excel® spread sheet for analysis of variance using the Genstat Statistical Software Version 19 to test for treatment effects. When these effects were statistically significant ($p \leq 0.05$), the Fisher's Protected Least Significant Difference (LSD) test ($p=0.05$) was used to separate treatment means (Baird *et al.,* 2017).

The procedures that were used to obtain the mineral N concentration of the soil in the different treatments were exactly the same as described in section 2.2.6 of this manuscript. In order to obtain the Olson P concentration of the soil in the different treatments, a calibration curve was constructed, using Microsoft Office Excel®, to relate the absorbance values of the standards to their extractable P concentrations expressed in mg ℓ^{-1}. Equation 3.1, taken from Anderson and Ingram (1993:74), was then used to convert the Olson P concentration in the extractant to mg Olson-P kg soil $^{-1}$.

Concentration in mg kg soil^{-1} = $(C.V) \div W$ **Equation 3.1**

whereby:

C = concentration of phosphorus in solution (mg ℓ^{-1});

V = volume of extractant used (ℓ); and

W = Mass of oven-dry soil (g)

The extractable P concentrations in the soil were captured on spread sheets using Microsoft Office Excel® (2013), which were subjected to analysis of variance (ANOVA) using the Genstat Statistical Software Version 19 to test for treatment effects. When these effects were statistically significant ($p \leq 0.05$), the Fisher's Protected Least Significant Difference (LSD) test ($p=0.05$) was used to separate treatment means.

3.3 Results

3.3.1 Treatment effects on Chinese cabbage biomass production

Table 3.5 shows the effect of fertiliser and application method on the total oven-dry above-ground biomass of Chinese cabbage. Statistical analysis of the data appears in Appendix 3.4.

TABLE 3.5: Effects of fertiliser and application method on biomass of Chinese cabbage

Treatment	Application rate			Application method	Total oven-dry above-ground biomass
	N	P	K		
	……................($kg\ ha^{-1}$)………..........				............($g\ m^{-2}$)………
NC	0.0	0.0	0.0		75.2_{f}
CFbr1	90.0	22.3	76.7	broadcasting	128.6_{a}
CLbr1	90.0	22.3	76.7	broadcasting	121.0_{b}
CFbr1-P	90.0	0.0	76.7	broadcasting	127.8_{ab}
CFbr1-K	90.0	22.3	0.0	broadcasting	125.1_{ab}
CFbr1-PK	90.0	0.0	0.0	broadcasting	92.9_{e}
CFbr2	15.0	3.7	12.8	broadcasting	101.3_{d}
CFba2	15.0	3.7	12.8	banding	105.1_{cd}
CFsp2	15.0	3.7	12.8	spot place	106.7_{cd}
CLbr2	15.0	3.7	12.8	broadcasting	103.7_{cd}
CLba2	15.0	3.7	12.8	banding	108.1_{c}
CLsp2	15.0	3.7	12.8	spot place	109.7_{c}
LSD ($p=0.05$) = 7.2 $g\ m^{-2}$					

All treatments in which the soil was amended with fertiliser produced more biomass than the control. The difference in biomass between the CFbr1 and the CLbr2 plots was small (7.6 g in favour of CFbr1) but significant ($p \leq 0.05$). The difference between the CFbr2 and CLbr2 plots was even smaller (2.4 g in favour of CLbr2) and not significant ($p > 0.05$). This result suggests that the two broadcast chicken litter treatments (CLbr1 and CLbr2) were (almost) as effective as the two broadcast chemical fertiliser treatments (CFbr1 and CFbr2).

Leaving out only P (CFbr1-P) or only K (CFbr1-K) from the high chemical fertiliser treatment (CFbr1) had no significant effect ($p > 0.05$) on biomass production of Chinese cabbage. However, eliminating both nutrients (CFbr1-PK) reduced biomass by 35.7 g, which was significant ($p \leq 0.05$). This suggests an interaction effect of P and K on biomass production of Chinese cabbage.

At the low rate of fertiliser application, method of application did not have a significant effect ($p > 0.05$) on biomass production of Chinese cabbage but there was a tendency for spot placement (CLsp2 and CFsp2) to produce higher biomass than band placement (CLba2 and CFba2), and for band placement to produce higher biomass than broadcasting (CLbr2 and CFbr2).

3.3.2 Treatment effects on maize biomass production

Table 3.6 shows the total oven-dry above-ground biomass values of maize obtained in the 12 treatments during the 2015-16 summer cropping season. Statistical analysis of the biomass data are presented in Appendix 3.5.

TABLE 3.6: Effects of fertiliser treatment and application method on maize production during the 2015-16 summer cropping season

Treatment	Application rate			Application method	Stover	Grain	Total oven-dry above-ground biomass
	N	P	K				
	……..........(kg ha^{-1})……..				……………….(g m^{-2})…………........		
NC	0.0	0.0	0.0		371.4_{g}	228.6_{h}	600.0_{i}
CFbr1	90.0	22.3	76.7	broadcasting	676.2_{b}	559.3_{b}	1235.5_{b}
CLbr1	90.0	22.3	76.7	broadcasting	714.3_{a}	593.1_{a}	1307.4_{a}
CFbr1-P	90.0	0.0	76.7	broadcasting	570.9_{d}	457.1_{c}	1028.0_{d}
CFbr1-K	90.0	22.3	0.0	broadcasting	638.1_{c}	541.3_{b}	1179.3_{c}
CFbr1-PK	90.0	0.0	0.0	broadcasting	514.3_{e}	400.0_{d}	914.3_{e}
CFbr2	15.0	3.7	12.8	broadcasting	371.4_{g}	257.1_{g}	628.5_{hi}
CFba2	15.0	3.7	12.8	banding	390.5_{g}	276.2_{g}	666.6_{h}
CFsp2	15.0	3.7	12.8	spot place	438.1_{f}	323.8_{ef}	761.9_{g}
CLbr2	15.0	3.7	12.8	broadcasting	380.9_{g}	276.2_{g}	657.1_{h}
CLba2	15.0	3.7	12.8	banding	466.6_{f}	314.3_{f}	780.9_{fg}
CLsp2	15.0	3.7	12.8	spot place	476.2_{f}	342.9_{e}	819.1_{f}
LSD (p=0.05) stover				= 35.0 g m^{-2}			
LSD (p=0.05) grain				= 22.5 g m^{-2}			
LSD (p=0.05) total oven-dry biomass				= 52.5 g m^{-2}			

The effects of treatment on stover, grain and total biomass production of maize were all highly significant ($p<0.001$) and the pattern of the effect of treatment on these three production variables was similar. For this reason the sole focus of what follows is on total above-ground biomass. Compared to the control, maize produced more biomass in all treatments in which the soil was amended with fertiliser, except for the CFbr2 treatment. Contrary to the previous experiment with Chinese cabbage, the CLbr1 treatment produced significantly ($p\leq0.05$) more biomass than the CFbr1 treatment. The difference between the CLbr2 treatment and the CFbr2 treatment was not significant ($p>0.05$) but biomass in the CLbr2 treatment tended to be higher than in the CFbr2 treatment.

Withholding P (CFbr1-P) from the high chemical fertiliser treatment (CFbr1) reduced biomass production of maize by a significant 207.5 g. Withholding K (CFbr1-K) caused a smaller but still significant reduction of 56.2 g. Withholding both nutrients (CFbr1-PK) reduced biomass by 321.2 g, which was somewhat greater than the sum of the separate effects of withholding P (-207.5 g) and K (-56.2 g), suggesting an interaction effect of P and K on biomass production of maize, which was also noted with Chinese cabbage.

At the low rate of fertiliser application, method of application had significant effects ($p \leq 0.05$) on biomass production of maize. For both types of fertiliser, spot placement (CLsp2 and CFsp2) produced higher ($p \leq 0.05$) biomass than broadcasting (CLbr2 and CLbr2). The benefit of band placing (CLba2 and CFba2) over broadcasting fertiliser (CLbr2 and CLbr2) was only significant ($p \leq 0.05$) when chicken litter was used, whilst the benefit of spot placing fertiliser (CLsp2 and CFsp2) over banding (CLba2 and CFba2) was only significant ($p \leq 0.05$) when chemical fertilisers were applied.

3.3.3 Treatment effects on mineral-N concentration in the topsoil

The effects of fertiliser treatment and application method on the mineral N concentration in the topsoil (0-200 mm) over time are shown in Table 3.7. Figures 3.1 and 3.2 summarise the effects for each of the two sources of N used. The statistical analysis of the data appears in Appendix 3.6.

TABLE 3.7: Effects of fertiliser treatment and application method on the mineral N concentration in the topsoil (0-200 mm) over time

Treatment	**Sampling dates**				**Mean**
	Before planting first season crop (28 June 2015)	Harvest of first season crop (5 September 2015)	Before planting second season crop (19 November 2015)	Harvest of second season crop (18 March 2016)	
	……(mg N kg soil^{-1})……				
NC	11.6	10.9	9.6	6.4	**9.6$_c$**
CFbr1	11.6	10.9	9.1	7.0	**9.7$_c$**
CLbr1	11.6	13.6	15.8	8.8	**12.5$_a$**
CFbr1-P	11.6	10.6	9.7	6.7	**9.7$_c$**
CFbr1-K	11.6	10.8	9.1	6.1	**9.4$_c$**
CFbr-PK	11.6	10.7	9.4	6.3	**9.5$_c$**
CFbr2	11.6	10.3	9.4	6.4	**9.4$_c$**
CFba2	11.6	10.4	9.1	6.4	**9.4$_c$**
CFsp2	11.6	10.4	9.3	6.8	**9.5$_c$**
CLbr2	11.6	12.8	14.0	8.8	**11.8$_b$**
CLba2	11.6	13.0	14.3	8.5	**11.9$_b$**
CLsp2	11.6	12.8	14.2	9.0	**11.9$_b$**
Mean	**11.6$_a$**	**11.4$_b$**	**11.1$_c$**	**7.3$_d$**	**10.3**
LSD (p=0.05) time	= 0.19 mg N kg soil^{-1}				
LSD (p=0.05) treatment	= 0.39 mg N kg soil^{-1}				
LSD (p=0.05) treatment x time	= 0.70 mg N kg soil^{-1}				

*NC: negative control, CF: chemical fertiliser, CL: chicken litter

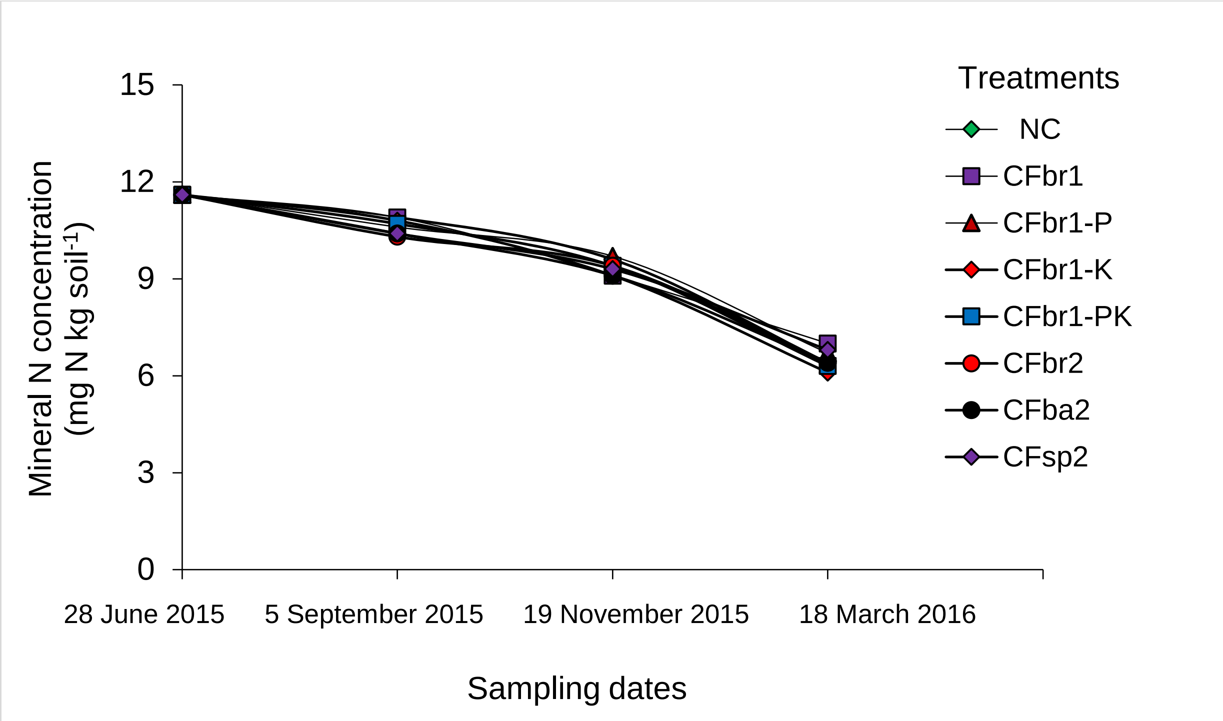

FIGURE 3.1: Effects of rate and method of applying N as urea on the mineral N concentration in the soil over time

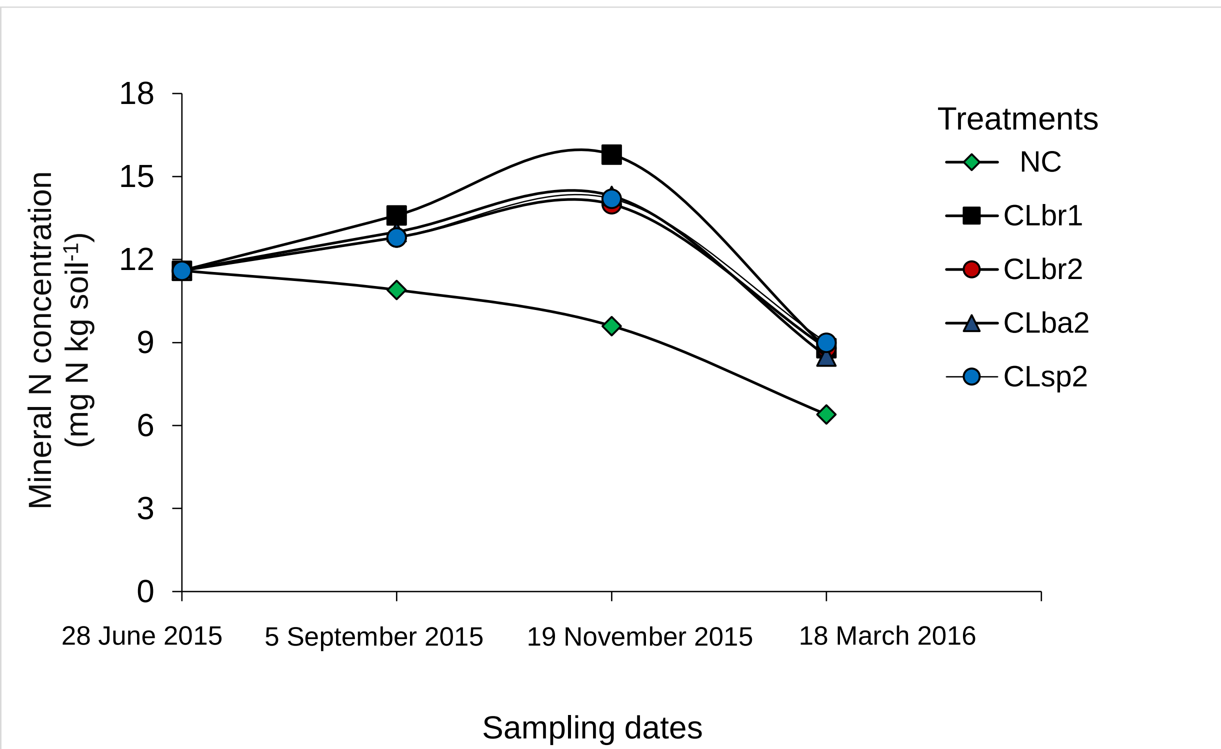

FIGURE 3.2: Effects of rate and method of applying chicken litter on the mineral N concentration in the soil over time

The effect of fertiliser treatment and application method on the mineral N concentration in the topsoil was highly significant ($p<0.001$) for each of the four dates of measurement. The results presented in Tables 3.7 show that the mineral N concentration in the soil was consistently higher ($p\leq0.05$) in soil amended with chicken litter than in soil that received urea. The results also show that the mineral N concentration declined during the ten month period. The observed drop was most severe in the control treatment and in the plots that received urea (Figure 3.1). In the chicken litter treatments (Figure 3.2), mineral N concentration in the soil increased during the first three sampling dates, despite uptake of N by Chinese cabbage during the period that separated first and second sampling date. However, during the growth of maize (period separating third and fourth sampling date), there was a sharp drop in the mineral N concentration in soil that was amended with chicken litter. Yet, despite this drop, at the end of the experiment the mineral N concentration in all chicken litter treatments was still higher ($p\leq0.05$) than in the control and chemical fertiliser treatments.

3.3.4 Treatment effects on the concentration of Olson P in the topsoil

The effect of fertiliser treatment and application method on the Olson P concentration in the topsoil (0-200 mm) over time are shown in Table 3.8. Figures 3.3 and 3.4 summarise the effects for the two sources of P used. The statistical analysis of the data appears in Appendix 3.7.

The effect of fertiliser treatment and application method on the Olson P concentration in the soil was highly significant ($p<0.001$) on each of the four dates of measurement.

TABLE 3.8: Effects of fertiliser treatment and application method on the Olson P concentration in the topsoil (0-200 mm) over time

Treatment	Sampling dates				Mean
	Before planting first season crop (28 June 2015)	Harvest of first season crop (5 September 2015)	Before planting second season crop (19 November 2015)	Harvest of second season crop (18 March 2016)	
	………………(mg P kg soil^{-1})………………				
NC	23.4	21.4	20.0	15.5	**20.1**$_{e}$
CFbr1	23.4	23.1	23.1	16.8	**21.6**$_{c}$
CLbr1	23.4	25.7	29.5	34.3	**28.2**$_{a}$
CFbr1-P	23.4	22.5	22.0	15.0	**20.7**$_{d}$
CFbr1-K	23.4	23.3	22.9	15.9	**21.4**$_{c}$
CFbr-PK	23.4	22.6	22.4	15.0	**20.9**$_{d}$
CFbr2	23.4	23.1	23.2	15.2	**21.2**$_{cd}$
CFba2	23.4	20.6	20.9	15.5	**20.1**$_{e}$
CFsp2	23.4	21.7	21.5	15.8	**20.6**$_{d}$
CLbr2	23.4	24.2	26.4	28.6	**25.7**$_{b}$
CLba2	23.4	24.2	26.8	29.4	**26.0**$_{b}$
CLsp2	23.4	24.2	26.8	29.8	**26.1**$_{b}$
Mean	**23.4**$_{b}$	**23.1**$_{b}$	**23.8**$_{a}$	**20.6**$_{c}$	**22.7**
LSD (p=0.05) time		= 0.26 mg P kg soil^{-1}			
LSD (p=0.05) treatment		= 0.59 mg P kg soil^{-1}			
LSD (p=0.05) treatment x time		= 0.98 mg P kg soil^{-1}			

*NC: negative control, CF: chemical fertiliser, CL: chicken litter

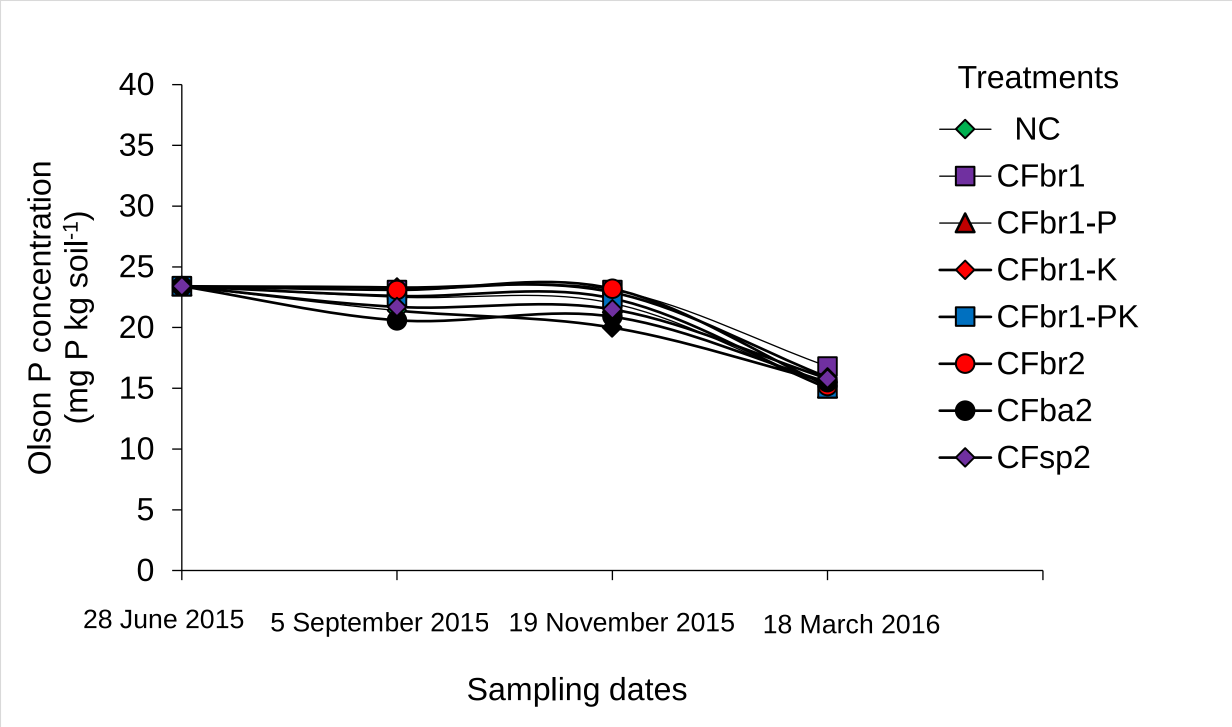

FIGURE 3.3: Effects of rate and method of applying P as single super phosphate on the Olson P concentration in the soil over time

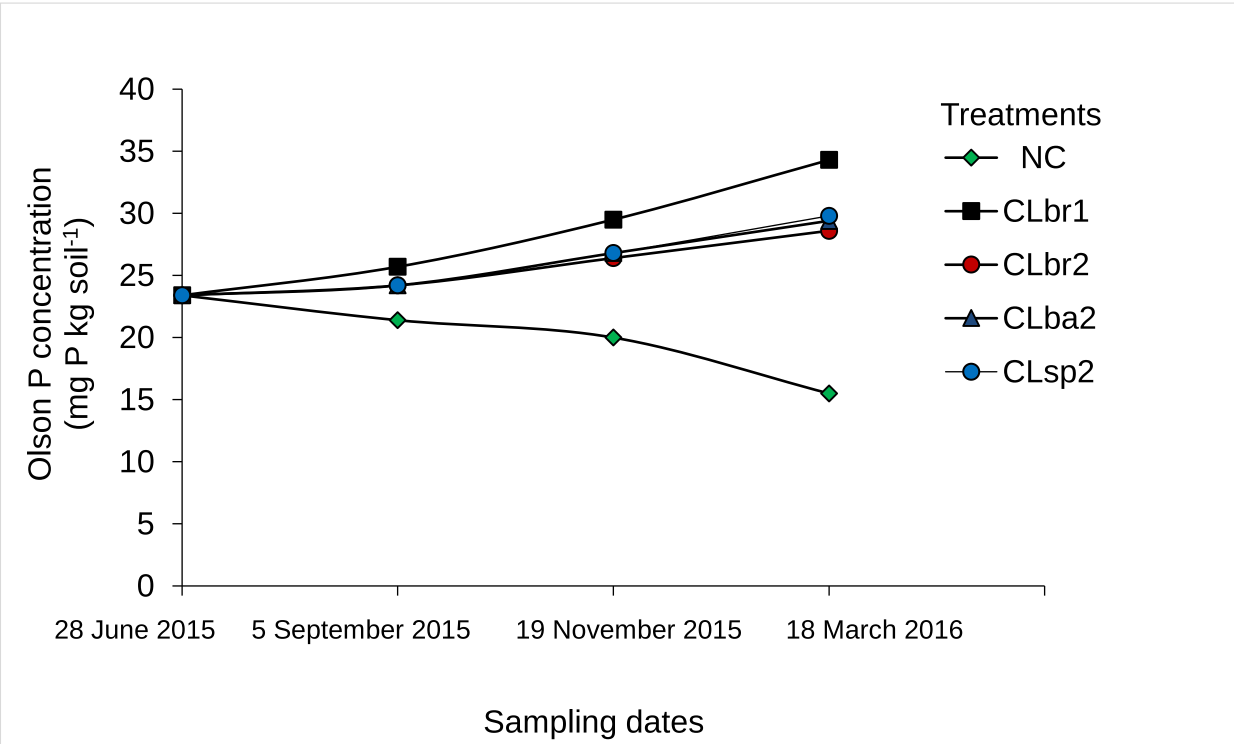

FIGURE 3.4: Effects of rate and method of applying P as chicken litter on the Olson P concentration in the soil over time

Olson P concentration in the soil was consistently higher ($p \leq 0.05$) in soil amended with chicken litter than in soil that received single super phosphate. In all treatments where soil was amended with single super phosphate, the Olson P concentration in the soil progressively declined ($p \leq 0.05$) during the period of observation. This was not the case in plots amended with chicken manure, in which the Olson P concentration increased throughout. As a result, at the end of the observation period, the Olson P concentration in all chicken litter treatments was higher ($p \leq 0.05$) than in the control and chemical fertiliser treatments.

3.4 Discussion

Production of both Chinese cabbage and maize was raised substantially when N, as well as P and K, were applied at the high rate of 90 kg N ha^{-1}, 22.3 kg P ha^{-1} and 76.7 kg K ha^{-1} either in chemical form or as chicken litter. Lowering the application rate of these nutrients to one-fifth of this high rate reduced the magnitude of the positive effect of fertiliser application on the yield of the two crops, even though the effect was still significant. Applying the three nutrients at the high rate in chemical form increased production of the first crop (Chinese cabbage) more than when nutrients were applied as chicken litter but for the second crop (maize) chicken litter produced better results than chemical fertiliser. These results confirm that chicken litter rapidly releases large proportions of the nutrients it contains when applied to soil, as previously reported by Wilkinson, (1979:122), Sims and Wolf (1994:18-19), Maerere, Kimbi and Nonga (2001:17-21), Tewolde *et al.* (2008:504), Vitale *et al.* (2011:154) and Ngwenya (2017:72). The observation that chicken manure increased the yield of the second crop (maize) more than when N, P and K were applied chemically at the same rates could be due to manure supplying other plant nutrients besides N, P and K, to residual N or P effects of the previous application, or to improved soil conditions not provided by chemical fertiliser (Silva *et al*., 2006:166; Zhang & Schroder, 2014:8).

The study results also demonstrated that applying N only to soil was insufficient to maintain optimum crop production. Compared to the CFbr1 treatment in which N, P and K were applied in chemical form at high rates, withholding P reduced crop production more than withholding K but the largest reduction was observed when both P and K were withheld. In the production of the first crop (Chinese cabbage), the negative effect of withholding these two nutrients was not significant but it became significant and substantial in the production of the second crop (maize) providing evidence of a cumulative effect, referred to in the literature as ‘nutrient depletion’ (Dreschel *et al.,* 2001:252) or ‘nutrient mining’ (Henao & Baanante, 2006:1-2).

The study results also draw attention to the difference between N and P when using chicken litter as a fertiliser in crop production. Monitoring of the mineral N content of the soil showed a decline across all treatments over the period of measurement. On the other hand, in the treatments where chicken litter was applied, a progressive rise in the Olson P content of the soil was observed, whilst this was not the case in plots where P was applied as super phosphate. Similar observations were recorded by Sharpley, Smith and Bain (1993:1134), Ramphisa (2015b:100) and Nwite and Alu, 2018:31). Over time, application of chicken manure can lead to excess P in soil, particularly when the manure is applied at rates aimed at meeting the N requirements of the crop (Zhang & Schroder, 2014:2; Kaiser, 2006:57). This was demonstrated by Claassens (1994:145) in KwaZulu-Natal, where repeated application of chicken manure had built up soil P to levels exceeding 800 mg P kg soil^{-1}, causing crop failure.

When access to chicken litter is limited, benefit can be derived by concentrating its application instead of broadcasting. Banding and spot placement of both chicken litter and chemical fertilisers increased biomass production of the two test crops relative to the control and the broadcast treatments. Similar benefits from concentrating fertilisers were reported by Mugwira and Murwira (1997:199), Mkhabela (2003:14) and Okebalama *et al*. (2015:1171). Gowariker *et al.* (2009:247) and Radhika *et al.* (2013:12) postulated that the superior crop production achieved by concentrating applied nutrients was probably due to a reduction in nutrient losses and more rapid root development of the crop, thus enabling the plant to exploit more quickly the nutrients located deeper down in the soil.

3.5. Conclusion

The objectives of this part of the study were to investigate the potential of chicken litter to rapidly restore the fertility of home garden soils in Thulamela, and to assess whether the use of banding or spot placement, also called micro-dosing, of chicken litter was a beneficial strategy for use when access to chicken litter was restricted. Overall, the study demonstrated that by applying chicken litter smallholder farmers and home gardeners in Thulamela can rapidly restore the fertility of soils that have been depleted of nutrients as a result of nutrient mining. The study also showed that chicken litter was a ‘complete fertiliser’, able to supply not only plant available N but also P and K. The findings draw attention to the potential risk of raising P levels to supra-optimal by repetitive use of chicken litter as a fertiliser applied at high rates. Finally, it was found that concentrating chicken litter by band or spot placement was superior to broadcasting this fertiliser, especially when access to fertiliser, such as chicken litter, is limited.

CHAPTER 4

4. GENERAL CONCLUSION

Incorporating animal manure into cultivated soil is the main way in which the majority of South African home gardeners and smallholder farmers replenish the nutrients removed from soil as through crop harvests and other processes. The physical and chemical properties of animal manure vary widely and at this stage knowledge of the different types of manure available in South Africa is inadequate to develop valid and reliable guidelines for farmers and gardeners who use animal manure as a fertiliser. The aim of this study was to contribute to the development of this knowledge. The specific objectives of the study were to determine residual and application rate effects on the nitrogen fertiliser value (NFV) of cattle kraal manure sourced in Thulamela under field conditions, to investigate the potential of chicken litter to rapidly restore the fertility of home garden soils in Thulamela, and to find out whether the use of banding or spot placement of chicken litter was a beneficial strategy for use when access to chicken litter was restricted..

The findings of the work on cattle kraal manure showed that NFV of cattle kraal manure with a first-season NFV of -0.9% reached a value of about 20% in the second-season, indicating a considerable and positive residual effect. Evidence of substantial net mineralisation of N during the two fallow periods between crops was further proof of this residual affect. However, the two annual applications of cattle kraal manure did not prevent a sustained decline in the mineral N content of the soil. Accordingly, when used on its own to maintain or improve soil fertility of cropped land, especially with reference to the N status of the soil, the application of cattle kraal manure as a fertiliser represents a medium to long-term strategy. When immediate increases in N content of the soil are required, N from other sources has to be secured. This could be achieved by applying N in a readily available form, as with the application of chemical fertilisers, or by using a crop rotation that has a leguminous green manure crop as one of the entries. The study also showed that application rate affected the apparent relative NFV of cattle kraal manure. It was found that the second-season NFV of cattle kraal manure ranged between 20 and 22% when manure was applied at rates of 60 kg N ha^{-1} and higher but dropped to 14.5% when manure application rate was reduced to 30 kg N ha^{-1}.

The findings of this study also showed that soils amended with chicken litter sometimes had higher oven-dry biomass yields of tested crops than soils which were amended with chemical fertiliser treatments or without fertiliser application. The result strengthen the view that higher yields can successfully be achieved by smallholder farmers in Thulamela using chicken litter as a fertiliser. This finding has an important implication to the home gardeners of Thulamela as far as immediate restoration of soil fertility is concerned. Chicken litter, which is easily accessible and cheap, is of great value as an 'immediate' source of N, P and other plant nutrients, and has the potential to immediately rise soil fertility and thus increases crop production. The study further revealed that when addressing low soil fertility with limited means, chicken litter or chemical fertiliser could be applied by means of spot placing, also called micro-dosing, whereby the resource (fertiliser) is concentrated in the soil that surrounds the seed or seedling for maximum effect. This implies that it is highly possible for the smallholder farmers in Thulamela to rise soil fertility and thus increase crop production with small quantities of chicken litter in their home gardens. The second part of the study clearly showed that when the soil was amended with chicken litter, mineral N and Olson P concentration increased in the topsoils during the two cropping seasons.

The following recommendations can be made from the results of this study. It is recommended that further work aimed at improving the soil fertility of home gardens in Thulamela assesses social acceptability, impact on the nitrogen economy of garden soils, and economic aspects of supplementing cattle kraal manure with other sources of N, which contain this nutrient in readily available forms, such as chemical fertilisers or use a crop rotation that has a leguminous green manure crop. Since circumstances prevented measurement of the first-season NFV of cattle kraal manure, further research is required to confirm the low first-season NFV of cattle kraal manure that was reported in pot experiments under field conditions. The field experiment needs to be conducted typically on a university farm over a long-term, to measure the residual

N effects of cattle kraal manure. It is also recommended that the design of the field experiment should have sufficient number of replications to enable modelling and increasing the statistical confidence of the results. Furthermore, the review of literature showed that there is a general lack of information on the residual N effect to fertiliser value of cattle kraal manure in South Africa. Since the current study was limited to cattle kraal manure generated by smallholders in Thulamela, there is a need to broaden the enquiry of residual N effect into cattle kraal manure generated in other parts of South Africa. Finally, the implication of the build-up of P in the topsoil where chicken litter was applied twice raises an environmental concern in Thulamela and so the accumulation of P from chicken litter needs to be monitored. The smallholders can also use biologically fixed N obtained by employing a crop rotation that incorporates a legume for use as green manure, and this will minimise P loading.

REFERENCES

ADEBISI, L.O. 2015. Safe rate of application and fertiliser value of kraal manure and Promis poultry manure. M Tech. Agric. dissertation, Pretoria, Tshwane University of Technology.

AGEHARA, S. & WARNCKE, D.D. 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. *Soil science society of America journal,* 69:1844-1855.

ANDERSON, J.M. & INGRAM, J.S.I. 1993. *Tropical soil biology and fertility: a hand book of methods*. Wallingford: Centre for Agriculture and Biosciences International.

ARCHER, J. 1988. *Crop nutrition and fertiliser use*. 2nd ed. Ipswich: Farming Press Ltd.

AZEEZ, J.O. & VAN AVERBEKE, W. 2010. Fate of manure phosphorus in a weathered sandy clay loam soil amended with three animal manures. *Bioresource Technology*, 101:6584-6588.

BAIRD, D., MURRAY, D., PAYNE, R. & SOUTAR, D. 2017. *Introduction to Genstat for windows.* Genstat 19th ed. Rothamsted: VSN International Ltd.

BALKCOM, K.S., BLACKMER, A. M. & HANSEN, D. J. 2009. Measuring soil nitrogen mineralisation under field conditions. *Communications in soil science and plant analysis*, 40:1073-1086.

BANNINK, A. & BOS, J.F.F.P. 2005. Manure quality: can it be manipulated and what are the effects on whole-farm N efficiency? In: Schröder, J.J. & Neeteson, J.J. (eds.). *N management in agrosystems in relation to the water framework directive.* Proceedings of the 14th N workshop, Maastricht, The Netherlands: Plant research international, 24-26 October 2005, 116:123-128.

BARNARD, R.O. & DU PREEZ, C.C. 2004. Soil fertility in South Africa: the last twenty five years. *South African journal of plant and soil,* 21(5):301-313.

BEAH, A. A., NORMAN, P. E., SCHOLBERG, J. C., LANTINGA, E. A. & CONTEH, A. R. 2015. Effect of organic manure on nitrogen mineralisation, nitrogen accumulation, nitrogen use efficiency and apparent nitrogen recovery of cauliflower. *International journal of plant & soil science,* 4(3):265-272.

BEMBRIDGE, T.J. 1984. A systems approach study of agricultural development problems in Transkei. PhD. dissertation, University of Stellenbosch, Stellenbosch.

BIEMOND, H., VOS, J. & STRUIK, P.C. 1995. Effects of nitrogen on development and growth of the leaves of vegetables: appearance, expansion growth and life span of leaves of Brussels sprouts plants. *Netherlands journal of agricultural science,* 43:217-232.

BRADY, N.C. & WEIL, R.R. 2008. *The nature and properties of soils*. 14th ed. New Jersey: Pearson Prentice Hall.

CLAASSENS, A.S. 1994. The influence of varying P concentrations on the yield and abnormalities of lettuce leaves. *South African journal of plant and soil*, 11(3):117-152.

CONNOR, D.J., VAN REES, H. & CARBERRY, P.S. 2015. Impact of systems modelling on agronomic research and adoption of new practices in smallholder agriculture. *Journal of integrative agriculture,* 15:1-17.

CROHN, D. 2004. Nitrogen mineralisation and its importance in organic waste recycling. *Journal of environmental engineering*, 129(12):1149-1156.

CUSICK, P.R., KELLING, K.A., POWELL, J.M. & MUÑOZ, G.R. 2006. Estimates of residual dairy manure nitrogen availability using various techniques. *Journal of environmental quality*, 35(6):2170-2177.

DE MEY, K. 2002. Gebruik en invloed van kraalmest op de fysische bodemvruchtbaarheid in de landelijke gebieden van de Noordelijke Provincie (Zuid-Afrika). Bio-engineer dissertation, Universiteit Gent, Belgium.

DENISON, J., DUBE, S., MASIYA, T.C., MOYO, T., MURATA, C., MPYANE, J., VAN AVERBEKE, L. & VAN AVERBEKE, W. 2016. *Smallholder irrigation entrepreneurial development paths in Limpopo Province, South Africa*. WRC Report No.2179/1/16. Gezina: Water Research Commission.

DIRECTORATE: FOOD SAFETY AND QUALITY ASSURANCE. 2007. *A guide for the control of plant pests.* 40th ed. Pretoria: Department of Agriculture.

DRESCHEL, P., GYIELE, L., KUNZE, D. & COFIE, O. 2001. Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. *Ecological economics*, 38: 251-258.

DU PLESSIS, J. 2003. Maize production. Department of Agriculture, South Africa. Available at www.nda.agric.za/docs/maizeproduction.pdf 21/03/2014. (Accessed 1 February 2016).

DU TOIT, M.E. & DU PREEZ, C.C. 1995. Effect of cultivation on the nitrogen fertility of selected dryland soils in South Africa. *South African journal of plant and soil*, 12:(2):73-81.

EGHBALL, B. & POWER, J.F. 1999. Phosphorus and nitrogen based manure and compost application: corn production and soil phosphorus. *Soil science society of America journal*, 63(4):895-901.

FAGERIA, N.K. & BALIGAR, V.C. 2005. Enhancing nitrogen use efficiency in crop plants. *Advances in agronomy,* 88:97-185.

FERTILISER SOCIETY OF SOUTH AFRICA. 2007. *Fertiliser handbook*. Lynnwood: The Fertiliser Society of South Africa.

FISHEL, F., BAIRLY, W., BOYD, M., JONSON, B., O'DAY., SWEETS, L & WIEBOLD, B. 2001. *Integrated Pest management: Introduction to crop scouting*. Columbia: University of Missouri Extension publications.

GOWARIKER, V., KRISHNAMURTHY, V.N., GOWARIKER, S., DHANORKAR, M. & PARANJAPE, K. 2009. Fertiliser placement. In: *The fertilizer encyclopedia.* John Wiley & Sons, Inc., Hoboken, New Jersey.

HALIMA, H., NESER, F.W.C., VAN MARLE-KOSTER, E. & DE KOCK, A. 2007. Village-based indigenous chicken production system in north-west Ethiopia. *Tropical animal health and production*, 39(3):189-197.

HENAO, J. & BAANANTE, C. 2006. *Agricultural production and soil nutrient mining in Africa: implications for resource conservation and policy development*. Muscle Shoals: IFDC.

HIJBEEK, R., TEN BERGE, H.F.M., WHITMORE, A.P., BARKUSKY, D., SCHRODER, J.J. & VAN ITTERSUM, M.K. 2018. Nitrogen fertiliser replacement values for organic amendments appear to increase with N application rates. *Nutrient cycling in agroecosystems*, 110:105-115.

JORDAN-MEILLE, L. & PELLERIN, S. 2004. Leaf area establishment of a maize (*Zea Mays* L.) field crop under potassium deficiency. *Plant and soil*, 265:75-92.

KAISER, D.E. 2006. Use of poultry manure as a phosphorus source for corn production in Iowa. PhD. thesis, Iowa State University, Ames, Iowa.

KUMWENDA, J.D.T., WADDINGTON, S.R., SNAPP, S.S., JONES, R.B. & BLACKIE, M.J. 1996. *Soil fertility management research for the maize cropping systems of smallholders in Southern Africa: A review*. Mexico, DF: Natural Resources Group.

KUMWENDA, J.D.T., WADDINGTON, S.R., SNAPP, S.S., JONES, R.B. & BLACKIE, M.J. 1997. Soil fertility management in Southern Africa. In: Byerlee, D. & Eicher, C.K. (eds.). *Africa's emerging maize revolution*. Boulder, Colorado, United States of America: Lynne Rienner:153-172.

KUMAR, K. & GOH, K.M. 2003. Nitrogen release from crop residues and organic amendments as affected by biochemical composition. *Communications in soil science and plant analysis*, 34(17&18):2441-2460.

LAKER, M.C. 2008. Challenges to soil fertility management in the third major soil region of the world, with special reference to South Africa. In: Haneklaus, S., Hera, C., Rietz, R.-M. & Schnug, E. (eds.). *Fertilisers and fertilisation for sustainability in agriculture: The First World meets the Third World - Challenges for the future*. Lasi (Romania): Terra Nostra:309-349.

LEHOHLA, P. 2016. *Community survey 2016: Agricultural households*. Pretoria: Statistics South Africa.

LOUSTAU, D., HUNGATE, B. & DRAKE, B.G. 2001. Water, nitrogen, rising atmospheric carbon dioxide and terrestrial productivity. In: Roy, J., Saugier, B & Mooney, H.A. (eds.). *Terrestrial global productivity.* San Diego: Academic press:123-168.

MAERERE, A.P., KIMBI, G.G & NONGA, D.L.M. 2001. Comparative effectiveness of animal manures on soil chemical properties, yield and root growth of amaranthus *(Amaranthus cruentus L.). Asian journal of science and technology*, 1(4):14-21.

MANDIRINGANA, O.T., MNKENI, P.N.S., MKILE, Z. VAN AVERBEKE, W. VAN RANST, E. & VERPANCKE, H. 2005. Mineralogy and fertility status of selected soils of the Eastern Cape province, South Africa. *Communications in soil science and plant analysis,* 36:2431-2446.

MANANZE, S.E., PÔÇAS, I. & CUNHA, M. 2018. Maize leaf area estimation in different growth stages based on allometric descriptors. *African journal of agricultural research,* 13(4):202-209.

MATERECHERA, S.A. 2010. Utilization and management practices of animal manure for replenishing soil fertility among small scale crop farmers in semi-arid farming districts of the North West Province, South Africa. *Nutrient cycling in agroecosystems*, 87:415-428.

MATERECHERA, S.A. & MODIAKGOTLA, L.N. 2006. Cattle manure increases soil weed population and species diversity in a semi-arid environment. *South African journal of plant and soil*, 23(1):21-28.

MATERECHERA, S.A. & MORUTSE, H.M. 2009. Response of maize to phosphorus from fertiliser and chicken manure in a semi-arid environment of South Africa. *Experimental agriculture,* 45:261-273.

MKHABELA, T.S. 2002. Determinants of manure use by small-scale crop farmers in the KwaZulu-Natal Province: A logit analysis. *Agrekon* 41(1):24-42.

MKHABELA, T.S. 2003. *The economics of using manure stored under two different systems for crop production by small-scale farmers in KwaZulu-Natal*. Pretoria: Contributed paper presented at the 41st annual conference of the Agricultural Economic Association of South Africa (AEASA), 1-15.

MKHABELA, T.S. & MATERECHERA, S.A. 2003. Factors influencing the utilization of cattle and chicken manure for soil fertility management by emergent farmers in the moist Midlands of KwaZulu-Natal Province, South Africa. *Nutrient cycling in agroecosystems,* 65:151-162.

MKHABELA, T.S. 2006. A review of the use of manure in small-scale crop production systems in South Africa. *Journal of plant nutrition*, 29:1157-1185.

MKILE, Z. 2001. The use and agronomic effectiveness of kraal manures in the Transkei region of the Eastern Cape, South Africa. M.Sc. dissertation, University of Fort Hare.

MOELETSI, M.E., MPANDELI, N.S. & MELLAART, E. 2011. Crop water satisfaction analysis for maize trial sites in Makhado during the 2007/2008 season. In: Attri, S.D., Rathore, L.S., Sivakumar, M.V.K. & Dash, S.K. (eds.). *Challenges and opportunities in agrometeorology*. Berlin Heidelberg: Springer:485-490.

MORRIS, M., KELLY, V.A., KOPICKI, R.J. & BYERLEE, D. 2007. *Fertiliser use in African agriculture: Lessons learned and good practice guidelines*. Washington, DC: World Bank.

MOSWETSI, G., FANADZO, M. & NCUBE, B. 2017. Cropping systems and agronomic management practices in smallholder farms in South Africa: Constraints, challenges and opportunities. *Journal of agronomy*, 16:51-64.

MPYANA, J.M. 2017. Home gardening and livelihoods of households in Manamani and Itsani, Thulamela local Municipality, South Africa. M Tech. Agric. dissertation, Pretoria, Tshwane University of Technology.

MTHIMKULU, N.P. 2019. Nitrogen and phosphorus fertiliser value of selected compost samples from Thulamela local Municipality, South Africa. M Tech. dissertation, Pretoria, Tshwane University of Technology.

MTILENI, B.J., MUCHADEYI, F.C., MAIWASHE, A., GROENEVELD, E., GROENEVELD, L.F., DZAMA, K. & WEIGEND, S. 2011. Genetic diversity and conservation of South African indigenous chicken populations. *Journal of animal breeding and genetics*, 128(3):209-218.

MUGWIRA, L.M. & MURWIRA, H.K. 1997. A review of research on cattle manure as a soil fertility amendment in Zimbabwe: some perspectives. In: Waddington, S.R., Murwira, H.K., Kumwenda, J.D.T., Hikwa, D. & Tagwira, F. (eds.). *Soil fertility research for maize-based farming systems in Malawi and Zimbabwe.* Proceedings of the Soil Fertility Net Results and Planning Workshop held from 7 to 11 July 1997 at Africa University, Mutare, Zimbabwe, 195-201.

MUÑOZ, G.R., KELLING, K.A., POWELL, J.M. & SPETH, P.E. 2004. Comparison of estimates of first-year dairy manure nitrogen availability or recovery using nitrogen-15 and other techniques. *Journal of environmental quality*, 33:719-727.

MURWIRA, K.H., SWIFT, M.J. & FROST, P.G.H. 1995. Manure as a key resource in sustainable agriculture. In: Powell, J.M., Fernández-Rivera, S., Williams, T.O. & Renard, C. (eds.). *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, Vol II: Proceedings of an International Conference held in Addis Ababa, Ethiopia, 22–26 November 1993*. Addis Ababa, Ethiopia: International Livestock Centre for Africa (ILCA):131-148.

MURUGAN, A.V. & SWARNAM, T.P. 2013. Nitrogen release pattern from organic manures applied to an acid soil. *Journal of agricultural science*, 6:174-184.

MYINT, A.K., YAMAKAWA, T., ZENMYO, T., THAO, H.T.B. & SARR, P.S. 2011. Effects of organic-manure application on growth, grain yield, and nitrogen, phosphorus, and potassium recoveries of rice variety Manawthuka in paddy soils of differing fertility. *Communications in soil science and plant analysis*, 42(4):457-474.

NÄSHOLM, T., HUSS-DANELL, K. & HOGBERG, P. 2000. Uptake of organic nitrogen in the field by four agriculturally important species. *Ecology*, 81:1155-1161.

NÄSHOLM, T., KIELLAND, K. & GANETEG, U. 2009. Uptake of organic nitrogen by plants. *New phytologist*, 182:31-48.

NETHONONDA, L.O., ODHIAMBO, J.J.O. & PATERSON, D.G. 2012. Assessment of spatial variability of selected soil chemical properties in a communal irrigation scheme under resource-poor farming conditions in Vhembe District of Limpopo Province, South Africa. *African journal of agricultural research,* 7(39):5438-5445.

NEVENS, F. & REHEUL, D. 2005. Agronomical and environmental evaluation of a long-term experiment with cattle slurry and supplemental inorganic nitrogen applications in silage maize. *European journal of agronomy,* 22:349-361.

NGWENYA, Z.D. 2017. Nitrogen fertiliser value of three types of animal manure sourced from Thulamela, Limpopo Province, South Africa. M Tech. Agric. dissertation, Pretoria, Tshwane University of Technology.

NHAMO, N., KINTCHE, K. & CHIKOYE, D. 2017. Advancing key technical interventions through targeted investment. In: Nhamo, N., Chikoye, D. & Gondwe, T. (eds.). *Smart technologies for sustainable smallholder agriculture: upscaling in developing countries*. London: Academic Press:39-79.

NORRIS, D., NGAMBI, J.W., BENYI, K., MAKGAHLELA, M.L., SHIMELIS, H.A. & NESAMVUNI, E.A. 2007. Analysis of growth curves of indigenous male Venda and Naked Neck chickens. *South African journal of animal science,* 37(1):21-26.

NWITE, J.N. & ALU, M.O. 2018. Evaluation of different rates of poultry manure on soil properties and grain yield of maize in a typic haplustult in Abakaliki, Southeastern Nigeria. *Global journal of agricultural research,* 6(4):24-35.

ODHIAMBO, J.J.O. & MAGANDINI, V.N. 2008. An assessment of the use of mineral and organic fertilisers by smallholder farmers in Vhembe district, Limpopo province, South Africa. *African journal of agricultural research,* 3(5):357-362.

OKALEBO, J.R., OTHIENO, C.O., WOOMER, P.L., KARANJA, N.K., SEMOKA, J.R.M., BEKUNDA, M.A., MUGENDI, D.N., MUASYA, R.M., BATIONO, A. & MUKHWANA, E.J. 2006. Available technologies to replenish soil fertility in East Africa. *Nutrient cycling in agroecosystems,* 76:153-170.

OKEBALAMA, C.B., IBRAHIM, A., SAFO, E.Y., YEBOAH, E., ABAIDOO, R.C., LOGAH, V. & UZOH I.M. 2015. Fertiliser micro-dosing in West African low-input cereals cropping: Benefits, challenges and improvement strategies. *African journal of agricultural research,* 12(14):1169-1176.

PAUL, J.W. & BEAUCHAMP, E.G. 1993. Nitrogen availability for corn in soils amended with urea, cattle slurry, and solid and composted manures. *Canadian journal of soil science,* 73:253-266.

PAUL, J.W. & BEAUCHAMP, E.G. 1995. Availability of manure slurry ammonium for corn using ^{15}N-labelled $(NH_4)_2S0_4$. *Canadian journal of soil science,* 75:35-42.

PRATT, P.F., BROADBENT, F.E. & MARTIN, J.P. 1973. Using organic wastes as nitrogen fertilisers. *California Agriculture,* 27:10-13.

RADHIKA, K., HEMALATHA, S., MARAGATHAM, S. & PRAVEENA KATHRINE, S. 2013. Placement of nutrients in soil: A review. *Journal of agriculture and allied sciences,* 2:12-19.

RALIVHESA, K., VAN AVERBEKE, W., HLUNGWANE, C., SIEBRITS, F.K., ADEBISI, L.O., RAMPHISA, P.D., OKOROGBONA, A.O.M., AZEEZ, J.O. & RAMUSANDIWA, T.D. 2013. Integrating crop and animal production: Grain and poultry. In: Van Averbeke, W. (ed. & comp.). *Improving plot holder livelihood and scheme productivity on smallholder canal irrigation schemes in the Vhembe District of Limpopo Province*. Water Research Commission Report TT 535/12. Gezina: The Water Research Commission: 279-357.

RAMARU, J., MAMABOLO, Z. & LEKGORO, J. 2000. *Improving soil fertility management in South Africa: Learning through participatory extension approaches.* Managing Africa's soils no.19. Nottingham: Russell press.

RAMPHISA, P.D. 2015a. Soil quality of South African home gardens: The case of Manamani village, Limpopo Province. MSc. dissertation, Ghent University.

RAMPHISA, P.D. 2015b. The effect of animal manure application rate on the concentration of $NH4^+$-N, $NO3^-$-N and plant available P and K in the soil over time. M Tech. Agric. dissertation, Pretoria, Tshwane University of Technology.

RUIZ DIAZ, D.A., SAWYER, J.E. & MALLARINO, A.P. 2011. On-farm evaluation of poultry manure as a nitrogen source for corn. *Soil science society of America journal,* 75:729-737.

SANCHEZ, P.A., SHEPHERD, K.D., SOULE, M.J., PLACE, F.M., BURESH, R.J., IZAC, A.N., MOKWUNYE, A.U., KWESIGA, F.R., NDIRITU, C.G. & WOMER, P.L. 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh, R.J., Sanchez, P.A. & Calhoun, F. (eds.). *Replenishing soil fertility in Africa*. Madison: Soil Science Society of America:1-46.

SANCHEZ, P.A. 2002. Soil fertility and hunger in Africa. *Science*, 295:2019-2020.

SCHRÖDER, J. 1998. Towards improved nitrogen management in silage maize production on sandy soils. PhD. thesis, Wageningen University, Wageningen, The Netherlands.

SCHRÖDER, J.J., JANSEN, A.G. & HILHORST, G.J. 2005. Long-term nitrogen supply from cattle slurry. *Soil use and management,* 21:196-204.

SCHRÖDER, J.J., UENK, D. & HILHORST, G.J. 2007. Long-term nitrogen fertilizer replacement value of cattle manures applied to cut grassland. *Plant and soil,* 299:83-99.

SHACKLETON, C.M., SHACKLETON, S.E & COUSINS, B. 2001. The role of land based strategies in rural livelihoods: The contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. *Development Southern Africa,* 18:581-604.

SHAH, G.M., SHAH, G.A., GROOT, J.C.J., OENEMA, O., RAZA, A.S. & LANTINGA, E.A. 2015. Effect of storage conditions on losses and crop utilization of nitrogen from solid cattle manure. *Journal of agricultural science,* 1-14.

SHARPLEY, A.N., SMITH, S.J. & BAIN, W.R. 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils*. Soil science society of America journal,* 57:1131-1137.

SEZER, I., ONER, F. & MUT, Z. 2009. Non-destructive leaf area measurement in maize (Zea mays L.). *Journal of environmental biology,* 30(5):785-790.

SILVA, P.S.L., SILVA, J., OLIVEIRA, F.H.T., SOUSA, A.K.F., DUDA, G.P. 2006. Residual effect of cattle manure application on green ear yield and corn grain yield. *Horticultura brasileira,* 24:166-169.

SIMS, J.T. & WOLF, D.C. 1994. Poultry manure management: agricultural and environmental issues. *Advances in agronomy,* 52:1-74.

SNAPP, S.S., MAFONGOYA, P.L. & WADDINGTON, S. 1998. Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agriculture, ecosystems and environment,* 71:185-200.

SOIL CLASSIFICATION WORKING GROUP. 1991. Soil Classification: A taxonomic system for South Africa. Pretoria: Department of Agricultural Development.

SUTHAMATHY, N & SERAN, T.H. 2013. Residual effect of organic manure EM Bokashi applied to proceeding crop of vegetable cowpea (*Vigna unguiculata*) on succeeding crop of radish (*Raphanus sativus). Research journal of agriculture and forestry sciences,* 1(1):2-5.

TEWOLDE, H., SHANKLE, M.W., SISTANI, K.R., ADELI, A. & ROWE, D.E. 2008. No-till and conventional-till cotton response to broiler litter fertilisation in an upland soil: lint yield. *Agronomy journal,* 100(3):502-509.

TEWOLDE, H. & SISTANI, K.R. 2014. Cotton production improvement and environmental concerns from poultry litter application in southern and south-eastern USA soils. In: He, Z. & Zhang, H. (eds.). *Applied manure and nutrient chemistry for sustainable agriculture and environment*. London: Springer Science:355-369.

VAN AVERBEKE, W. 1991. The effect of planting density on the water use efficiency by maize. D.Sc. (Agric.) thesis, University of Fort Hare, Alice.

VAN AVERBEKE, W. 2008. *Best management practices for small-scale subsistence farming on selected irrigation schemes and surrounding areas through participatory adaptive research in Limpopo Province.* WRC Report TT344/08. Gezina: Water Research Commission.

VAN AVERBEKE, W. & NETSHITHUTHUNI, C. 2010. Effect of irrigation scheduling on leaf yield of non-heading Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*). *South African journal of plant and soil,* 27(4):322-327.

VAN AVERBEKE, W., MBULI, S.S., NETSHITHUTHUNI, N.C., CHABALALA, M.P. & OKOROGBONA, A.O.M. 2013. Irrigation scheduling on canal schemes. In: Van Averbeke, W. (ed.). *Improving plot holder livelihood and scheme productivity on smallholder canal irrigation schemes in the Vhembe District of Limpopo Province*. WRC Report TT566/13. Gezina: Water Research Commision:181-212.

VAN BILJON, J.J., FOUCHE, D.S. & BOTHA, A.D.P. 2008. The lower and upper threshold values, biological optimum and mineralisation of nitrogen in the main maize producing soils of South Africa. *South African journal of plant and soil,* 25(1):8-13.

VAN FASSEN, H.G. & VAN DIJK, H. 1987. Manure as a source of nitrogen and phosphorus in the soil. In: van der Meer, H.G., Unwen, R.J., van Dijk, T.A. & Ennik, G.C. (eds.). *Animal manure on grassland and fodder crops: Fertiliser or waste? Development in plant and soil sciences*. Dordrecht, The Netherlands: Martinus Nijhoff Publishers:27-45.

VITALE, J.D., PENN, C., PARK, S., PAYNE, J., HATTEY, J. & WARREN, J. 2011. Animal manure as alternatives to commercial fertilisers in the southern high plains of the United States: how Oklahoma can manage animal waste. In: Sunil Kumar, ER. (ed.). *Integrated waste management*: *Vol II:* Rijeka, Croatia: InTech publishers:143-164.

WAITHAKA, M.M., THORNTON, P.K., SHEPTHERD, K.D. & NDIWA, N.N. 2007. Factors affecting the use of fertilisers and manure by smallholders: the case of Vihiga, western Kenya. *Nutrient cycling in agroecosystems,* 78:211-224.

WATTS, D.B. & TORBERT, H.A. 2014. Nitrogen mineralisation in soils amended with manure as affected by environmental conditions. In: He, Z. & Zhang, H. (ed.). *Applied manure and nutrient chemistry for sustainable agriculture and environment*. London: Springer Science:83-98.

WEBB, J., SØRENSEN, P., VELTHOF, G., AMON, B., PINTO, M., RODHE, L., SALOMON, E., HUTCHINGS, N., BURCZYK, P. & REID, J. 2013. An assessment of the variation of manure nitrogen efficiency throughout Europe and an appraisal of means to increase manure N efficiency. In: Donald, S. (ed.). *Advances in agronomy,* 119:371-442.

WILKINSON, S.R. 1979. Plant nutrient and economic value of animal manures. *Journal of animal science,* 48(1):123-133.

YOGANATHAN, S., SOTANA, M.M., VAN AVERBEKE, W., MANDIRINGANA, O.T., MATERECHERA, S., HARRIS, P.C.J. & MNKENI, P.S. 1998. Kraal manure as a fertiliser in small scale crop production in central Eastern Cape, South Africa. 15th International Symposium of the AFSRE, 29 November - 4 December 1998. *Proceedings*, Vol 1:361-368.

ZECH, W., SENESI, N., GUGGENBERGER, G., KAISER, K., LEHMANN, J., MIANO, T.M., MILTNER, A., & SCHROTH, G. 1997. Factors controlling humification and mineralisation of soil organic matter in the tropics. *Geoderma,* 79(1):117-161.

ZHANG, H. & SCHRODER, J. 2014. Animal manure production and utilization in the US. In: He, Z. & Zhang, H. (ed.). *Applied manure and nutrient chemistry for sustainable agriculture and environment*. London: Springer:1-22.

ZHAO, D., RAJA REDDY, K., KAKANI, V.G. & REDDY, V.R. 2005. Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. *European journal of agronomy,* 22:391-403.

ZINGORE, S., NJOROGE, S., CHIKOWO, R., KIHARA, J., NZIGUHEBA, G. & NYAMANGARA, J. 2014. *4R plant nutrient management in African agriculture: An extension handbook for fertiliser management in smallholder farming systems*. Nairobi, Kenya: International Plant Nutrition Institute (IPNI).