EFFECTS OF SHEEP KRAAL MANURE AND INTERCROPPING WITH MAIZE ON GROWTH, NUTRIENT UPTAKE AND YIELD OF A VEGETABLE *AMARANTHUS* ACCESSION IN THE CENTRAL REGION OF THE EASTERN CAPE, SOUTH AFRICA

SIMPHIWE MHLONTLO

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BY

SIMPHIWE MHLONTLO

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Department of Agronomy, Faculty of Science and Agriculture

University of Fort Hare, Alice

Supervisors:

Dr. P. Muchaonyerwa

Professor P. N. S. Mnkeni

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DECLARATION

I, Simphiwe Mhlontlo, hereby declare that this dissertation is the result of my own original work, unless where specifically indicated in the text, and acknowledgement is made to the work of others.

Dated…………..this day of…....……….2008

Signed ……………………......

S. Mhlontlo

Place: University of Fort Hare, Alice

DEDICATION

This work is dedicated to my parents **Chaplain Luvuyo** and **Virginia Ntombikayise Mhlontlo.**

*“Because of what you have done, the ground will be under curse. You will have to **work hard** all your life to make it **produce enough food** for you. It will produce weeds and thorns, and you will have to **eat wild plants**”*

Genesis 3: 17-18 (Today’s English Version)

ABSTRACT

Amaranthus is among the nutritious indigenous plant species that are gathered from the wild in the Eastern Cape to prepare a traditional meal known as '*imifino'* or '*isigwampa'* to supplement the necessary proteins, vitamins and minerals which are poor in maize-based meals. *Amaranthus* species are adapted to wild conditions unsuitable for exotic vegetables and could be cultivated but information on its fertility requirements, as sole or intercrop, is the key for its domestication and production as a leafy vegetable, particularly where manure is used. Two dry-land and one glasshouse experiments were conducted to study the effects of sheep kraal manure application rate, intercropping with maize and soil type on growth, fresh and dry matter yields, nutrient uptake and grain yield of a local *Amaranthus* accession that grows wild in the Eastern Cape. Sheep kraal manure rates ranging from 0 to 10 t ha^{-1} and an NPK {2:3:4(30) + 0.5% Zn} fertilizer as a positive control, applied at rates recommended for spinach, were tested.

In the Gqumahashe experiment, where *Amaranthus* was grown as a sole crop, low manure rates ($\leq$ 2.5 t ha^{-1}) resulted in plant heights and fresh matter yields which were comparable to those in the unfertilized control, whereas higher rates (5 and 10 t ha^{-1}) and recommended NPK fertilizer had higher levels both at 30 and 60 days after transplanting (DAT) at $p < 0.05$. At 30 DAT, manure application rates of $\geq$ 2.5 t ha^{-1} and the NPK fertilizer treatment, produced greater shoot dry-matter yields (29.35, 30.75 and 37.68 g $plant^{-1}$) than the unfertilized control (17.11 g $plant^{-1}$) at $p < 0.05$. Uptake of N and P in the leaves increased with increase in manure application rate with N uptake reaching a maximum (308 mg $plant^{-1}$) at a manure rate of 2.5 t ha^{-1} which corresponded with the maximum dry matter yield. There was no effect of manure rate or fertilizer on residual soil N and Ca, whereas P, K, Mg and Zn increased.

In a pot experiment with soils from Ntselamanzi and Gqumahashe Villages, manure rates $\geq$ 2.5 t ha^{-1} resulted in plant heights and fresh matter yield that compared well with the NPK fertilizer treatment in the Gqumahashe soil whereas only the 10 t ha^{-1} manure treatment was comparable to the NPK fertilizer treatment in the Ntselamanzi soil. Only treatments with ≥ 5 t ha^{-1} manure had stem girth (1.00 and 1.07 cm) that compared well to NPK fertilizer (1.03 cm) in the Ntselamanzi soil whereas in the Gqumahashe soil, all manure levels compared well to NPK fertilizer (1.02 cm). However, no significant difference was observed in plant height and stem girth and fresh matter due to soil type. In both soils, the 1.3-10 t ha^{-1} manure treatments had dry leaf weight comparable to plants fertilized with NPK fertilizer (3.72 g $plant^{-1}$ for the Ntselamanzi soil and 3.65 g $plant^{-1}$ for the Gqumahashe soil) and were bigger than the unfertilized control (2.2 g $plant^{-1}$ for the Ntselamanzi soil and 1.38 g $plant^{-1}$ for the Gqumahashe soil) at $p < 0.05$. Uptake of N, P and K increased as result of manure application but nonetheless, it was less when compared to plants fertilized with NPK fertilizer in both soils.

In a field intercropping experiment carried out at Ntselamanzi, growth and yield of sole and intercropped *Amaranthus* plants grown with manure improved when compared to the unfertilized control and compared well to NPK fertilizer. At 30 days after transplanting (DAT), both sole and intercropped plants grown with ≥ 2.5 t ha^{-1} manure had fresh and dry matter yield comparable to plants fertilized with NPK fertilizer. At 60 DAT, intercropped plants grown with all manure levels had bigger fresh matter yield when compared to unfertilized control (836.0 g $plant^{-1}$) whereas for sole cropped plants only those grown with ≥ 2.5 t ha^{-1} compared to NPK fertilizer (1467.7 g $plant^{-1}$) at $p < 0.05$. Uptake of N, P, K, Ca and Mg increased with increase in manure application in both sole and intercropped *Amaranthus*. Whereas *Amaranthus* did not suffer from the competition in the intercrop, maize biomass and grain yield were severely reduced with the effects being evident after 60 DAT. Based on results of this study, it is therefore suggested that, if *Amaranthus* is to be intercropped with maize under dry land conditions of the Central Region of the Eastern Cape, sheep manure should at least be applied at rate of ≥ 2.5 t ha^{-1} and *Amaranthus* be harvested at 30 DAT.

Keywords: *Amaranthus* accession, dry matter, intercropping, maize grain yield, nutrient composition, residual soil nutrients, sheep kraal manure

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ACRONYMS

ANOVA	-	Analysis of Variance
ARC	-	Agricultural Research Council
ARDRI	-	Agricultural and Rural Development Research Institute
CCETSA	-	Cannon Collins Education Trust of Southern Africa
CS	-	Cropping System
CV	-	Coefficient of Variation
DAT	-	Days after transplanting
df	-	Degrees of freedom
g	-	gram
Gqu	-	Gqumahashe
ha	-	hectare
LER	-	Land Equivalent Ratio
LSD	-	Least Significant Difference
LWP	-	Leaf water potential
mg	-	milligram
m	-	metre
Ntse	-	Ntselamanzi
NRF	-	National Research Foundation
OC	-	Organic Carbon
RCBD	-	Randomized Complete Block Design
RWC	-	Relative Water Content
t	-	ton

CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL INTRODUCTION

Modern agriculture has grown to be a major contributor to the economy of the world. However, in many countries, it has not done enough in addressing key issues of hunger and malnutrition (Aphane *et al*., 2003). Major causes of hunger and malnutrition in the world are not only growing population and decline in crop yields but also destruction of natural plant resources and loss of food diversity (Dresher, 1997). Health problems associated with malnutrition are experienced more in developing countries and have consequences on growth, development and health among children (Aphane *et al*., 2003). This problem threatens millions of people in sub-Saharan Africa, with 20% or more of the communities suffering from food insecurity (Jansen van Rensburg *et al*., 2004).

Foods of animal origin, which are known to be the major source of vitamins and proteins are, in most cases, too expensive for poor households (Aphane *et al*., 2003; Wehmeyer and Rose, 1983). Vegetables could alternatively play a major role in alleviating problems associated with malnutrition as they could supply enough proteins, vitamins, calories and other nutrients needed in a balanced diet (Van den Heever, 1995; Wehmeyer and Rose, 1983). However, harsh climatic and resources-poor conditions encountered in rural areas, where the problem of malnutrition occurs, make production of exotic vegetables difficult whereas a number of indigenous and traditionally grown plant species could tolerate these conditions (Van den Heever, 1995; Allenman *et al*., 1996). Most indigenous plants are adapted to the prevailing conditions and, when domesticated, require few agricultural inputs and perform well in areas unsuitable for introduced vegetables (Aphane *et al*., 2003).

The most widely consumed of the more than 100 different indigenous leafy vegetable species occurring in South Africa are *Amaranthus* species, melons and cowpeas (Jansen van Rensburg *et al*., 2004; Laker, 2007). Communities such as in the former Transkei, South Africa, gather their leaves from the wild, chop and mix with maize meal to prepare a traditional meal known as '*imifino*' or '*isigwampa*' (Wehmeyer and Rose, 1983).

When cooked as '*imifino'*, the indigenous leafy vegetables supplement the necessary proteins, minerals and vitamins, of which maize is a very poor source (Wehmeyer and Rose, 1983). *Amaranthus* leaves contain 17.5 – 38.3 % protein of which 5 % is lysine; an essential amino acid that is lacking in most diets based on cereals and tubers (Kauffman and Weber, 1990; Mnkeni, 2005). Lysine plays a vital role in the treatment and prevention of a disease known as *osteoporosis* that makes bones prone to fracture (Anonymous, 2006). When compared to spinach, *Amaranthus* contains 3 times more vitamin C, calcium, iron and niacin. It contains 18 times more vitamin A, 20 times more calcium and 7 times more iron when compared to lettuce (Mnkeni 2005; Makus, 1984).

Amaranthus is a C4 plant that has often been referred to as drought tolerant (Liu and Stutzel, 2002). The crop is often grown on acid, marginal soils under subsistence conditions (Foy and Campbell, 1984). Whitehead and Singh (1993) cited by Liu and Stutzel (2002) reported that in sandy-loam soil, the crop can perform very well over a 6 –

18 % soil moisture range indicating an ability to perform in low soil moisture environments. According to Palada and Chang (2003), *Amaranthus* grows best in loam or silty-loam soil with good water holding capacity although it can also grow on a wide range of soil types and soil moisture levels and can tolerate a soil pH between 4.5 and 8.0. *Amaranthus* is also known to be a low management crop that can grow in poor soils but studies have shown that its yields could be improved by application of fertilizers (Palada and Chang, 2003). Myers (1998) and Schippers (2000) reported that like any other crop, *Amaranthus* responds well to good soil fertility and organic matter.

Laker (1976), reported that most soils in former homelands of South Africa have very low fertility status. In the Central Region of the Eastern Cape, soils contain low to very low amounts of plant nutrient elements except S, Mn, Zn, Cu and B (Mandiringana *et al*., 2005; Mkile, 2001). The production potential of these soils is often limited by such factors as low infiltration rate, soil compaction, acidity, phosphorus, nitrogen and sometimes potassium deficiencies and low organic carbon contents (van Averbeke *et al*., 2000; Mnkeni and Mkile, 2006). In the former Ciskei, poor soil fertility could be associated with practices of monoculture and continuous cropping which results in removal of nutrients with nothing being returned to the soil whether in the form of chemical fertilizer or manure (Mandiringana *et a*l., 2005; Mkile, 2001).

Most small-scale farmers in the Eastern Cape grow maize (*Zea mays* L.) as a dominant crop and use kraal manure to address problems of declining soil fertility (van Averbeke and de Lange, 1995; Mafu, 2006; Mnkeni and Mkile, 2006). Silwana (2000) reported that farmers in the Transkei region intercrop maize with crops such as beans and pumpkins. This practice could be used if *Amaranthus* could be adopted in that region. Intercropping may broaden the household availability of nutrients as two or more crops are planted in the same piece of land (Mukhala *et al*., 1999). It could also result in more efficient use of land as it has been demonstrated that more land is required in mono-cropping than intercropping to produce the same yield per unit area (Mukhala *et al*., 1999).

Willey (1979) reported that higher yields are usually obtained from intercropping because the component crops are in some way able to utilize growth resources such as light, nutrients and water rather differently, so that when grown together they complement each other and make better overall use of resources than when grown alone. Moreover, intercropping provides more household nutrients per unit area when compared to mono-cropping (Mukhala *et al*., 1999). *Amaranthus* is among the crops which, when intercropped with maize, could improve the nutrient status of the households because of its nutritional value, adaptability to hot, dry climate and its potential for acceptance by processors, seed men and growers (Makus, 1984; Liu and Stűtzel, 2004, Spreeth *et. al*., 2004). No information could be found on intercropping of *Amaranthus* with maize in the Eastern Cape using kraal manure as a source of nutrients but Early (1990) and Apaza-Gutierrez (2002) citing Guillen–Portal (1992b) reported that farmers in Andean region and Bolivia have successfully intercropped *Amaranthus* with maize (*Zea mays* L.). Studies were carried out to establish the fertility requirements, using sheep kraal manure, of a vegetable *Amaranthus* accession, as sole and intercropped with maize in the Central region of the Eastern Cape, South Africa.

1. 2 HYPOTHESES

(a) Sheep kraal manure application has no effect on growth, fresh and dry matter yields and nutrient uptake of *Amaranthus* in the Central Eastern Cape

(b) Neither soil type nor sheep manure application rates has effect on growth, fresh and dry matter yields and nutrient uptake of *Amaranthus*

(c) Growth, fresh and dry matter yields and nutrient uptake of *Amaranthus* are not affected by sheep manure application when intercropped with maize

1.3 OBJECTIVES

The objectives of the study were to:

(a) determine the effects of sheep kraal manure application rates on growth, fresh and dry matter yields and nutrient uptake of *Amaranthus* in Central Eastern Cape;

(b) evaluate the effects of sheep kraal manure application rates and soil type on growth, fresh and dry matter yields and nutrient uptake of *Amaranthus*

(c) determine the effects of sheep kraal manure application rates and intercropping with maize on growth, fresh and dry matter yields and nutrient uptake of *Amaranthus.*

1.4 LITERATURE REVIEW

1.4.1 BOTANY OF *AMARANTHUS*

Although it is obscure, *Amaranthus*' centre of origin is believed to be Central America but it has spread to other countries such as India, Nepal, China, Europe, Asia and Africa (Putman *et al*., 1989; Myers, 1998, Mposi, 1999). *Amaranthus* is a dicotyledonous plant that carries on photosynthesis by specialized C_4 carbon-fixation pathway, in which the first photosynthesis product is a four carbon-compound (National Research Council, 1984; Stallknecht and Schulz-Schaeffer, 1993; Myers, 1998; Ribeiro and Combrink, 2006). The process of C_4 carbon fixation is used by few fast growing crops such as maize, sorghum and sugarcane where they use an especially efficient type of photosynthesis to convert the raw materials of soil, sunlight and water into plant tissues. Plants that use the C_4 carbon fixation pathway tend to require less water than the more common C_3 carbon-fixation pathway plants (National Research Council, 1984). The combination of *Amaranthus* features, such as well developed root system, stomatal conductance, maintenance of leaf area and C_4 metabolism results in increased efficiency to use CO_2 under a wide range of temperatures, moisture stress environments and enables plant to adapt under wide geographic and environmental conditions. This is the reason why *Amaranthus* performs well under adverse temperature and moisture conditions as compared to many C3 plants such as wheat and soybeans (Schippers, 2000; Stallknecht and Schulz-Schaeffer, 1993; Spreeth *et al*. 2004).

The family *Amaranthaceae* has more than 800 species of which about 60 are considered weedy and about 50 are consumed as pot-herbs or leafy vegetables worldwide (Olufaji, 1989; Janick, 1997). Schippers (2000) noted that all species found in Africa are grown for their leaves. Some varieties were introduced from America for grain production but this is not very popular in Africa. Three principal species considered for grain production are *A. hypochondriaachus* (L.), *A. cruentus* (L.), and *A. caudatus* (L.) (Jansen van Rensburg *et al*., 2004; National Research Council, 1984). There is no distinct separation between vegetable and grain type species since even the leaves of young grain type plants can be eaten as leafy vegetables. The most popular leafy species are *A. hypochondriacus* (L.), *A. tricolor* (L.), *A. hybridus* (L.), and *A. blitum* (L.) (Jansen van Rensburg *et al*., 2004; National Research Council, 1984) and the most frequently cultivated species in Asia is *A. tricolor* (L.) but is hardly ever seen in Africa (Schippers, 2000). *Amaranthus* species have been separated into four principal groups: cultivated (improved species or cultivars), wild and weedy (growing in the veld), racial (based on geographic morphological patterns) and landrace or accession (populations from specific locations) (Stallknecht and Schulz-Schaeffer, 1993). Even in South Africa various *Amaranthus* species are widely distributed, except in the more arid south western areas (Van Zyl *et al*., 2002 and Jansen van Rensburg *et al*., 2002 cited by Jansen van Rensburg, 2004)

1.4.2 FOOD USES AND NUTRITIONAL VALUE OF *AMARANTHUS*

Amaranthus is mostly grown and used as a leafy vegetable in Africa where tender leaves and stems are boiled as greens and added to soups and stews (Ore-Oluwa, 1981; National Research Council, 1984; Olufaji, 1989; Schippers, 2000). *Amaranthus*' grain contains 13 to 18 % protein with well balanced nutritional quality including a high level of lysine, an essential amino acid that is often lacking in most diets based on cereals and tubers. Lysine can be used in treatment and prevention of *osteoporosis,* a condition that makes bones prone to fracture (Anonymous, 2006). *Amaranthus* grain can be used in breakfast cereals (cleaned, unprocessed whole grain can be made into porridge by simply boiling it briefly in water) or be milled to produce sweet, light-coloured flour suitable for making biscuits, bread, cakes and other confectioneries (National Research Council, 1984; Olufaji, 1990). *Amaranthus* grains contain some functional gluten making a possibility for it to be blended with wheat flour to make yeast-leavened goods rise (National Research Council, 1984). Unprocessed *Amaranthus* grain can also be used as poultry feed (National Research Council, 1984).

The leaves taste much like spinach species but are nutritionally superior as they contain 3 times more vitamin C, 3 times more calcium and 3 times more niacin than spinach (Makus and Davis, 1984; Mnkeni, 2005). When compared to lettuce, *Amaranthus* leaves contain 18 times more vitamin A, 13 times more vitamin C, 20 times more calcium and 7 times more iron (Mnkeni, 2005). *Amaranthus* leaves contain 17 to 38 % protein on dry weight basis and have potential as a protein supplement. They have high levels of carotene and micronutrients such as sodium, copper, manganese, chlorine (Schippers, 2000; Janick, 1997; Kauffman and Weber, 1990; Mnkeni, 2005, Ore-Oluwa *et al*., 1981).

1.4.3 AGRONOMY OF *AMARANTHUS*

1.4.3.1 Climatic requirements

Although *Amaranthus* is known to be a relatively drought resistant crop, insufficient water reduces yield (Palada and Chang, 2003). When planted directly; *Amaranthus* seeds require well moistened soil to germinate. Even when transplanted as seedlings, water is required for establishment (National Research Council, 1984; Palada and Chang, 2003). After seedlings have established well, *Amaranthus* usually performs well even under limited water conditions. This is because most species are able to maintain high Relative Water Content (RWC) through factors such as stomatal conductance, maintenance of leaf area and biochemical factors such as enzyme function, photosynthesis and respiration (Spreeth *et al*., 2004). When grown for grain production purposes, *Amaranthus* can tolerate dry-land conditions of regions receiving as little rainfall as 200 mm per annum whereas vegetable *Amaranthus* prefer higher rainfall (National Research Council, 1984).

The mean annual rainfall for the Ciskei region of the Eastern Cape ranges between 400 and 500 mm. Most of this rainfall is received during the summer season between the months of October and April. Rain-fed crop production in the region is considered risky because the rainfall is erratic and unreliable (Austin, 1989). According to Palada and Chang (2003) and National Research Council (1984), *Amaranthus* grows well when temperatures are between 21 and 30^0C and is photoperiod sensitive and most species flower when day-length is shorter than 12 hours (Palada and Chang, 2003). No reports could be accessed on planting of *Amaranthus* when hours were shorter than 12 hours.

The ideal time to plant *Amaranthus* in the Central Eastern Cape would be in summer when the mean temperature for three summer months (December, January, February) is 22.5 °C and the days are long enough.

1.4.3.2 Pests and Diseases

Pests and diseases have been reported to be a serious problem in *Amaranthus* production. In Nigeria, many *Amaranthus* lines suffered wet rot of leaves and young stalks as a result of *Choenophora cucurbitarium* (Mposi, 1999). Insect pests such as lygus bug (*Lygus lineolarius*), Lixus weevil (*Lixus masterii*), Fall Armyworm (*Spodoptera frugiperda*), beet leafhopper (*Circulifer temellus*), which transmit curly top virus disease, leafrollers, cabbage looper (*Trichoplusia ni*), corn ear worm (*Heliothis zea*), cutworms, aphids, flea-beetles and mites, can cause severe losses in *Amaranthus* production if no corrective measures are taken (Mposi, 1999; Palada and Chang, 2003, Stalknecht and Schultz-Schaeffer, 1993). No literature could be accessed on prevalent pests species in the Eastern Cape, but where pests are prevalent, selective pesticides such as Biobit and Cypermethrin that target specific insects are recommended. Pesticides that kill or inhibit development of beneficial organisms are to be avoided (Palada and Chang, 2003).

1.4.3.3 Soil requirements

Amaranthus is often grown on acid, marginal soils under subsistence conditions (Foy and Campbell, 1984). It has been reported to grow well in soils with pH range between 4.5 and 8.0 (National Research Council, 1984; Stallknecht & Schulz-Schaeffer, 1993; Palada and Chang, 2003). Field studies have shown that *Amaranthus* grows well on soils varying widely in levels of soil nutrients (National Research Council, 1984), though better yields are generally obtained when the crop is grown in loamy or silty-loamy soils with good water holding capacity (Palada and Chang, 2003). Leaf water potential (LWP) and relative water content (RWC) of *Amaranthus* leaves may decrease due to an increase in soil water deficit (Liu and Stutzel, 2002).

In Central Eastern Cape, where annual rainfall ranges from 400 to 600 mm per annum, a gradual or abrupt increase in clay content from surface horizon to sub-soil had been observed. Soil acidity commonly occurs along the coast where annual rainfall exceeds 600 mm per annum. The major factors that limit potential of Eastern Cape soils are low infiltration rates, soil compaction, shallow rooting depth, phosphorus deficiency, soil alkalinity in the west and soil acidity in the east (Mkile, 2001). Therefore, a thorough knowledge of the soil is needed for production of *Amaranthus* in the Eastern Cape. Animal manures could play an important role in improving the soil conditions, particularly plant nutrients like phosphorus.

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1.4.3.4 Fertilization of *Amaranthus*

Although *Amaranthus* is known to be a low management crop that can grow in poor soils, studies have shown that yield is improved by fertilizer (Palada and Chang, 2003). Myers (1998) and Schippers (2000) reported that *Amaranthus* responds well to good soil fertility and organic matter. Although Mhlontlo *et al*. (2007) reported that sheep kraal manure rates as low as 2.5 t/ha produced significant increases in the fresh and dry matter yields of mono-cropped *Amaranthus*, information on fertility requirements of both grain and vegetable *Amaranthus* is scanty (Elbehri *et al*., 1993). Elbehri *et al.* (1993) noted that application of N-P-K fertilizer (at recommended rates) and irrigation during *Amaranthus* production could increase grain yield from 700 kg ha^{-1} to 3000 kg ha^{-1}. Increased yields due to fertilizer application were observed by Spreeth *et al.* (2004) at the University of Zululand, South Africa who applied 250 kg ha^{-1} of 2:3:2 compound fertilizer. According to Stalknecht and Schultz-Schaeffer (1993) a general suggested fertilization guide for *Amaranthus* is 112 to 135 kg ha^{-1} of total available N, with a soil test of 15 to 30 ppm P and 80 to 120 ppm K. Studies conducted by Schippers (2000) indicated that the crop needs high potassium levels and best results were obtained with 400 kg ha^{-1} of compound fertilizer 10-10-20 (N-P-K). Plants grown with poultry manure had better yields when compared to those grown with kraal manure (Spreeth *et al*., 2004)

1.4.3.5 Animal manure as a potential source of nutrients for *Amaranthus*

Manure is usually a mixture of animal faeces, urine and plant materials (Lekasi *et al*., 1998; Legget *et al*., 1996; Yoganathan *et al*., 1998). It contains all the nutrients required for plant growth although not in the desired proportions hence it is important to apply enough manure to meet crop requirements (van Averbeke and Yoganathan, 1997). According to Mkile (2001), nutrient contents of cattle, sheep and goat manures differ. Goat manure had the highest N, P and K content followed by sheep and cattle. Agronomic use of manure also improves the physical conditions of soils, such as soil structure and soil chemical composition (Pagliai and Vignozzi 1998). According to Schippers (2000), like most crops, growth and yield of *Amaranthus* improve enormously when enough manure is applied.

Farmers in the Eastern Cape practice mixed farming which involves rearing of cattle, goats and sheep on communal owned rangelands whereas field crop production focuses mainly on growing of crops such as maize, beans and pumpkins on individual holdings of between 1 and 3 ha and vegetable production of cabbage, spinach, onions, peas and carrots in gardens of about 0.1 to 0.3 ha next to their homesteads (Mandiringana *et al*. 2005, Yoganathan *et al*., 1998). During the night, cattle, sheep and goats are usually kept in kraals mainly for security reasons (Bembridge *et al*., 1992). With time, the animals' excreta often mixed with fodder, accumulate in layers which are locally referred to as kraal manure (Yoganathan *et al*., 1998). It is estimated that about 1.6 million tons of dry manure are produced in Eastern Cape each year (Mnkeni and Mkile 2006). Van Averbeke and de Lange (1995); Mnkeni and Mkile (2006) and Mafu (2006) reported that farmers in the Eastern Cape use kraal manure in their maize-based cropping systems to address problems of declining soil fertility.

1.4.3.6 Seedbed preparation and planting

A firm moist seedbed with soil temperatures above 15^0C and a soil pH between 4.5 and 8.0 are required to establish a good plant stand (National Research Council, 1984; Stalknecht and Schultz-Schaeffer, 1993; Palada and Chang, 2003). A very fine seedbed similar to that for small seeded vegetables or legumes is recommended because *Amarathus* seed is very small (Stalknecht and Schultz-Schaeffer, 1993). The seedbed should be of good tilth, well drained, and fairly level to help prevent rain from washing away the tiny seeds and seedlings (National Research Council, 1984). *Amaranthus* can be planted by direct seeding or transplanting (Palada and Chang 2003). Direct seeding is practiced only when plenty of seed is available and labour is limited (National Research Council, 1984; Palada and Chang, 2003). The recommended seeding rate is from 1.2 to 3.5 kg seed/ha planted on average depth of 1.3 cm and for vegetable *Amaranthus*, a density of up to about 220 000 plants ha^{-1} is acceptable (National Research Council, 1984; Mposi, 1999, Apaza-Gutierrez *et al*., 2002). No literature could be accessed which compared the fertility requirements of *Amaranthus* using direct seeding and the use of seedlings.

Where there is limited amount of seed and plenty of labour, transplanting is preferred (Palada and Chang, 2003). Singh and Whitehead (1993) obtained a maximum fresh shoot yield of 15 t ha^{-1} when an inter-row and intra-row spacing of 90 and 30 cm respectively were used.

1.4.3.7 Harvesting of *Amaranthus*

Vegetable *Amaranthus* is ready for harvesting in 20 – 45 days after planting or sowing depending on cultivar (Palada and Chang, 2003). Once-off harvesting can be done for short maturing and quick growing cultivars (20 – 30 days after planting or sowing) whereas multiple harvests at 2 - 3 weeks intervals are preferable to cultivars that mature late (more than 30 days after planting or sowing) (Palada and Chang, 2003). Harvesting is usually carried out by cutting the plants at above the second leaf from the ground, at a height of about 7.5 cm, after the plant leaves have attained marketable size. Harvesting may also be done by uprooting the whole plant and the plants are bunched together for sale after the roots have been washed (Mposi, 1999). In Eastern Cape, the young leaves and growth points are hand harvested and cooked for use as vegetable (Jansen van Rensburg *et al*., 2007).

Amaranthus leaves are highly perishable after harvesting. Therefore it is traditional in West Africa to soak the plants in water before transporting to the market to keep them fresh. The leaves are arranged in bunches that are usually spread on a raffia tray in the market or street and to avoid loss of water from the leaves through evaporation, more water is sprinkled on a regular basis (Mposi, 1999).

In grain *Amaranthus* production, harvesting is considered the most critical stage because if not performed well, shattering during the cutting process can lead to serious losses (Putnam *et al*., 1989). Most of the seeds could be lost due to careless harvest techniques (National Research Council, 1984).

To avoid problem of non-uniform maturity, grain *Amaranthus* in Latin America and South Asia is harvested by hand, sun-dried, threshed and winnowed by hand (National Research Council, 1984). Although, yields of between 4 and 15 t ha^{-1} green weight are commonly obtained for vegetable *Amaranthus* (National Research Council, 1984 citing Campbell and Abbott, 1982; Singh and Whitehead, 1993), yields of up to 40 t ha^{-1} have also been reported (National Research Council, 1984). *Amaranthus* grain yields of 450 to 700 kg ha^{-1} dry-land and 900 to 3 000 kg ha-1 under irrigation are considered reasonable (Stalknecht and Schultz-Schaeffer, 1993, Elbheri *et al*. 1993).

1.4.4 INTERCROPPING AS A FARMING SYSTEM IN THE EASTERN CAPE

A farming system is an agricultural enterprise, activity or business consisting of a combination of inputs (e.g. crop varieties, land, farm practice, etc) whether in numbers, amounts, sequences and timing used to satisfy specific objectives of the farmer under a specified environmental setting (Okigbo, 1978 cited by Silwana, 2000).

In Africa, farming systems are classified into two categories, namely:

(a) Traditional and transitional farming system which consists of nomadic herding, shifting cultivation and intensive subsistence agriculture; and

(b) Modern farming systems consists of mixed farming, livestock farming, large scale farms and plantations, irrigation projects involving crop production, mono-cropping and specialized horticulture (Okigbo, 1978).

Although modern farming system is commonly practiced by most small-holder farmers in the Eastern Cape, mono-cropping is practiced by a minority while the majority practices multiple cropping (Silwana, 2000). One of the major reasons for multiple cropping is lack of good agricultural land for crop production (Mukhala *et al.*, 1999). According to Silwana (2000), two types of multiple cropping systems commonly found in the Eastern Cape are sequential cropping system and intercropping. Sequential cropping system is growing of two or more crops in sequence on the same field per year but the succeeding crop is planted after the preceding crop has been harvested thereby the farmer only manages one crop at a time (Silwana, 2000). Intercropping is defined as growing of two or more crops on the same land at the same time or the simultaneous growing of two or more crops in the same field (Ncube, 2003).

More land is required in mono-cropping than intercropping to produce the same yield per unit area (Mukhala *et al*., 1999). Willey (1979) and Silwana (2005) reported that higher yields are usually obtained from intercropping because the components crops are in some way able to utilize growth resources such as light, nutrients and water rather differently, so that when grown together they complement each other and make better overall use of resources than when grown alone. Moreover, intercropping provides more household nutrients per unit area when compared to mono-cropping (Mukhala *et al*., 1999).

The land equivalent ratio (LER), defined as the total land area required under mono-cropping to give the yields that are obtained under intercropping mixture, is normally used for analysis of possible advantages of intercropping (Mazaheri *et al*., 2006). An LER value of 1.0 indicates no difference in yield between intercrop and sole crop whereas a value > 1.0 indicates a yield advantage for intercrop because larger area of land is required to produce the same yield of sole crop of each component than with comparable intercrop (Mazaheri *et al*., 2006; Azam-Ali and Squire, 2002).

CHAPTER 2

EFFECTS OF SHEEP KRAAL MANURE APPLICATION RATES ON GROWTH, YIELD AND LEAF NUTRIENT COMPOSITION OF A LOCAL *AMARANTHUS* ACCESSION IN THE CENTRAL REGION OF THE EASTERN CAPE - (Published as a journal article in Water SA – Appendix 4)

2.1 INTRODUCTION

Hunger and malnutrition mostly experienced in developing countries, affect growth and development of children (Aphane *et al*., 2003). Foods of animal origin, which are major sources of vitamins and proteins, are often too expensive for poor households (Aphane *et al*., 2003; Wehmeyer and Rose, 1983), whereas vegetables that supply abundant amounts of protein, vitamins, calories and minerals, needed in a diet, could alleviate problems associated with malnutrition (Wehmeyer and Rose, 1983). However, harsh climatic and resource-poor conditions in most rural areas, where problems of malnutrition occur, make production of exotic vegetables difficult.

More than 100 different indigenous species, including *Amaranthus sp*., *Corchorus* genera, *Cleome gynandra*, grow well in such areas (Jansen Van Rensburg *et al*., 2004; Aphane *et al*., 2003). They are popular to communities such as in former Transkei, South Africa, where their leaves are gathered from the wild, chopped and mixed with maize meal to prepare a traditional meal known as '*imifino*' or '*isigwampa*' (Wehmeyer and Rose, 1983). *Amaranthus* could be cultivated in areas of southern Africa where there is inadequate or unreliable rainfall (Jansen Van Rensburg *et al*., 2004) but information on its fertility requirements is limited (Elbehri, Putman and Schmitt, 1993). According to Schippers (2000), the crop gives good yield when high levels of nitrogen are applied and responds well to organic matter. Chemical fertilizers are expensive for the resource poor farmers who often utilize those vegetables (Jansen Van Rensburg *et al*., 2004), and hence there is need to investigate cheaper sources of nutrients such as animal manures. Farmers in the Eastern Cape use kraal manure in their maize-based cropping systems to address problems of declining soil fertility (van Averbeke and de Lange, 1995; Mnkeni and Mkile, 2006). While guidelines exist on the use of kraal manure for crops such as maize (van Averbeke & Yoganathan, 1997), no information could be found on the use of kraal manure on *Amaranthus* in the Eastern Cape. This chapter reports on effects of sheep kraal manure application rates on growth, fresh and dry matter yields, nutrient uptake and grain yield of a local *Amaranthus* accession in the central region of the Eastern Cape.

2.2 MATERIALS AND METHODS

The experiment was conducted between November 2002 and May 2003 in Gqumahashe village (32^o 45' S; 26^o 52' E), five km north of Alice town. The soil was sandy loam classified as the Glenecho family of the Mayo form (Soil Classification Working Group, 1991). It contained 14.2 % clay, 0.73 % organic carbon, 2.0 mg P kg^{-1}, 207 mg K kg^{-1}, 2802 mg Ca kg^{-1}, 355 mg Mg kg^{-1} and 2.4 mg Zn l^{-1} with pH of 4.7 (KCl).

The land was ploughed and disked using tractor-drawn plough and disk harrow. Sheep kraal manure collected from the village and contained 1.8% N, 3.7% Ca, 1.4% Mg, 0.37% P, 16000 ppm Fe and 872 ppm Zn was broadcast in the designated plots and incorporated into the soil using a rotovator two weeks before *Amaranthus* seedlings were transplanted. It was applied at different rates (0, 0.3, 0.6, 1.2, 2.5, 5.0 and 10 tons ha^{-1}) into the soil with inorganic NPK fertilizer {2:3:4(30) + 0.5% Zn} applied at a rate of 150 kg ha^{-1} (recommended for spinach) as a positive control (Makus, 1984). The experiment was arranged in a randomized complete block design (RCBD) with four replications.

Amaranthus seedlings, grown in seedling trays for one month, were transplanted on 17th December 2002, in 6 m rows (six rows per plot) with an inter-row spacing of 1 m and intra-row spacing of 30 cm. The seedlings were then irrigated for the first week to aid establishment and solely depended on rain afterwards. Rainfall data was recorded throughout the growing season. Other management practices, like weeding, were the same across the treatments with no pesticides applied. Data collection and sampling for growth, fresh and dry matter yields, were done after 30 and 60 days transplanting (DAT). Two plants were randomly selected from the two middle rows in each plot and uprooted. Stem girth (measured in the middle, between the first leaf and the soil surface), plant height, number of leaves and fresh weight (stems and leaves) were determined, before dry matter (leaves and stems) was determined after drying in an oven at $60^{o}C$ to constant weight. All oven dried leaf samples were ground, digested and analyzed for total N, P, K, Ca, Mg, Fe and Zn as described by Okalebo *et al*. (2002). These nutrients were extracted by wet digestion using the concentrated sulphuric acid, selenium, lithium sulphate and hydrogen peroxide mixture (Anderson and Ingram, 1996). The concentration of P in the digest was then determined by the molybdenum blue colorimetric method while total bases were determined in an aliquot of the digestd sample by atomic absorption spectrometry (AAS). Total nitrogen (N) was measured using a Truspec CN Carbon / Nitrogen Determinator (Anonymous, 2003). Nutrient uptake (N, P, K, Ca, Mg, Fe and Zn) was then calculated from the leaf dry matter and the composition of the nutrients in the leaves. Soil samples were taken (at a depth of 0 – 20 cm) from each individual plot to determine residual soil nutrient composition at 90 DAT. *Amaranthus* grain yield was also determined. The data were subjected to analysis of variance (ANOVA) using the MStat C statistical software and least significant differences (LSD) at 5% significant level were used to separate the means.

2.3 RESULTS AND DISCUSSION

2.3.1 Effects of sheep manure application rates on growth of Amaranthus

Plant height, number of leaves and stem girth, increased significantly with an increase in sheep kraal manure application rate (Table 2.1). At low manure rates ($\leq$ 2.5 t ha^{-1}), the plants had comparable height to those in the unfertilised control, whereas higher rates (5 and 10 t ha^{-1}) and recommended NPK fertilizer resulted in greater plant heights both at 30 and 60 DAT. Similar results were observed by Elbehri *et al*. (1993), who reported increased Amaranthus plant height at higher nitrogen application rate. Number of leaves, at low manure rates ($\leq$ 1.3 t ha^{-1}), were comparable to the unfertilized control whereas higher rates (2.5-10 t ha^{-1}) and the NPK fertilizer treatments produced larger number of leaves both at 30 and 60 DAT. These findings were probably due to increased uptake of nutrients as a result of the accumulation of larger amounts of nutrients in the soil as the amount of manure increased.

Manure application resulted in larger stem girth when compared to the unfertilized control but there was no additional response to increased application from 0.3 to 10 t ha^{-1}, which compared well with the recommended fertilizer. These results appear to indicate that addition of manure at 0.3 t ha^{-1} provided sufficient nutrients for maximum stem girth at growth stages up to 60 DAT and the rest of the nutrients were partitioned towards stem elongation and leaf production.

Table 2.1: Effects of sheep kraal manure application on growth of *Amaranthus*

Manure Rates	Plant Height (cm)		Stem Girth (cm)		Number of leaves	
(t ha^{-1})	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
0	30.50c*	37.00d	0.75c	1.40b	67b	92c
0.3	34.00bc	42.25cd	1.00bc	1.68ab	86ab	111bc
0.6	33.75bc	41.50d	1.10ab	1.70ab	86ab	112bc
1.3	38.75abc	48.25bcd	1.18ab	1.73a	99ab	122bc
2.5	40.50abc	47.75bcd	1.25ab	1.90a	117a	140abc
5.0	45.00ab	54.25abc	1.35a	1.95a	118a	150ab
10.0	47.25a	61.00a	1.30a	2.03a	126a	153ab
NPK fertilizer	46.50a	57.50ab	1.23ab	2.03a	114ab	181a
CV (%)	21	17	17	16	32	27

* Means within each growth parameter and sampling time followed by the same letter or none at all are not significantly different at $p < 0.05$.

2.3.2 Sheep manure application effects on fresh yield of Amaranthus

Fresh matter yield (leaf, stem and shoot) increased significantly with an increase in sheep kraal manure application rate (Table 2.2). Where low rates of kraal manure ($\leq$ 2.5 t ha^{-1}) were applied, leaf stem and shoot fresh matter yields were comparable to unfertilized control both at 30 and 60 DAT except for shoot weight at 60 DAT. Higher rates of kraal manure (5 and 10 t ha^{-1}) produced higher fresh matter yields than the unfertilised control and were comparable to the NPK fertilizer, indicating a response to greater addition of nutrients. At higher rates, the results compared well with those reported by Makus (1984) for different accessions of the crop fertilized with mineral fertilizer at recommended rates for spinach. However, they were lower than those reported by Allemann *et al*. (1996) for different varieties of *Amaranthus* at ARC-Roodeplaat Vegetable and Ornamental Plant Institute's Research Station, Pretoria. The difference was attributed to heavy fertilizer application and irrigation water used in the study by Allemann *et al.* (1996) in relation to dry-land conditions used in our experiment, in a dry year (rainfall data were 116 mm, 13.6 mm and 57.1 mm for December, January and February respectively), with almost five times less basal fertilizer without topdressing. The highest leaf fresh matter was at 5 t ha^{-1} manure and in the inorganic fertiliser treatment for 30 and 60 DAT, respectively. These results indicate that a sheep kraal manure application rate of 5 t ha^{-1} is critical to maximize *Amaranthus* fresh matter yield if the crop is to be used as a vegetable.

Table 2.2: Effects of sheep kraal manure application on fresh matter yield of *Amaranthus*

Manure rate ($t\ ha^{-1}$)	Leaves ($g\ plant^{-1}$)		Stems ($g\ plant^{-1}$)		Shoots ($g\ plant^{-1}$)	
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
0	18.88d*	28.50c	21.73d	45.76d	45.66c	97.16d
0.3	25.85cd	51.82bc	31.39cd	66.08cd	67.47bc	132.66cd
0.6	31.08abcd	56.05bc	43.33bcd	66.43cd	96.14abc	143.53cd
1.3	28.48bcd	54.06bc	43.93bcd	96.90bcd	103.27abc	154.70bcd
2.5	38.90abcd	68.21abc	51.55abcd	113.15abcd	106.54abc	194.85abc
5.0	50.45a	77.25ab	78.00ab	129.40abc	149.17a	239.05ab
10.0	48.88ab	78.73ab	90.28a	156.60ab	149.72a	262.45a
NPK fertilizer	41.95abc	104.10a	70.28abc	181.38a	127.94ab	258.80a
CV (%)	39	46	53	49	50	35

* Means within each yield parameter and sampling time followed by the same letter or none at all are not significantly different at $p < 0.05$.

2.3.3 Effects of sheep manure rates on dry matter and grain yield of Amaranthus

Dry matter (leaf, stem and shoot) yields increased with increase in manure application rate (Table 2.3). At 30 DAT, manure application rates of $\geq 2.5\ t\ ha^{-1}$ and the NPK fertilizer, produced greater shoot dry-matter yields than the unfertilized control. The results were lower than those reported by Allemann *et al*. (1996) and the difference could be attributed to differences in soil moisture and fertilization. The unfertilized control produced yields which were comparable to those of manure rates from 0.3 to 1.27 $t\ ha^{-1}$. Elbehri *et al*. (1993) reported improved forage yield of *Amaranthus* as a result of nitrogen addition. The findings suggested that 2.5 $t\ ha^{-1}$ of sheep kraal manure would supply sufficient nutrients (compared to recommended fertilizer) for vegetable *Amaranthus*, especially when the leaves are to be harvested at a young age (30 DAT) as recommended and practiced in the Eastern Cape (Wehmeyer and Rose, 1983; Bhat and Rubuluza, 2002). This critical manure rate is lower than the one based on fresh matter and this could be a result of differences in water uptake of the plants at the time of sampling. From the differences in fresh and dry matter, the results indicated that the plants in the 5 t ha^{-1} manure treatment took up more water than in the 2.5 t ha^{-1} treatment. Grain yield did not respond to sheep kraal manure or fertilizer application when compared to the control (Table 2.3).

Table 2.3: Effects of sheep kraal manure application rates on dry matter yield of *Amaranthus*

Manure rate (t ha^{-1})	Leaves (g $plant^{-1}$)		Stems (g $plant^{-1}$)		Shoots (g $plant^{-1}$)		Grain yield (g $plot^{-1}$)
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	
0	6.17c*	10.26f	4.11d	5.69d	17.11c	19.35c	362
0.3	8.44bc	14.62ef	6.15cd	10.09cd	21.88bc	28.74b	402
0.6	9.79abc	16.63de	7.55bcd	12.65bcd	26.67abc	31.27b	405
1.3	9.75abc	18.32cde	7.71bcd	15.49bcd	27.03abc	36.69b	412
2.5	11.84ab	21.96bcd	9.30abc	18.28abc	29.35ab	45.97a	428
5.0	12.49ab	23.52abc	9.86abc	22.28ab	30.74ab	46.97a	443
10.0	13.44a	24.68ab	14.03a	25.35a	37.68a	49.77a	488
NPK fertilizer	12.16ab	27.72a	12.07ab	26.49a	38.09a	52.78a	532
CV (%)	30	19	38	39	27	16	33

*Means within each growth parameter and sampling time followed by the same letter or none at all are not significantly different at $p < 0.05$.

2.3.4 Sheep manure effects on nutrient composition and uptake of Amaranthus leaves

The composition of Ca, Mg, P, N and K in the *Amaranthus* leaves agreed very well with those reported for different accessions of the crop by Markus (1984) while Fe and Zn were much lower. There were no effects of rate of manure application on N, P, K, Ca, Mg, and Zn composition of *Amaranthus* leaves at 30 DAT (Table 2.4). These results agree with those of Ore-Oluwa *et al*. (1981) who reported no effects of nitrogen on accumulation of Ca, K, N, Na, Cu and Zn in *Amaranthus* leaves. However, uptake of N and P in the leaves increased with increase in manure application rate with N uptake reaching a maximum at a manure rate of 2.5 t ha^{-1} which corresponded with maximum dry matter yield (Table 2.5). The findings indicated that 2.5 t ha^{-1} or higher rates of sheep kraal manure supplied larger amounts of nutrients resulting in greater nutrient uptake (especially N and P), with subsequent increase in fresh and dry matter yields.

Leaf Fe composition results agreed with those reported by Jansen Van Rensburg *et al*. (2004), and varied with manure and fertilizer application though no specific trend was observed (Table 2.4). Rates of manure application greater than 0.6 t ha^{-1}, however, generally resulted in levels of Fe that were higher than in the control treatment. The same trend was observed for crude protein, which compared well with other indigenous vegetables consumed in the Eastern Cape, and thus could supplement the maize-based diets with protein (Wehmeyer and Rose, 1983). Since Fe is an important element in human nutrition, these results suggest that in addition to improving yields, fertilization of

Amaranthus with sheep manure will have the added benefit of improving its nutritional value, including Fe.

Table 2.4: Effects of sheep kraal manure application on nutrient composition of *Amaranthus* leaves at 30 DAT.

Manure Rate	Selected nutrients						
($t\ ha^{-1}$)	N	P	K	Mg	Ca	Fe	Zn
	---------------------------- (%) --------------------------------					------- ($mg\ kg^{-1}$) -------	
0	2.17*	0.09	3.3	1.4	3.9	60.0bc	2.9
0.3	2.19	0.12	3.5	1.4	3.9	46.9c	3.2
0.6	2.57	0.09	3.8	1.3	3.6	132.3a	2.4
1.3	2.34	0.12	3.4	1.3	3.8	90.9abc	2.2
2.5	2.53	0.12	3.6	1.5	3.7	100.6abc	2.3
5.0	2.13	0.11	3.7	1.3	3.5	81.1abc	2.5
10.0	2.25	0.13	4.3	1.5	3.7	97.8abc	3.8
NPK fertilizer	2.47	0.14	4.7	1.3	3.7	116.5ab	2.3
CV (%)	17	14	16	13	12	43	49

*Means within each nutrient followed by the same letter or none at all are not significantly different at $p < 0.05$.

Table 2.5: Effects of sheep kraal manure rate on nutrient uptake in *Amaranthus* leaves at 30 DAT

Manure Rate ($t\ ha^{-1}$)	Nutrient uptake ($mg\ plant^{-1}$)					Crude protein ($g\ plant^{-1}$)
	N	P	K	Mg	Ca	
0	134c	6.03d	207	82	240	0.84c
0.3	178bc	9.05cd	288	116	324	1.11bc
0.6	264ab	9.88bcd	360	138	352	1.65ab
1.3	262ab	11.88abcd	310	130	369	1.64ab
2.5	308a	13.10abc	482	176	436	1.93a
5.0	273ab	13.38abc	506	158	443	1.71ab
10.0	267ab	17.83a	520	182	503	1.67ab
NPK fertilizer	315a	16.80ab	565	154	452	1.97a
CV (%)	35	35	34	34	34	21

*Means within each nutrient followed by the same letter or none at all are not significantly different at $p < 0.05$.

2.3.5 Effects of sheep manure application rates on residual soil nutrient composition

Residual soil pH increased from 5.4 to 5.8 in response to increasing manure rate from 0 to 10 t ha^{-1} whereas the NPK fertilizer depressed it (Table 2.6). Manure rates < 2.5 t ha^{-1} had post cropping pH values which were comparable to the unfertilized control, whereas higher rates had significantly higher pH values ($p<0.05$). There was no effect of manure rate or fertilizer on residual soil N, suggesting that the crop had exhausted the soil N from manure or fertilizer and this could have restricted uptake of other nutrients. Lower manure rates (≤ 1.3 t ha^{-1}) resulted in lower residual soil P than the higher rates (2.5-10 t ha^{-1}), which had lower P levels than the NPK fertilizer (Table 2.6), which agreed with Eghball and Power (1999), who reported an accumulation of soil P as a result of manure application. This could probably benefit the next crop grown on this soil.

Although residual soil K from plots fertilized with NPK fertilizer, and low manure rates (0.3-1.3 t ha^{-1}), compared well with the unfertilized control, an increase at higher kraal manure rates (2.5 -10 t ha^{-1}) was observed. All the treatments ranged at more than 200 mg K kg^{-1} and above the critical level of 80 – 120 mg K kg^{-1} (Bornman *et al*., 1989) which explains the lack of K uptake response to manure or fertilizer application. The results are in agreement with Laker (1976), who reported that, in general, South African soils do not have K deficiency problem. Although the uptake of Mg did not respond to manure and fertilizer application, however, its residual levels increased at manure rates of 5 and 10 t ha^{-1} (Table 2.6). Calcium ranged between 3914 and 4690 mg Ca kg^{-1} and the manure rate of 10 t ha^{-1} gave a significantly higher calcium level than all the other treatments (Table 2.6). Low manure rates (0.3-1.3 t ha^{-1}) gave residual Zn levels comparable to unfertilized control, while higher rates (≥ 2.5 t ha^{-1}) had higher levels indicating that the application of sheep manure can increase the zinc fertility of deficient soils. In this study, however, Zn was not a problem as levels in all treatments including the control were within or above the critical range of 1.5 – 2 mg Zn kg^{-1} (Bornman *et al*., 1989). The inorganic NPK {2:3:4(30) + 0.5% Zn} fertilizer treatment had the highest level of residual Zn (Table 2.6) because the fertilizer contained Zn in its formulation.

Table 2.6: Effects of sheep kraal manure application rates on residual soil nutrient composition

Manure rate (t ha^{-1})	pH (KCl)	Total N (%)	OC (%)	Selected nutrients (mg kg^{-1})				
				P	K	Mg	Ca	Zn
0	5.40c	0.07	1.70b	4.00d	212.00d	309.70c	3914b	1.61e
0.3	5.50c	0.09	1.93a	4.50d	203.28d	325.63bc	3943b	2.13cde
0.6	5.45c	0.09	1.74ab	4.87d	237.55d	344.83bc	3900b	1.88de
1.3	5.50c	0.10	1.88ab	6.21d	268.75d	359.75bc	3822b	2.02cde
2.5	5.55bc	0.10	1.89ab	15.28c	351.75c	350.50bc	4038 b	2.28bcd
5.0	5.70ab	0.09	1.92a	19.50c	433.61b	376.00b	4019 b	2.43bc
10.0	5.80a	0.09	1.87ab	28.00b	533.75a	456.50a	4690a	2.78b
NPK fertilizer	5.20d	0.09	1.78ab	36.23a	267.25d	362.63bc	3968b	6.04a
CV (%)	2.02	17.50	7.01	29.21	14.36	10.71	9.32	13.12

*Means within each soil nutrient followed by the same letter or none at all are not significantly different at $p < 0.05$.

2.4 CONCLUSIONS

Sheep kraal manure rates of 2.5 t ha^{-1}or higher could result in *Amaranthus* growth, yield and nutrient uptake, similar to that of the recommended NPK{2:3:4(30) + 0.5% Zn} fertilizer at 150 kg ha^{-1} under dry land conditions of the Central Region of the Eastern Cape. In addition to improved growth, the crop was enriched with iron and crude protein, important for human nutrition. Sheep manure had a liming effect and high residual fertility as indicated by high levels of P, K, Mg and Zn at harvest time. *Amaranthus* need not be fertilized with mineral fertilizers where sheep kraal manure or other forms of manure are available. Fertility requirements of *Amaranthus* could vary, with soil type, and/or in intercropping systems. Organoleptic tests are needed to establish whether or not the yield increase observed with manure addition was at the expense of the good taste of the vegetable.

CHAPTER 3

EFFECTS OF SHEEP KRAAL MANURE APPLICATION RATES ON GROWTH, YIELD AND NUTRIENT COMPOSITION OF A VEGETABLE *AMARANTHUS* ACCESSION GROWN IN TWO DIFFERENT SOILS UNDER GLASSHOUSE CONDITIONS

3.1 INTRODUCTION

Amaranthus is among more than 100 different popular indigenous species that are gathered from the wild by communities in the Eastern Cape (Wehmeyer and Rose, 1983). However, indigenous vegetables are not cultivated because vegetable production mainly focuses on cultivation of exotic species such as cabbage, spinach, onions, peas and carrots in gardens of about 0.1 to 0.3 ha next to the homesteads (Mandiringana *et al*., 1996). In most instances, production of exotic vegetables is difficult because of harsh climates, poor soils and resource-poor conditions while most indigenous vegetables, when cultivated, grow well in areas unsuitable for growth of introduced or exotic vegetables (Jansen Van Rensburg *et al*., 2004; Aphane *et al*., 2003).

Amaranthus is often grown on acid, marginal soils under subsistence conditions (Foy and Campbell, 1984, Lui and Stutzel, 2002). In sandy-loam soil, the crop has been reported to grow well even when the soil moisture ranged between 6 – 18 %, indicating that it has an ability to perform well under low soil moisture environments (Liu and Stutzel 2002). The crop grows well on wide range of soil types with good water holding capacity including loam or silty-loam soil and can tolerate a soil pH between 4.5 and 8.0 (Palada and Chang, 2003). Most soils in former homelands of South Africa have very low fertility status (Laker, 1976). In Eastern Cape, soils contain low amounts of plant nutrient elements except S, Mn, Zn, Cu and B and are shallow because climate in some places is too dry for deep soils to develop (Mandiringana *et al*., 2005; van Averbeke *et al*., 2006). The production potential of these soils is often limited by such factors as low infiltration rate, soil compaction, acidity, phosphorus, nitrogen and sometimes potassium deficiencies and low organic carbon contents (Mkile, 2001; Mnkeni and Mkile, 2006). Although *Amaranthus* is known to be a low management crop that can grow in poor soils, its yields could be improved by application of fertilizers (Palada and Chang, 2003). Myers (1998) and Schippers (2000) reported that *Amaranthus* responds well to good soil fertility and organic matter. Information on fertility requirements of both grain and vegetable *Amaranthus* is scanty (Elbehri *et al*., 1993) but Mhlontlo *et al*. (2007) reported that sheep kraal manure rates as low as 2.5 t ha^{-1} produced significant increases in the fresh and dry matter yields of a local *Amaranthus* accession in the Central region of the Eastern Cape.

Even though some farmers use kraal manure in their homesteads to address problems of declining soil fertility (van Averberke and de Lange, 1995; Mnkeni and Mkile, 2006; Mafu, 2006), poor soil fertility in the Ciskei region has often been associated with practices of monoculture and continuous cropping which results in removal of nutrients with little or nothing being returned to the soil whether in the form of chemical fertilizer or manure (Mandiringana *et al*. 2005; Mkile 2001). The response of *Amaranthus* to soil fertility management could therefore be dependent on soil type. A pot study was therefore conducted to evaluate the effects of sheep kraal manure on performance of *Amaranthus* grown in two soils collected from different villages in Central Eastern Cape.

3.2 MATERIALS AND METHODS

The experiment was conducted in a glasshouse at the University of Fort Hare between December 2006 and February 2007. The soils used were collected from Ntselamanzi and Gqumahashe Villages in the Central Eastern Cape. The Gqumahashe experimental site used in the previous field experiment, (Chapter 2), was no longer available for the second season, and the only available land was at Somgxada Farm near Ntselamanzi Village. The Gqumahashe soil was sandy loam classified as the Glenecho family of the Mayo form (Soil Classification Working Group, 1991). It contained 14.2 % clay, 0.73 % organic carbon, 2.0 mg P kg^{-1}, 207 mg K kg^{-1}, 2802 mg Ca kg^{-1}, 355 mg Mg kg^{-1} and 2.4 mg Zn l^{-1} with pH of 4.7 (KCl). The Ntselamanzi soil was sandy loam classified as the Ritchie family of the Oakleaf form (Soil Classification Working Group, 1991), with 14.2 % clay, 0.73 % organic carbon, 9.5 mg P kg^{-1}, 367 mg K kg^{-1}, 3874 mg Ca kg^{-1}, 315 mg Mg kg^{-1} and 2.4 mg Zn l^{-1} with pH 5.5 (KCl).

Each soil type (not sieved) was filled into thirty six (10 kg) pots to give a total of seventy two pots. Sheep kraal manure collected from Ntselamanzi Village containing 2.1% N, 7.1 % Ca, 1.5 % Mg, 3.0% K, 0.2 % P, 13354 ppm Fe and 210 ppm Zn was applied at different rates {0, 1.3, 2.5 5.0 and 10 t/ha} to the pots and inorganic NPK fertilizer {2:3:4 (30) + 0.5% Zn} was applied at rates recommended for spinach at both soils (Makus, 1984). The manure was collected from the same kraal as the one used in the Gqumahashe field experiment in Chapter 2 and the difference in nutrient composition was because of different seasons.

Seedlings of an unclassified local *Amaranthus* accession, raised in seedling trays for three weeks, were transplanted in January 2007. Two plants for each treatment were transplanted into two separate pots, which formed one replicate. The treatments were then arranged in a randomized complete block design (RCBD) with three replications. Pots were watered daily in the morning to replenish the water lost through evapotranspiration, until harvesting at 30 days after transplanting (DAT). Plants were harvested by cutting from the ground level after which stem girth, plant height, number of leaves and fresh and dry matter (stems and leaves) were determined. Dry matter was determined by drying at 60^oC to constant mass.

Dried leaf samples were ground, digested and analyzed for total N, P, K, Ca, Mg, Fe and Zn as described by Okalebo, Gathua and Woomer (2002). These were extracted by wet digestion using the concentrated sulphuric acid, selenium, lithium sulphate and hydrogen peroxide mixture (Anderson and Ingram, 1996). The concentration of P in the digest was then determined by the molybdenum blue colorimetric method while total bases were determined in an aliquot of the digestd sample by atomic absorption spectrometry (AAS). Total nitrogen (N) was measured using a Truspec CN Carbon / Nitrogen Determinator (Anonymous, 2003). Nutrient uptake (N, P, K, Ca, Mg, Fe and Zn) was calculated from the leaf dry matter yield and the composition of the nutrients in the leaves. Soil in the pots was sampled after experiment for determination of residual soil nutrients. The data obtained were subjected to analysis of variance (ANOVA) using the MStat C statistical software and least significant differences (LSD), at 5% significant level, were used to separate the means.

3.3 RESULTS AND DISCUSSIONS

3.3.1 Chemical and physical properties of the experimental soils used in the glasshouse study

Laboratory results indicated that Gqumahashe soil was acidic and low in nutrients (P, K, Mg, Ca and Zn) when compared to the Ntselamanzi soil (Table 3.1). Both soils did not have K, Ca and Mg deficiency problems but the Gqumahashe soil had below critical levels of P and Zn whereas the Ntselamanzi soil fell in the medium range (Bornman *et al*., 1989). The results are consistent with Laker (1976) who reported that, in general, South African soils do not have K deficiency problem. The texture of both soils was sandy loam but the Ntselamanzi soil had more sand and clay whereas the Gqumahashe soil had more silt.

3.3.2 Effects of manure application rates on growth of Amaranthus in two different soils

In both the Gqumahashe and the Ntselamanzi soils, plant height, stem girth and number of leaves increased significantly with increased kraal manure application rates (Table 3.2). In the Ntselamanzi soil, the 10 t ha^{-1}manure treatment had plant height comparable to those fertilized with NPK fertilizer while in the Gqumahashe soil, the manure treatments ≥ 2.5 t ha^{-1} compared well to NPK fertilizer. The results agree with Elbehri *et al.* (1993) who noticed an increased plant height due to increased nitrogen application rates. Although, plants grown in the Ntselamanzi soil had greater plant heights when compared to those grown in Gqumahashe soil, the difference was not statistically significant. The manure treatments ≥ 5 t ha^{-1} had stem girth that compared well with those fertilized with NPK fertilizer in Ntselamanzi soil whereas in the Gqumahashe soil, all manure treatments compared well with NPK fertilizer, which agreed with the findings of the field work with the Gqumahashe soil as in Chapter 2 and in Mhlontlo *et al*. (2007). No significant difference was observed in stem girth due to soil type. In the Ntselamanzi soil, all manure treatments had more leaves when compared to unfertilized control plants and compared well to plants fertilized with NPK fertilizer. However, in the Gqumahashe soil, only plants in the manure treatments ≥ 5 t ha^{-1} compared well with those fertilized with NPK fertilizer while plants fertilized with ≤ 2.5 t ha^{-1} manure compared well with unfertilized control. Generally, plants grown in the Ntselamanzi had many leaves than those grown in the Gqumahashe soil. The results are consistent with Spreeth *et al*. (2004) who reported increased number of leaves of *Amaranthus* as a result of application of poultry manure, kraal manure and inorganic NPK fertilizer. The variations in responses to manure treatments could be explained by the differences in the fertility status of the two soils, with the Ntselamanzi soil being more fertile and less responsive to manure.

Table 3.1: Chemical and physical properties of the Ntselamanzi and Gqumahashe soils

a. Chemical properties of soils from Ntselamanzi and Gqumahashe

Site	P	K	Ca	Mg	Zn	pH	Total cations
	---------------------------mg kg^{-1} soil----------------------------						--cmol(+) l^{-1}--
Ntselamanzi	9.5	367	3874	315	2.4	5.0	23.71
Gqumahashe	2	207	2802	355	1.4	4.7	17.43

b. Physical properties of soils from Ntselamanzi and Gqumahashe

Property	Ntselamanzi	Gqumahashe
% Sand	69.8	57.8
% Clay	14.2	10.2
% Silt	16.0	32.0
% Corse Sand	1.0	3.6
% Medium Sand	8.4	2.9
% Fine Sand	60.5	51.4
Classification	Sandy loam	Sandy loam

3.3.3 Effects of sheep manure application rates on fresh and dry matter yields of Amaranthus in two different soils

Fresh matter yield (leaf, stem and shoot) responded positively to applied sheep manure in both soils (Table 3.3). Fresh leaf weight of plants fertilized with ≤ 5 t ha^{-1} manure compared well to the unfertilized control while those in the10 t/ha manure treatment were comparable to plants fertilized with NPK fertilizer in the Ntselamanzi soil. In the

Gqumahashe soil, plants in manure treatments ≥ 2.5 t ha^{-1} had fresh leaf weight that compared well to plants fertilized with NPK fertilizer and greater than in the 1.3 t ha^{-1} manure treatment and the unfertilized control. In the Ntselamanzi soil, manure treatments ≥ 5 t ha^{-1} manure had fresh stem and shoot yield comparable to plants fertilized with inorganic NPK fertilizer while those fertilized with ≤ 2.5 t ha^{-1} manure compared well with unfertilized control. However, in the Gqumahashe soil, plants in the manure treatments ≥ 2.5 t ha^{-1} manure had fresh stem weight that compared well with NPK fertilizer treatment and greater than in the 1.3 t ha^{-1} manure and unfertilized control treatments. All manure treatments had greater fresh shoot yield than the unfertilized

Table 3.2: Effects of sheep manure application rates and on growth of *Amaranthus* in two different soils

Manure Rate (t ha^{-1})	Plant Height (cm)		Stem Girth (cm)		Number of leaves	
	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu
0	45.77de*	33.37f	0.70cd	0.50d	60d	52d
1.3	51.67bcde	45.03e	0.88bc	0.95b	82ab	64cd
2.5	53.43bc	49.77bcde	0.88bc	0.93b	82ab	64cd
5.0	52.90bcd	49.50bcde	1.00ab	1.20a	90a	74bc
10	55.83ab	50.33bcde	1.07ab	0.87bc	84ab	76b
NPK fertilizer	61.50a	47.67cde	1.03ab	1.02ab	84ab	81ab
CV (%)	10.28		16.33		11.71	

Ntse = Ntselamanzi Soil Gqu = Gqumahashe Soil

*Means within each growth parameter and soil type followed by the same letter are not significantly different at $p < 0.05$ according to the LSD test control but were comparable to the NPK fertilizer treatment. There ware no significant differences observed on fresh matter yield of *Amaranthus* due to soil type.

Amaranthus dry matter yield increased as a result of increased sheep manure application in both soils (Table 3.4). In both soils, plants fertilized with manure (1.3-10 t ha^{-1}) had dry leaf weight comparable to the NPK fertilizer treatment and greater than the unfertilized control. A similar trend was observed in dry stems and shoot yields of plants grown in the Gqumahashe soil whereas plants grown in the Ntselamanzi soil did not respond to manure application. This variation could be explained by the better fertility status of the Ntselamanzi soil.

Table 3.3: Effects of sheep manure application rates on fresh weight of *Amaranthus* in two different soils.

Manure rates (t ha^{-1})	Leaves (g $plant^{-1}$)		Stems (g $plant^{-1}$)		Shoots (g $plant^{-1}$)	
	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu
0	11.28ef*	10.97f	17.21d	18.33d	28.49d	29.29d
1.3	13.14def	16.32bcd	21.53cd	24.42bc	34.67cd	40.74abc
2.5	13.36def	17.41abc	22.03cd	26.14abc	35.41bcd	43.54ab
5.0	14.97cde	19.15ab	25.22abc	27.34ab	40.19abc	46.49a
10	17.50abc	18.08abc	29.84a	24.67abc	47.34a	42.75abc
NPK fertilizer	21.08a	18.74ab	26.77abc	24.56abc	47.85a	43.31ab
CV (%)	15.93		14.91		13.97	

Ntse = Ntselamanzi Soil Gqu = Gqumahashe Soil

*Means within each yield parameter and soil type followed by the same letter are not significantly different at $p < 0.05$ according to the LSD test.

Table 3.4: Effects of sheep manure application rates and soil type on dry matter yield of *Amaranthhus*

Manure rates ($t\ ha^{-1}$)	Leaves ($g\ plant^{-1}$)		Stems ($g\ plant^{-1}$)		Shoot ($g\ plant^{-1}$)	
	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu
0	2.20bc*	1.38c	3.85ab	1.38c	6.05ab	2.77c
1.3	3.30ab	3.22ab	4.87a	3.13abc	7.65ab	5.35b
2.5	2.73ab	3.50a	4.05ab	3.47ab	6.90ab	6.32ab
5.0	3.52a	3.85a	4.50ab	3.38ab	7.23ab	7.32ab
10	3.50a	3.33ab	4.52ab	3.08bc	8.10a	6.93ab
NPK fertilizer	3.72a	3.65a	3.68ab	3.10abc	7.40ab	6.77ab
CV (%)	24.97		34.03		24.94	

Ntse = Ntselamanzi Soil Gqu = Gqumahashe Soil

*Means within each yield parameter and soil type followed by the same letter are not significantly different at $p < 0.05$ according to the LSD test.

3.3.4 Effects of sheep manure application rates on nutrient composition and uptake of Amaranthus leaves grown in two different soils

The concentrations of N, P, K and Mg in leaves of *Amaranthus* were lower than those reported by Makus (1984) and Mhlontlo *et al*. (2007) who conducted their studies under field conditions (Table 3.5). The difference could be as a result of the photoperiod effect affecting the pot study commenced in January compared to the field studies that were established in December. In the Gqumahashe soil, nitrogen concentration in manure treatments (1.3 - 10 $t\ ha^{-1}$) compared well to those fertilized with NPK fertilizer.

Although nitrogen concentration increased with manure application in Ntselamanzi soil, there was no specific trend. There was more nitrogen accumulation in plants grown in the Gqumahashe soil than those in Ntselamanzi soil. Phosphorus, K and Mg did not show significant response to the applied sheep manure in both soils although there was more P accumulation in plants fertilized with NPK fertilizer. In both soils, Ca increased with an increase in manure application. In the Gqumahashe soil plants in the manure treatments had Ca accumulation comparable to those fertilized with NPK fertilizer, whereas manure application resulted in lower Ca accumulation than the NPK fertilizer treatment in the Ntselamanzi soil. Concentration of Fe in leaves in manure treatments, in Ntselamanzi soil, compared well with unfertilized control but was less than in the NPK fertilizer treatment, while manure treatments ≥ 5 t ha^{-1} manure had Fe accumulation comparable to those fertilized with NPK fertilizer in the Gqumahashe soil. There was more Fe accumulation in the Gqumahashe soil than in Ntselamanzi soil. Accumulation of Zn did not respond to manure or fertilizer application in Ntselamanzi soil where in the Gqumahashe soil, plants fertilized with manure or NPK fertilizer accumulated more Zn than the unfertilized control. Concentration of nutrients in the leaves could be explained by the manure level and the fertility status of the soil, suggesting that a fertile soil would not respond to manure addition. Uptake of N, P and K was improved by manure application although it was less than in plants fertilized with NPK fertilizer (Table 3.6). In both soils, uptake of N, P, and K increased with increased manure application but it was not significantly different from the unfertilized control. Uptake of Ca in plants fertilized with manure in the Gqumahashe soil, compared well to those fertilized with NPK fertilizer and was more than in the unfertilized control. In the Ntselamanzi soil, Ca uptake in plants fertilized with manure compared well to unfertilized control and was less when compared to plants fertilized with NPK fertilizer. Uptake of Mg did not respond to manure or fertilizer application.

TABLE 3.5: Effects of sheep manure application on nutrient composition of *Amaranthus* leaves grown in two different soils.

Manure rate (t ha^{-1})	Selected nutrients in leaves													
	N		P		K		Mg		Ca		Fe		Zn	
	----------%----------										----------mg kg^{-1}----------			
	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu
0	1.5e	2.3cd	0.2e	0.2e	2.7a	2.6ab	0.8	0.8	4.5g	5.8de	203.7f	460.3de	57.7a	42.7b
1.3	1.6e	3.1ab	0.2e	0.2cde	2.2b	2.7a	0.7	0.8	4.9fg	6.4abc	204.0f	715.0c	61.7a	64.3a
2.5	1.7de	2.9abc	0.2cde	0.3cd	2.7a	2.7a	0.8	0.8	4.6fg	6.5abc	235.7ef	1019.3b	64.3a	70.0a
5.0	1.8de	3.4ab	0.3cd	0.3bc	2.8a	2.8a	0.8	0.8	5.0fg	6.7a	259.3ef	1040.3ab	64.0a	66.3a
10	1.7de	3.0ab	0.2de	0.3cd	2.7a	2.8a	0.8	0.8	5.2ef	6.0bcd	265.0def	1162.7ab	61.3a	61.7a
NPK fert.	2.9bc	3.6a	0.4ab	0.4a	2.9a	2.8a	0.8	0.8	6.0cd	6.6ab	497.7cd	1265.0a	61.3a	62.3a
CV (%)	16.6		17.9		10.2		1.4		6.6		22.6		11.9	

Ntse = Ntselamanzi Soil Gqu = Gqumahashe Soil

*Means within each nutrient and soil type followed by the same letter are not significantly different at $p < 0.05$ according to the LSD test.

TABLE 3.6: Effects of manure application on nutrient uptake of *Amaranthus* leaves grown in two different soils

Manure Rates ($t\ ha^{-1}$)	Nutrient uptake ($mg\ plant^{-1}$)									
	N		P		K		Ca		Mg	
	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu
0	11.0d	29.1cd	0.2d	0.2cd	37.0de	34.8e	101.1f	169.7de	2.8	2.9
1.3	13.0d	47.1abc	0.2cd	0.3bcd	36.7de	36.9de	121.7f	209.7abc	2.8	2.9
2.5	14.2d	43.1bc	0.3bcd	0.4bc	37.9bcd	37.4cde	108.3f	213.0ab	2.9	2.8
5.0	16.6d	58.7ab	0.4bc	0.4b	38.2bcd	38.7abcd	126.3f	224.3a	2.8	2.9
10.0	14.3d	45.0bc	0.2cd	0.4bc	37.0de	40.2abc	135.0ef	181.7bcd	2.8	2.8
NPK fert.	41.5bc	65.7a	0.7a	0.7a	41.2a	40.7ab	175.7cd	216.3ab	2.9	2.8
CV (%)	35.2		35.9		4.5		13.2		2.7	

Ntse = Ntselamanzi Soil Gqu = Gqumahashe Soil

*Means within each nutrient and soil type followed by the same letter are not significantly different at $p < 0.05$ according to the LSD test

3.3.5 Effects of sheep manure application rates on residual soil nutrients in two different soils

The NPK fertilizer treatment resulted in lower pH values than manure and the unfertilized control treatments (Table 3.7). There was no effect of manure or fertilizer application on residual soil nitrogen in both soils which could suggest that the plants exhausted nitrogen from manure or fertilizer. Although organic carbon (OC) increased with manure rate in the Gqumahashe soil, there was no specific trend observed in the Ntselamanzi soil. In the Gqumahashe soil, manure rates ≥ 2.5 $t\ ha^{-1}$ resulted in greater residual soil OC than the NPK fertilizer and the unfertilized control treatments. Ntselamanzi soil had less residual OC when compared to Gqumahashe soil.

Residual soil P increased significantly with increased manure application in both soils, although the Gqumahashe soil had lower residual P than the Ntselamanzi soil. The results agree with Eghball and Power (1999) who reported accumulation of soil P as a result of manure application.

In both soils, residual soil K was observed to be above the critical levels of 80 to 120 mg K ha^{-1} (Bornman *et al*. 1989). The 10 t ha^{-1} manure rate compared well with the NPK fertilizer while manure rates $\leq$ 5 t ha^{-1} were comparable to unfertilized control. The Gqumahashe soil had more residual soil K when compared to the Ntselamanzi soil. Although both residual Mg and Ca increased with manure application in Ntselamanzi soil, the increase was not consistent, whereas there was no response in the Gqumahashe soil. This may be due to the fact that these nutrients were above the critical levels. Gqumahashe soil had more of these nutrients when compared to Ntselamanzi soil.

Zinc was not a problem in both the Ntselamanzi and the Gqumahashe soils as levels in all treatments including the unfertilized control were above the critical range of 1.5 – 2 mg Zn kg^{-1} (Bornman *et al*., 1989). In both soils plots fertilized with NPK fertilizer had highest levels of residual Zn when compared to plots fertilized with manure and the unfertilized control. This observation could be explained by the Zn included in the formulation of the NPK fertilizer. The Gqumahashe soil had greater residual Zn when compared to the Ntselamanzi soil.

Table 3.7: The effects of manure application on residual nutrients of two different soils

Manure rate ($t\ ha^{-1}$)	pH (KCl)		Total N %		OC %		Selected nutrients									
							P		K		Mg		Ca		Zn	
							---mg kg^{-1}---									
	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu	Ntse	Gqu
0	5.0de*	4.7f	0.1	0.1	0.7e	1.4bc	16.2f	6.9f	147h	294de	417.7c	606.7a	1950d	4041ab	3.13de	4.6cd
1.3	5.0de	4.8ef	0.1	0.1	0.9d	1.4c	31.5de	14.7f	177gh	363bc	410.3c	678.3a	2075cd	4049ab	2.79e	6.3c
2.5	5.2bcd	4.9ef	0.1	0.1	0.8de	1.5ab	39.4c	19.7def	198gh	343cd	427.0c	671.3a	2051cd	3985b	3.75de	6.7
5.0	5.3bc	5.1cde	0.1	0.1	0.7e	1.6ab	40.9c	20.5ef	206fg	381bc	415. 7c	659.0a	2010d	4219a	2.50e	6.4b
10	5.7a	5.4b	0.1	0.2	0.8de	1.7a	68.5b	34.7cd	297de	448a	479.0b	651.0a	2268c	4017ab	3.39de	5.7bc
NPK fert	4.2g	4.4g	0.1	0.2	0.5f	1.4c	168.3a	62.8b	262ef	410ab	389.7c	622.3a	1893d	4087ab	9.61a	8.4a
CV (%)	3.28		13.0		7.1		21.7		11.6		8.1		4.4		19.4	

Ntse = Ntselamanzi Soil   Gqu = Gqumahashe Soil

*Means within each soil nutrient and soil type followed by the same letter are not significantly different at $p < 0.05$ according to the LSD test.

3.4 CONCLUSIONS

Plants grown in the Ntselamanzi soil had greater plant height when compared to those grown in the Gqumahashe soil. However, there was more positive response to manure application in plants grown in the Gqumahashe soil than those in Ntselamanzi soil. As a result, plants grown in the Gqumahashe soil accumulated more fresh and dry matter yield even when low manure rates ($\geq$ 2.5 t ha^{-1}) were applied. There was more response in terms of accumulation of nutrients such as N, Ca and Fe in plants grown in the Gqumahashe soil when compared to those in the Ntselamanzi soil. There were also more residual nutrients (OC, K, Mg and Ca) left in the Gqumahashe soil than in the Ntselamanzi soil. Whereas the reverse was true for soil P, these nutrients could benefit the next crop, and the P accumulation could have negative effects if it ends up in surface water bodies where it causes eutrophication.

CHAPTER 4

EFFECTS OF SHEEP KRAAL MANURE APPLICATION RATES AND INTERCROPPING WITH MAIZE ON GROWTH, NUTRIENT UPTAKE AND YIELD OF VEGETABLE *AMARANTHUS* ACCESSION IN CENTRAL EASTERN CAPE, SOUTH AFRICA

4.1 INTRODUCTION

Small-scale crop production in the Eastern Cape focuses mainly on growing crops such as maize, beans and pumpkins on individual holdings of between 1 and 3 ha and vegetable production of cabbage, spinach, onions, peas and carrots in gardens near their homesteads (Mandiringana *et al*., 2005, Yoganathan *et al*., 1998). Farmers use kraal manure in their homesteads to address problems of declining soil fertility (van Averberke and de Lange, 1995; Mnkeni and Mkile, 2006; Mafu, 2006). Myers (1998) and Schippers (2000) reported that *Amaranthus* responds well to good soil fertility and organic matter. Information on fertility requirements of both grain and vegetable *Amaranthus* is scanty (Elbehri *et al*., 1993). Mhlontlo *et al*. (2007) reported that sheep kraal manure applied at rates of 2.5 t ha^{-1} or higher resulted in growth, yield and nutrient uptake of *Amaranthus* similar to those of recommended NPK fertilizer.

Research has demonstrated that more land is usually required in mono-cropping than intercropping to produce the same yield per unit area (Mukhala *et al*., 1999). Willey (1979) reported that higher yields are usually obtained from intercropping because the components crops are in some way able to utilize growth resources such as light, nutrients and water rather differently, so that when grown together they complement each other and make better overall use of resources than when grown alone. Moreover, intercropping provides more household nutrients per unit area when compared to mono-cropping (Mukhala *et al*., 1999). Silwana (2000) reported that farmers in the Transkei Region of South Africa intercrop maize with crops such as beans and pumpkins in their farming systems. As a result of the limited good quality land, these farmers are not likely to grow *Amaranthus* as a sole crop but they could intercrop it with the staple maize. *Amaranthus* is reported to be among the crops which, when intercropped with maize, could improve household nutrition (Early, 1990) due to its nutritional value, adaptability to hot, dry climate and its potential for acceptance by processors and growers (Makus, 1984; Liu and Stűtzel, 2004; Spreeth *et al*., 2004).

No information could be found on intercropping of *Amaranthus* with maize in the Eastern Cape, but there have been reports that intercropping of these two crops was successful in Bolivia (Early, 1990; Apaza-Gutierrez, 2002). In the U.S., *Amaranthus*–cowpea intercrops had better yield response when compared to cowpea-millet intercrops (Myers, 1996). Responses of *Amaranthus* to fertility management could therefore be affected by its companion crop in an intercropping system. This chapter focuses on the effects of sheep kraal manure application rates and intercropping with maize on the growth, nutrient uptake and yield of *Amaranthus* in the central Region of the Eastern Cape, South Africa.

4.2 MATERIALS AND METHODS

The experiment was conducted between November 2005 and May 2006 at Somgxada Farm near Ntselamanzi Village, 3.4 km north of Alice between latitudes 32°46′52″ and 32°46′46″S and longitudes 26°50′26″ and 26°50′46″E. The soil was sandy loam classified as the Ritchie family of the Oakleaf form (Soil Classification Working Group, 1991), with 14.2 % clay, 0.73 % organic carbon, 9.5 mg P kg^{-1}, 367 mg K kg^{-1}, 3874 mg Ca kg^{-1}, 315 mg Mg kg^{-1} and 2.4 mg Zn l^{-1} with pH 5.5 (KCl). Sheep kraal manure used in the experiment was collected from Ntselamanzi Village and contained 2.1% N, 7.1% Ca, 1.5% Mg, 3.0% K, 0.2% P, 13354 ppm Fe and 210 ppm Zn.

The experiment was arranged as a split plot in a randomized complete block design (RCBD) with four replications. Main-plots comprised of sole *Amaranthus*, maize-*Amaranthus* intercropping and sole maize. Sub-plots comprised of five sheep kraal manure rates (0, 1.3, 2.5, 5.0 and 10 tons ha^{-1}) and inorganic NPK fertilizer {2:3:4(30) + 0.5% Zn} applied at a rate of 100 kg ha^{-1} (recommended for spinach) as a positive control (Makus, 1984). The land was ploughed and disked using tractor-drawn plough and disk harrow. Manure was broadcast in the designated plots and incorporated into the soil using a rotovator two weeks before *Amaranthus* seedlings were transplanted. Inorganic fertilizer was also applied by broadcasting and incorporated a day before planting.

One month old seedlings of an unclassified *Amaranthus* accession were transplanted on 08th December 2005 and maize seed, cultivar PAN 6479, was planted the following day.

In sole crop plots, maize and *Amaranthus* were planted in 4 m rows (six rows per plot) with an inter-row and intra-row spacing of 1 m and 0.3 m, respectively. Inter-row spacing in the intercrop plots was similar to the sole crop plots except that *Amaranthus* occupied the middle of the inter-row spaces of maize which also occupied inter-row spaces of *Amaranthus*. The inter-row spacing between maize and *Amaranthus* was therefore 0.5 m. Seedlings were irrigated for the first week to aid establishment and depended solely on rain afterwards. Rainfall data was recorded throughout the growing season. Management practices such as weeding were the same across the treatments and no pesticides were applied.

Data collection and sampling was done at 30 and 60 days after transplanting (DAT) of *Amaranthus*. Two plants were randomly selected from the two middle rows in each plot and uprooted. Stem girth, plant height, number of leaves and fresh matter yield (stems and leaves) were determined, before dry matter yield (leaves and stems) was determined after drying in an oven at 60^{o}C to constant weight. Oven dried leaf samples were ground, digested and analyzed for total N, P, K, Ca, Mg, Fe and Zn as described by Okalebo, Gathua and Woomer (2002). These nutrients were extracted by wet digestion using the concentrated sulphuric acid, selenium, lithium sulphate and hydrogen peroxide mixture (Anderson and Ingram, 1996). The concentration of P in the digest was then determined by the molybdenum blue colorimetric method while total bases were determined in an aliquot of the digestd sample by atomic absorption spectrometry (AAS). Total nitrogen (N) was measured using a Truspec CN Carbon / Nitrogen Analyzer (Anonymous, 2003). Nutrient uptake (N, P and K, Ca and Mg) was then calculated from the leaf dry matter and the composition of the nutrients in the leaves. Numbers of leaves, stem girth, fresh and dry shoot yields of maize were also determined at the same time. Maize grain yield at 12.5 % moisture content was also determined at physiological maturity. The data were subjected to Analysis of variance (ANOVA) using the MStat C statistical software and least significant differences (LSD), at 5% significant level, were used to separate the means.

Analysis of the advantages of intercropping was carried out using the land equivalent ratio (LER) both at 30 and 60 DAT (Mazaheri *et. al*., 2006). In calculating the LER, the assumption was that all *Amaranthus* would be harvested after 30 DAT or after 60 DAT without continuous harvesting. Partial land equivalent ratios (LERs) of *Amaranthus* dry shoot yield and maize grain yield were calculated to determine the effect of each component crop in the intercrop, using the formula LER = ∑ (Ypi / Ymi), where Yp is the yield of each crop in the intercrop and Ym is the yield of each crop in the sole crop (Mazaheri *et. al*., 2006). The partial LERs were then summed to give the total LER for the intercrop.

4.3 RESULTS AND DISCUSSIONS

4.3.1 Effects of sheep kraal manure application rates on growth of Amaranthus intercropped with maize

Plant height, number of leaves and stem girth of *Amaranthus* increased with manure rates at 30 and 60 DAT in both sole cropping and intercropping (Table 4.1). Intercropped

Amaranthus plants had higher plant height when compared to sole cropped plants at manure rates ≥ 2.5 t ha^{-1}, both at 30 and 60 DAT. While intercropped plants fertilized with manure rates ≥ 2.5 t ha^{-1}were comparable to NPK fertilizer, sole cropped plants needed manure rates ≥ 5 t ha^{-1} to be comparable to NPK and lower rates compared well to unfertilized control. This could be as a result of competition for light between maize and *Amaranthus.* Willey, (1979) also observed that intercropped plants grew faster than sole cropped plants as a result they used nutrients more efficiently when compared to sole cropped plants. The results are also consistent with the conclusion reached by Elbehri *et al*. (1993) who reported that *Amaranthus* plant height was increased at higher nitrogen application rates.

At 30 DAT, intercropped plants grown with manure had more leaves and greater stem girth when compared to unfertilized control. Manure rates 1.3 and 2.5 t ha^{-1}, resulted in intercropped plants with comparable number of leaves and stem girth but less than the 5, 10 t ha^{-1} manure and NPK fertilizer treatments. Sole cropped plants fertilized with 1.3 t ha^{-1} manure had number of leaves and stem girth comparable to unfertilized control. While plants fertilized with 2.5 and 5 t ha^{-1} manure had comparable number of leaves and stem girth, they were less when compared to 10 t/ha manure and NPK fertilizer.

At 60 DAT, both intercropped and sole-cropped plants grown with ≤ 5.0 t ha^{-1} manure had comparable number of leaves with the unfertilized control whereas plants grown with 10 t ha^{-1} manure compared well to NPK fertilizer. This could be as a result of exhaustion of nutrients after 60 days of growth. Sole-cropped plants grown with manure (≥ 1.3 t ha^{-1}) had comparable stem girth with those in the inorganic NPK fertilizer treatment, whereas intercropped plants fertilized with ≤ 5 t ha^{-1} had stem girth comparable to the unfertilized control at 60 DAT. Plants fertilized with 10 t ha^{-1} manure compared well with those grown with inorganic NPK fertilizer.

Generally, intercropped plants had fewer leaves when compared to sole-cropped plants and this could suggest that in intercropping system, more nutrients were partitioned towards stem elongation than leaf production. The results are in agreement with those of Spreeth *et al*. (2004), who also reported increased number of leaves in *Amaranthus* due to application of poultry manure, kraal manure and inorganic NPK fertilizer.

Table 4.1: Effects of kraal manure application and intercropping with maize on growth of *Amaranthus*

Manure Rates (t ha^{-1})	Plant Height (cm)				Number of leaves				Stem Girth (cm)			
	30 DAT		60 DAT		30 DAT		60 DAT		30 DAT		60 DAT	
	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2
0	42.5e*	43.9e	102.6e	139.4cd	141f	146f	412e	404e	1.8ef	1.7f	2.8d	2.9cd
1.3	43.8e	48.4cde	122.7de	167.8a	166ef	188cde	427de	418de	1.9def	2.2cd	3.3abc	3.1bcd
2.5	47.1de	52.3bcd	144.0abcd	162.1abc	182de	205bcd	508cd	479cde	2.2cde	2.3bcd	3.3abc	3.1bcd
5.0	50.7cd	54.5abc	145.1abcd	154.0abc	183de	213abc	492cde	488cde	2.3bc	2.3bc	3.2ab	3.0cd
10.0	54.4abc	57.9ab	142.6bcd	165.3ab	227ab	229ab	613ab	566bc	2.6abc	2.4abc	3.2abcd	3.3abc
NPK fertilizer	58.7a	57.4ab	144.3abcd	158.0abc	242a	236a	665a	549bc	2.7a	2.7ab	3.5a	3.3abc
CV (%)	8.30		11.73		10.61		12.65		12.50		8.34	

CS1= Amaranthus Sole Cropping   CS2= Maize/*Amaranthus* Intercropping

*Means within each growth parameter and sampling time followed by the same letter are not significantly different at $p < 0.05$.

4.3.2 Effects of sheep kraal manure application rates on fresh and dry matter yields of Amaranthus intercropped with maize

Amaranthus fresh and dry matter yields increased significantly as a result of increased manure application rates (Tables 4.2 and 4.3).

Fresh matter yield of sole cropped *Amaranthus* plants grown with ≤ 5 t ha^{-1} manure was comparable to unfertilized control while those grown with 10 t ha^{-1} manure compared well to NPK fertilizer at 30 and 60 DAT. Conversely, intercropped plants grown at all manure rates compared well with NPK fertilizer in terms of fresh matter yield when compared to unfertilized control. However, fresh leaf and stem weight of intercropped plants grown with 1.3 t ha^{-1} manure compared well with unfertilized control while those grown with ≥ 2.5 t ha^{-1} manure compared well to NPK fertilizer at 30 DAT. The results show that the nutrients absorbed by fast growing intercropped *Amaranthus* plants were partitioned towards leaf biomass and stem thickening. Intercropping *Amaranthus* could therefore result in earlier harvests of the leaves as the crop is forced to grow faster as a result of competition.

Sole and intercropped plants grown with ≥ 2.5 t ha^{-1} manure had comparable dry shoot yield with the NPK fertilizer whereas plants grown with 1.3 t ha^{-1}manure compared well with the unfertilized control. There were no interaction effects between cropping system and manure/fertilizer treatments, which suggested that competition for nutrients between maize and *Amaranthus* was not evident at 30 DAT. Intercropped plants had lower fresh and dry shoot yields when compared to sole-cropped plants across the treatments and did not respond to manure rates at 60 DAT. Shoot yield results compared well with those obtained by Allenmann *et al.* (1996) at ARC-Roodeplaat in Pretoria, South Africa. This may be because of the higher rainfall obtained during the growing season (rainfall data were 28.1 mm, 90.4 mm, 110.3 mm, 24.4 mm and 72.7 for December, January, February, March and April respectively)

Table 4.2: Effects of kraal manure application and intercropping with maize on fresh matter yield of *Amaranthus*

Manure Rates (t ha^{-1})	Leaves (g plant^{-1})				Stems (g plant^{-1})				Shoot (g plant^{-1})			
	30 DAT		60 DAT		30 DAT		60 DAT		30 DAT		60 DAT	
	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2
0	74.90f*	85.1f	170.2cd	159.5d	100.8f	135.5ef	563.5d	676.5cd	194.5f	362.6abcd	733.7d	836.0cd
1.3	86.70ef	123.0de	240.2bcd	229.2bcd	127.5ef	189.1cde	697.0bcd	842.5abcd	239.3def	306.7cdef	937.3bcd	1071.7abcd
2.5	84.60f	143.7bcd	290.6ab	239.1bcd	149.7def	219.0bcd	883.7abcd	1071.5ab	218.1ef	336.9abcde	1174.4abcd	1310.7ab
5.0	110.90def	170.9abc	235.4bcd	298.7ab	209.5bcd	261.9ab	793.4abcd	1074.1ab	320.4bcdef	377.2abc	1028.8abcd	1372.8ab
10.0	129.80d	173.1ab	269.2abc	265.8abc	252.5abc	248.0abc	794.2abcd	98.8abc	382.3abc	454.7a	1063.4abcd	1251.6abc
NPK fertilizer	135.7cd	180.7a	360.0a	259.8abcd	312.8a	301.7a	1108.7a	1183.5a	448.6ab	325.3bcde	1467.7a	1443.4a
CV%	20.2		28.5		23.9		30.5		27.2		28.5	

CS1= *Amaranthus* Sole Cropping CS2= Maize/*Amaranthus* Intercropping

*Means within each yield parameter and sampling time followed by the same letter are not significantly different at $p < 0.05$.

Table 4.3: Effects of kraal manure application and intercropping with maize on dry matter yield of *Amaranthus*

Manure Rates ($t\ ha^{-1}$)	Leaves ($g\ plant^{-1}$)				Stems ($g\ plant^{-1}$)				Shoot ($g\ plant^{-1}$)			
	30 DAT		60 DAT		30 DAT		60 DAT		30 DAT		60 DAT	
	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2
0	14.2ef*	10.4f	46.1de	43.9e	13.9e	14.6de	114.9d	123.2cd	28.3ef	25.0f	161.0e	167.0de
1.3	17.8de	17.8cde	54.1bcde	50.2cde	16.0cde	19.5bcde	166.2bcd	130.8cd	31.3def	37.4cde	220.3bcde	181.0cde
2.5	20.2bcde	19.2bcde	60.1abcde	59.7abcde	16.8cde	22.7abc	174.1abc	187.7ab	36.6cde	41.9bcd	234.2abcd	247.3abc
5.0	24.0abcd	20.8bcd	60.5abcd	64.2abc	22.4abc	21.7abcd	177.7abc	194.8ab	43.5bc	42.5bc	238.2abc	258.9ab
10.0	24.3ab	24.2abc	64.3abc	60.7abcd	19.4bcde	24.8ab	179.7abc	212.4ab	44.2bc	49.0ab	244.0abc	273.1ab
NPK fertilizer	28.9a	27.9a	73.1a	69.6ab	27.1a	28.5a	215.0ab	230.2a	57.3a	56.3a	288.1ab	299.7a
CV (%)	21.6		19.4		25.1		22.5		18.6		20.2	

CS1= *Amaranthus* Sole Cropping   CS2= Maize/*Amaranthus* Intercropping

*Means within each yield parameter followed by the same letter are not significantly different at $p < 0.05$.

4.3.3 Effects of sheep manure rates on nutrient composition and uptake of Amaranthus leaves intercropped with maize 30 DAT

In both sole and intercropped *Amaranthus*, the composition of N, P, K, Ca, Mg and Zn, in the leaves, was similar to those reported by Makus (1984) who worked with different accessions of *Amaranthus* except for Fe, which had lower values (Table 4.4). Nitrogen in leaves of sole cropped *Amaranthus* plants did not respond to the applied manure as compared to intercropped plants. Intercropped plants grown with ≥ 2.5 t ha^{-1} manure had more nitrogen than plants grown with 1.3 t ha^{-1} manure and the unfertilized control, and were comparable to NPK fertilizer. An increase in nitrogen and phosphorus in intercropped *Amaranthus* plants could have emanated from the fast growth (Table 4.1) which resulted in more nutrients absorption when compared to sole cropped plants. No effects of manure application were observed on K, Ca, Mg and Fe in both systems possibly because the soil had high levels of these nutrients. The results agree with Ore-Oluwa (1981) who observed no effects of nitrogen on accumulation of N, P, K, Ca, Mg and Zn in sole cropped *Amaranthus* leaves. Although leaf Fe results agree with those reported by Jansen van Rensburg *et al*. (2004), application of different manure rates in sole and intercropped *Amaranthus* plants did not show significant response.

Uptake of N, P, K, Ca and Mg increased with increase in manure application in both cropping systems (Table 4.5). Uptake of N, P, K and Ca of sole-cropped *Amaranthus* grown with ≤ 2.5 t ha^{-1} manure compared well to unfertilized control, while higher manure rates resulted in uptake similar to NPK fertilizer. Irrespective of the cropping system, responses of *Amaranthus* to manure treatments in the Ntselamanzi experiment were essentially similar to those reported by Mhlontlo *et al*., (2007) who applied different levels of manure on sole cropped *Amaranthus* grown on the Gqumahashe soil as in Chapter 2. This is despite the fact that *Amaranthus* responded differently to manure treatments in the two soils in the pot study. Manure rates from 1.3 to 5 t ha^{-1} resulted in more N and P uptake when compared to unfertilized control, which could explain the biomass response to manure application. However, the levels of nutrient uptake for the corresponding treatments were higher in the Ntselamanzi than the Gqumahashe work. This could be the effect of a more fertile, deeper soil or better season and better quality manure.

Table 4.4: Effects of sheep manure rates and intercropping with maize on nutrient composition of *Amaranthus* leaves 30 DAT

Manure Rates ($t\ ha^{-1}$)	Selected Nutrients													
	N		P		K		Ca		Mg		Fe		Zn	
	---%---										---mg kg^{-1}---			
	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2
0	1.9g	2.7cde	0.2c	0.3bc	3.7bc	3.7c	6.3abc	5.3c	1.6ab	1.6b	153.5bc	133.0bc	63.8abc	58.8bc
1.3	2.3efg	3.0bcd	0.2c	0.3a	3.9abc	4.0abc	6.5abc	5.5bc	1.7ab	1.7ab	182.6abc	139.8bc	74.5abc	65.5abc
2.5	2.4defg	3.3abc	0.2c	0.3ab	4.5ab	4.0abc	5.7abc	5.6abc	1.7ab	1.7ab	177.1abc	181.6abc	68.1abc	57.0c
5.0	2.6def	3.4ab	0.3bc	0.4a	4.3abc	4.2abc	6.1abc	5.3c	1.6ab	1.6ab	179.2abc	146.8bc	73.0abc	78.4a
10.0	2.0fg	3.7a	0.2c	0.4a	4.7a	4.0abc	6.6ab	5.6abc	1.7ab	1.7a	223.1a	122.0c	73.6abc	75.6ab
NPK fertilizer	2.3efg	3.9a	0.3bc	0.4a	4.4abc	3.7c	6.7a	5.9abc	1.7a	1.7a	190.95ab	146.6bc	63.8abc	67.4abc
CV (%)	15.7		19.7		12.6		13.8		6.5		26.9		18.3	

CS1= *Amaranthus* Sole Cropping CS2= Maize/*Amaranthus* Intercropping

*Means within each nutrient and sampling time followed by the same letter are not significantly different at $p < 0.05$.

Table 4.5: Effects of sheep manure application and intercropping with maize on nutrient uptake of *Amaranthus* leaves at 30 DAT

Manure Rates (t ha^{-1})	Nutrient uptake (mg plant^{-1})									
	N		P		K		Ca		Mg	
	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2	CS 1	CS 2
0	281.2e	279.9e	30.9ef	24.7f	537.6de	372.0e	903.9de	548.3e	229.9ef	159.6f
1.3	406.7de	554cd	39.8def	61.0cd	705.3cde	722.0cde	1178.4bcd	989.0cde	297.1de	293.2de
2.5	492.4cde	669.17bc	46.6cdef	62.0cd	913.1abcd	777.5bcd	1259.1bcd	1028.7cde	339.8cd	316.2cde
5.0	619.5cd	696.5bc	61.6cd	71.8bc	1024.5abc	881.0abcd	1468.1abc	1123.2bcd	390.7bcd	339.4cd
10.0	495.4cde	888.5ab	56.1cde	92.1ab	1139.1ab	999.4abc	1615.6ab	1407.9bcd	403.2abc	406.6abc
NPK fertilizer	649.2bcd	1082.5a	72.4bc	107.5a	1250.2a	1037.0abc	1930.9a	1625.9ab	505.3a	470.7ab
CV (%)	29.6		29.8		30.6		28.5		20.8	

CS1= *Amaranthus* Sole Cropping CS2= Maize/*Amaranthus* Intercropping

*Means within each nutrient and sampling time followed by the same letter are not significantly different at $p < 0.05$.

4.3.4 Effects of sheep manure application rates on shoot matter yield of maize intercropped with Amaranthus 30 and 60 DAT

Fresh and dry shoot yields of both sole-cropped and intercropped maize increased with increased manure application rates at 30 DAT (Table 4.6). However, number of leaves and stem girth did not respond to the applied manure. Both sole and intercropped plants grown with ≥ 2.5 t ha^{-1} manure had fresh and dry shoot yield comparable to NPK fertilizer whereas plants grown with 1.3 t ha^{-1} manure compared well to the unfertilized control. There were no interaction effects observed due to cropping system and the manure treatments, in agreement with the results of *Amaranthus* dry shoot yield, which further suggested that competition for nutrients between maize and *Amaranthus* was not evident at 30 DAT.

At 60 DAT, manure application did not have an effect on number of leaves in both cropping systems and across the treatments (Table 4.7). A similar trend was observed for the stem girth of sole-cropped maize plants. However, intercropped plants grown with ≥ 2.5 t ha^{-1} manure had comparable stem girth with the NPK fertilizer while plants grown with 1.3 t/ha compared well to the unfertilized control. Manure application resulted in increased fresh and dry shoot yield of sole cropped maize when compared to the unfertilized control and was comparable to the NPK fertilizer treatment. Although fresh and dry shoot yield of intercropped plants appeared to increase as a result of manure application, the response was not statistically significant. This lack of response of intercropped plants to manure rates could be associated with competition for nutrients between maize and *Amaranthus*. The sole cropped maize results agreed with those observed by Mkile (2001) who reported that sole-cropped maize dry matter yield increased with increased kraal manure rates

Table 4.6: Effects of kraal manure application and intercropping with *Amaranthus* on growth and shoot matter yield of maize 30 DAT

Manure Rates ($t\ ha^{-1}$)	Number of leaves		Stem Girth (cm)		Fresh Shoot Yield ($g\ plant^{-1}$)		Dry Shoot Yield ($g\ plant^{-1}$)	
	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2
0	11.0	12.0	1.7	1.8	87.7b	80.4b	27.6bc	24.9c
1.3	11.0	11.0	1.9	1.8	88.2b	88.0b	27.4bc	24.8c
2.5	11.0	12.0	2.1	1.9	109.2ab	104.4ab	35.3abc	34.0abc
5.0	11.0	11.0	2.1	1.9	118.4ab	100.0ab	41.3ab	30.8abc
10.0	10.0	11.0	1.8	2.1	111.7ab	119.2ab	39.4ab	41.2ab
NPK fertilizer	11.00	11.0	2.1	2.03	135.27a	110.2ab	44.6a	38.0abc
CV (%)	6.6		15.3		26.0		28.4	

CS1= Maize Sole Cropping CS2= Maize/*Amaranthus* Intercropping

*Means within each yield parameter followed by the same letter or none at all are not significantly different at $p < 0.05$ according to the LSD test.

Table 4.7: Effects of kraal manure application and intercropping with *Amaranthus* on growth and shoot matter yield of maize 60 DAT

ManureRates (t ha^{-1})	Number of leaves		Stem Girth (cm)		Fresh Shoot Yield (g plant^{-1})		Dry Shoot Yield (g plant^{-1})	
	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2
0	16.0*	16.0	2.2e	2.3e	1016.3b	581.5cd	566.4c	173.9d
1.3	15.0	16.0	3.4a	2.4de	1186.4ab	630.6c	730.8ab	193.4d
2.5	15.0	16.0	3.2a	2.7cd	1089.9ab	767.7c	604.6bc	231.0d
5.0	16.0	16.0	3.1a	2.8bc	1168.4ab	793.4c	714.8ab	253.2d
10.0	16.0	16.0	3.1a	2.6cd	1246.0a	772.2c	740a	252.4d
NPK fertilizer	16.0	16.0	3.1ab	2.8c	1208.7a	752.4c	776.35a	223.7d
CV (%)	4.7		7.4		13.2		19.9	

CS1= Maize Sole Cropping CS2= Maize/*Amaranthus* Intercropping

*Means within each yield parameter followed by the same letter or none at all are not significantly different at $p < 0.05$ according to the LSD test.

4.3.5 The effects of sheep manure application rates on maize grain yield intercropped with Amaranthus

Although sole cropped maize grain yield increased with increase in manure application rates, intercropped maize grain yield did not respond significantly to manure application (Figure 4.1). Grain yield obtained from intercropped plants was far below the yield obtained from sole cropped plants and followed a similar trend observed for maize dry shoot yield at 60 DAT (Table 4.7). Sole-cropped maize grown with ≥ 5 t ha^{-1} manure had grain yield comparable to NPK fertilizer whereas when ≤ 2.5 t ha^{-1} manure was applied, grain yield compared well with unfertilized control. The results were consistent with those of Mkile (2001) who reported that when kraal manure is applied at the rate of 5 t ha^{-1} maize yields were comparable to those obtained with the recommended inorganic fertilizer

The relationship observed between maize dry shoots and grain yield was linear and had a low positive correlation, (R^2=0.29), at 30 DAT (Fig. 4.2a) and a high positive correlation (R^2=0.97) at 60 DAT (Fig. 4.2b). These results suggested that intercropping will result in negative effects on maize growth and grain yield and the effects become more apparent by 60 DAT. There is need to understand what happens to maize grain yield in the intercrop with continuous harvesting of *Amaranthus* through the season, more especially when the leafy vegetable is grown by direct seeding.

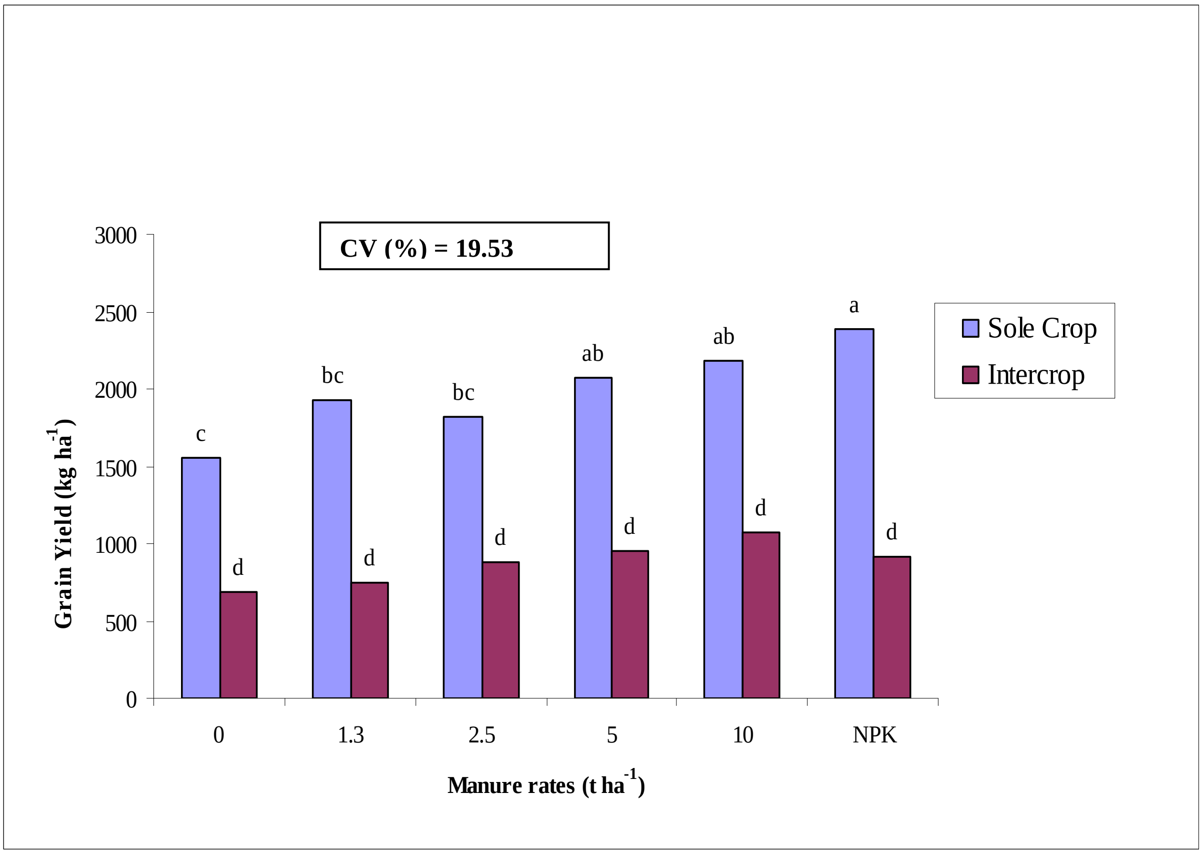
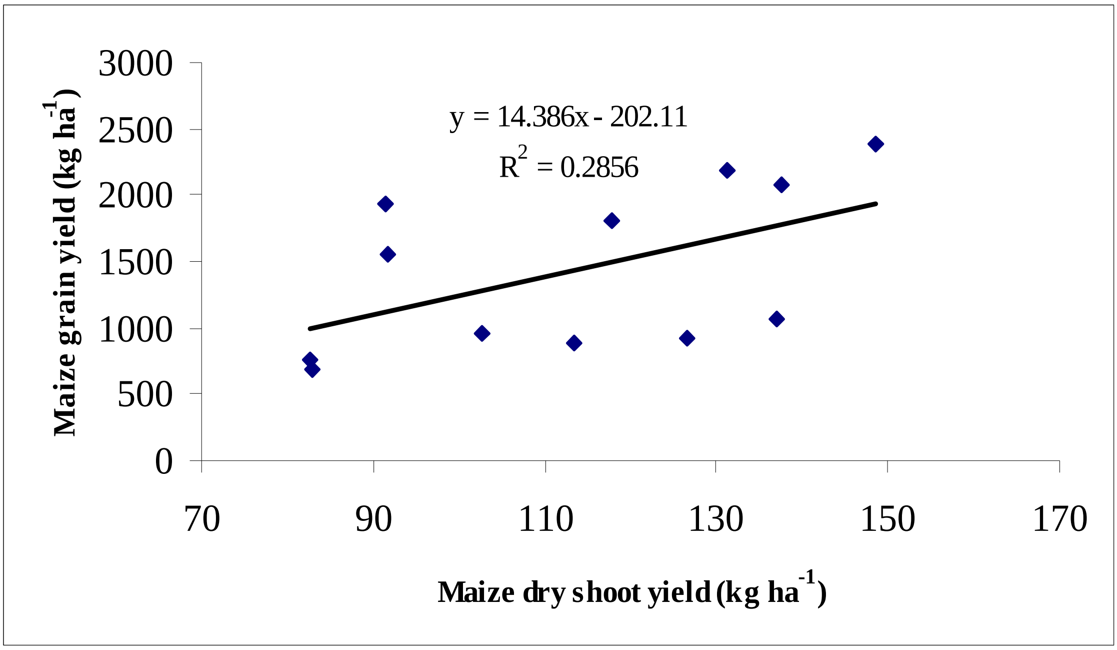


Fig. 4.1 Effects of sheep kraal manure application rates and intercropping with Amaranthus on maize grain yield

(a)



(b)

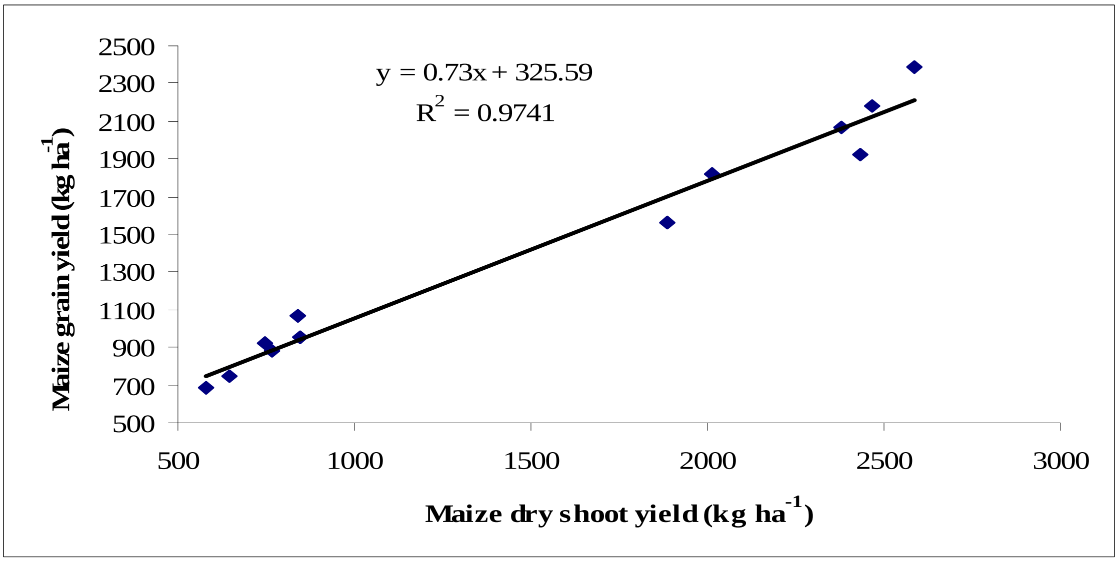


Fig. 4.2 Relationship between maize dry shoot yield at 30 DAT (a) and 60 DAT (b) with grain yield

4.3.6 The effects of sheep kraal manure application rates on residual soil nutrients

Application of manure increased residual soil pH from 5.2 to 5.4 while the NPK fertilizer had an acidifying effect (Table 4.8). Both manure and fertilizer application did not have effect on residual soil N in both sole and intercropped *Amaranthus*, suggesting that the crops exhausted most of the added N. In both sole and intercropped plots, residual extractable soil P was observed to be above the critical range. Although residual extractable P tended to increase with increase in manure application in both cropping systems there was higher residual extractable P in intercropped plots than in sole-cropped (Table 4.8). The results are consistent with Eghball and Power (1999) who reported accumulation of P as a result of manure application. The higher residual soil P could benefit the next crop, but it could also have a negative effect on Zn uptake. High soil P levels could also cause eutrophication if it ends up in surface water bodies.

Manure application had no effect on residual soil K although intercropped plots were observed to have more residual K when compared to sole-cropped plots. This could be because the experimental field did not have K deficiency problem. Residual levels of Mg increased in fertilized plots as opposed to the unfertilized controls. Plots with ≤ 5 t ha^{-1} manure had residual Ca that compared well to the unfertilized control plots although the experimental field had Ca levels above the critical value of < 800 mg Ca kg^{-1}. Although Zn residual levels increased with application of manure and fertilizer, effects of cropping system was observed in manure rates of 2.5 and 5 t ha^{-1}, where sole cropping system had more residual Zn when compared to intercropping. The presence of Zn and its uptake could explain the lower Zn levels in the intercrop than in the sole *Amaranthus* crop. Generally, the experimental field did not have Zn deficiency problem because all the treatments including control were above the critical range of 1.5 mg Zn kg^{-1} (Bornman et al. 1989).

Table 4.8: Effects of sheep kraal manure application rates and intercropping with maize on residual soil nutrients

Manure rate ($t\ ha^{-1}$)	Selected nutrients															
	pH (KCl)		Total N		OC		P		K		Mg		Ca		Zn	
			--------------------------%----------------				--mg kg^{-1}--									
	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2	CS1	CS2
0	5.3ab	5.2ab	0.1	0.1	0.5bc	0.5c	11.3d	20.5bcd	164.8	216.3	339	351	1871cd	1800d	11def	4.7f
1.3	5.3ab	5.1ab	0.1	0.1	0.6bc	0.6bc	10.9d	30.8ab	175.3	216.0	366	373	1889bcd	2059abc	17bcde	11def
2.5	5.3a	5.2ab	0.1	0.1	0.5c	0.6abc	12.7d	33.2a	193.5	220.8	386	368	1966abcd	2019abcd	19abcd	10ef
5.0	5.4a	5.4a	0.1	0.1	0.7a	0.8a	15.5d	30.6abc	202.8	231.0	397	370	1974abcd	1996abcd	27a	13cdef
10	5.4a	5.4a	0.1	0.1	0.7ab	0.6abc	18.4cd	38.1a	202.0	277.3	376	364	2135ab	2155a	21abc	12cdef
NPK fertilizer	5.1ab	5.0b	0.1	0.1	0.7ab	0.7ab	19.0bcd	37.6a	200.8	231.3	358	384	2065abc	2099abc	22ab	17bcde
CV (%)	4.0		7.0		20.6		31.1		24.1		14.8		8.6		34.6	

CS1= *Amaranthus* Sole Cropping CS2= Maize/*Amaranthus* Intercropping

*Means within each soil parameter and sampling time followed by the same letter are not significantly different at $p < 0.05$

4.3.7 Evaluation of Amaranthus dry shoot and maize grain yields at 30 and 60 DAT using partial and total Land Equivalent Ratio (LER)

Total land equivalent ratio (LER) in all treatment levels was observed to be greater than 1 at 30 DAT (Table 4.9), which indicated that intercropping of *Amaranthus* and maize had an advantage over sole cropping at this stage of growth (Mazaheri *et al*., 2006). However, at 60 DAT all treatments had a total LER of less than 1 (Table 4.10), an indication that intercropping had a negative effect on the yields of both crops. This suggests that the intercropping of *Amaranthus* with maize would be beneficial up to 30 DAT and negative effect would set in between 30 and 60 DAT, mainly affecting the maize crop. It could be useful to harvest all the *Amaranthus* at 30 DAT before it causes a negative effect on the maize. It could also be necessary to explore the possibility of continuous harvesting of *Amaranthus*. Another possibility could be to use direct seeding of *Amaranthus* at the time of planting of maize in order to get the best out of the intercropping system.

Table 4.9: Effects of sheep kraal manure application rates and intercropping of *Amaranthus* and maize on partial and total LER of *Amaranthus* dry shoot and maize grain yields at 30 DAT

Manure Rate ($t\ ha^{-1}$)	*Amaranthus* shoot yield ($g\ plant^{-1}$) Intercrop (Yp)	*Amaranthus* shoot yield ($g\ plant^{-1}$) Sole crop (Ym)	Partial LER (Ypi / Ymi)	Maize grain yield ($kg\ ha^{-1}$) Intercrop (Yp)	Maize grain yield ($kg\ ha^{-1}$) Sole crop (Ym)	Partial LER (Ypi / Ymi)	Total LER ∑(Ypi / Ymi)
0	24.9	27.6	0.9	686.0	1558.9	0.4	1.3
1.3	24.8	27.4	0.9	751.7	1927.5	0.4	1.3
2.5	34.0	35.3	1.0	883.2	1815.5	0.5	1.5
5.0	30.8	41.3	0.8	948.9	2069.7	0.5	1.2
10	41.2	39.4	1.0	1070.1	2178.8	0.5	1.5
NPK fertilizer	38.0	44.6	1.0	918.9	2385.1	0.4	1.2

Table 4.10: Effects of sheep kraal manure application rates and intercropping of *Amaranthus* and maize on partial and total LER of *Amaranthus* dry shoot and maize grain yields at 60 DAT

Manure Rate ($t\ ha^{-1}$)	*Amaranthus* shoot yield ($g\ plant^{-1}$) Intercrop (Yp)	*Amaranthus* shoot yield ($g\ plant^{-1}$) Sole crop (Ym)	Partial LER (Ypi / Ymi)	Maize grain yield ($kg\ ha^{-1}$) Intercrop (Yp)	Maize grain yield ($kg\ ha^{-1}$) Sole crop (Ym)	Partial LER (Ypi / Ymi)	Total LER ∑(Ypi / Ymi)
0	173.9	566.4	0.3	686.0	1558.9	0.4	0.7
1.3	193.4	730.8	0.3	751.7	1927.5	0.4	0.7
2.5	231.0	604.6	0.4	883.2	1815.5	0.5	0.9
5.0	253.2	714.8	0.4	948.9	2069.7	0.5	0.8
10	252.4	740.0	0.3	1070.1	2178.8	0.5	0.8
NPK fertilizer	223.7	776.4	0.3	918.9	2385.1	0.4	0.7

4.4 CONCLUSIONS

Application of manure at the rates of 2.5 t ha^{-1} or higher could improve growth and yield of both sole and intercropped *Amaranthus* in a similar way as the recommended NPK fertilizer at 30 DAT. More growth and yield was obtained from intercrops when compared to mono-crops. Although *Amaranthus* yield was not affected by presence of maize at 60 DAT, maize shoot and grain yields in intercropped plants dropped significantly when compared to sole-cropped plants. Sole cropped maize responded significantly to applied manure rates and grain yield of plants grown with 5 t ha^{-1} manure compared well to inorganic NPK fertilizer. Sheep manure application at rates of $\geq$2.5 t ha^{-1} also improved leaf nutrient composition of *Amaranthus* while at the same time there were high levels of residual soil nutrients such as P, K, Mg, Ca and Zn. It is suggested that, if *Amaranthus* is to be intercropped with maize under dry land conditions of the Central Region of the Eastern Cape, sheep manure should be applied at rate of ≥ 2.5 t/ha and the vegetable should be harvested at 30 DAT before it starts to negatively affect the yield of the companion crop. Van Averbeke (1991) also reported that planting density in maize had on water use until 30 days after planting. Other possible options that need to be investigated include continuous harvesting of *Amaranthus* in intercropping system or *Amaranthus* should be planted as seeds at the same time as maize.

CHAPTER 5

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL DISCUSSIONS

Manure rates > 2.5 t ha^{-1} resulted in increased growth, fresh and dry matter yield of *Amaranthus,* which were comparable with in the inorganic fertilizer treatment, both at 30 and 60 DAT. The results are consistent with those reported by Makus (1984), who worked with different accessions of *Amaranthus*, grown with mineral fertilizer. Elbehri *et al*. (1993) also reported increased *Amaranthus* plant height at higher nitrogen application rate. The increase in number of leaves of the accession at manure rates ≥ 2.5 t ha^{-1}also agreed with Spreeth *et al*. (2004) who grew *Amaranthus* with poultry manure, kraal manure and inorganic NPK fertilizer. However, results obtained in this study were lower than those observed by Allemann *et al.* (1996) who worked with different *Amaranthus* cultivars and the difference could be as a result of the higher fertilizer rates (700 kg ha^{-1}) and water supply through irrigation compared to the dry-land condition used in this study. Results of this study could be explained by increased nutrient supply and uptake especially N and P, which increased significantly with manure rates ≥ 2.5 t ha^{-1}. Although leaf concentrations of N, P, K, Ca and Mg were consistent with those reported by Makus (1984), Fe and Zn were lower. The difference in Fe and Zn concentrations could be as a result of different *Amaranthus* accessions used in the experiments (Walters *et al*., 1988). Although manure rates ≥ 2.5 t ha^{-1} appeared to be critical in most of the parameters studied, the critical manure rate was 1.3 t/ha for stem girth, which compared well with the inorganic fertilizer. This suggested that low amounts of nutrients were needed for increasing stem girth while the rest appear to be distributed towards stem elongation and leaf biomass production. Based on these findings, it can be concluded that sheep kraal manure rates of 2.5 t ha^{-1} or higher could result in *Amaranthus* growth, yield and nutrient uptake, similar to those of the recommended NPK{2:3:4(30) + 0.5% Zn} fertilizer under dry land conditions of the Central Region of the Eastern Cape and similar soils. Post cropping soil pH increased as a result of increased manure application, suggesting the liming effect of sheep manure, whereas NPK fertilizer resulted in lower residual soil pH values. The higher manure rates ($\geq$ 2.5 t ha^{-1}) did not have an effect on residual soil N but resulted in higher residual levels of soil P, K and Zn, when compared with the control, and this was in agreement with Eghball and Power (1999), who reported accumulation of soil P as a result of manure application. Eghball (1996) reported that higher P accumulation in the soil may result in Zn deficiency, however, this scenario was only observed in *Amaranthus* leaf concentration of these nutrients. Manure rate of 10 t/ha resulted in significantly higher residual soil Ca levels than all other treatments.

Accumulation of P, K and Ca in leaves of *Amaranthus* followed similar trends as the amounts of these nutrients in the soil after the experiment when $\geq$ 2.5 t ha^{-1} manure was applied. The results could suggest that the plants did not take up all these nutrients but only exhausted N and Zn in the soil. It could be concluded that manure rates $\geq$ 2.5 t ha^{-1} supplied enough nutrients for *Amaranthus* production in the Gqumahashe soil.

The glasshouse experiment showed that the response of *Amaranthus* growth and dry matter yield, to sheep manure application, was dependent on soil type. Application of $\geq$

2.5 t ha^{-1} manure in the Gqumahashe soil resulted in plant heights and fresh matter yield that compared well with the NPK fertilizer treatment whereas only the 10 t ha^{-1} manure treatment was comparable to the NPK fertilizer treatment in Ntselamanzi soil. Only plants grown with ≥ 5 t ha^{-1} manure had stem girth that compared well to NPK fertilizer in Ntselamanzi soil whereas in Gqumahashe soil, all manure levels compared well to NPK fertilizer. However, the opposite trend was observed for the number of leaves, with similar number of leaves across all manure and inorganic fertilizer treatments in the Ntselamanzi soil whereas only manure levels ≥ 5 t ha^{-1} compared well with the inorganic fertilizer in the Gqumahashe soil. The results are consistent with Lekasi *et al*. (1998), who obtained different results on maize grain and stover yields under two different soil conditions although similar manure treatments were applied.

In both soils, the 1.3-10 t ha^{-1} manure treatments had dry leaf weight comparable to plants grown with NPK fertilizer and it was greater than the unfertilized control and a similar trend was observed for dry stems and shoot yields in Gqumahashe soil whereas plants grown in Ntselamanzi soil did not respond, in terms of dry stems and shoot yields, to manure application. These results could be explained by nutrient composition of the plants particularly N, Fe, Zn which responded to manure application mainly in the Gqumahashe soil and only to a small extent in the Ntselamanzi soil. In Gqumahashe soil, nitrogen concentration in plants fertilized with manure (1.3 to 10 t ha^{-1}) compared well to NPK fertilizer, whereas there was no specific trend in Ntselamanzi soil. There was more nitrogen accumulation in plants grown in Gqumahashe soil than those in Ntselamanzi soil. In Gqumahashe soil, Fe accumulation compared well between plants grown with ≥ 5 t ha^{-1} manure and those grown with NPK fertilizer. There was more Fe accumulation in

Gqumahashe soil than in Ntselamanzi soil. Accumulation of Zn did not respond to manure or fertilizer application in Ntselamanzi soil whereas in Gqumahashe soil, plants in all manure treatments or NPK fertilizer accumulated more Zn than the unfertilized control.

The soil effects could be explained by the differences in the fertility status of the soils. The Gqumahashe soil was acidic (pH 4.7) and low in nutrients (P, K, Mg, Ca and Zn) when compared to the Ntselamanzi soil (pH 5.0). Both soils did not have K, Ca and Mg deficiency problems but the Gqumahashe soil was below critical levels of P and Zn whereas Ntselamanzi soil fell in the medium range (Bornman *et al.*, 1989). The liming effect of the manure raised the pH from 5.0 to 5.7 for Ntselamanzi soil and from 4.7 to 5.4 for the Gqumahashe soil (post cropping pH), while the large amounts of nutrients could have had a more significant effect on the poorer Gqumahashe soil than on Ntselamanzi soil. The added nutrients, through manure, would result in a small modification of the fertility status of the fertile Ntselamanzi soil which explains the poor response to manure treatments. The results are consistent with Myers (1998) who reported that growth and yield of *Amaranthus* plants grown on poor soils responded more to fertilizer application as compared to those grown on fertile soils. Based on these findings, improved *Amaranthus* growth and yield could be expected in fertile soils even if low manure rates are applied. In both soils, uptake of N, P and K increased as result of manure application but nonetheless, it was less when compared to plants fertilized with NPK fertilizer.

Although both soils were classified as sandy loam, the Ntselamanzi soil had more sand and clay when compared to Gqumahashe soil which had more silt. In agreement with results of the Gqumahashe field experiment (Chapter 2), residual soil P and pH increased significantly with increased manure application in both soils but Gqumahashe soil had lower levels when compared to Ntselamanzi soil. The results agree with Eghball and Power (1999) who reported accumulation of soil P as a result of manure application. In Gqumahashe soil, residual Mg and Ca did not respond to manure or fertilizer application, while Zn was higher in the Gqumahashe soil. This may be due to the fact that these nutrients were above the critical levels. Gqumahashe soil had more of these nutrients when compared to Ntselamanzi soil.

When *Amaranthus* was intercropped with maize in the Ntselamanzi soil, under field conditions, both sole and intercropping systems responded significantly to manure at 30 and 60 DAT. Cropping system did not affect fresh stem and shoot matter, and dry matter yield of *Amaranthus* both at 30 and 60 DAT, and the trend could be explained by uptake of the different nutrients. Uptake of N, P, K, Ca and Mg increased with increase in manure application in both cropping systems. However, uptake of N, P, K and Ca of sole-cropped *Amaranthus* grown with $\leq$ 2.5 t ha^{-1} manure compared well to unfertilized control while manure rates $\geq$ 5 t ha^{-1} resulted in uptake similar to NPK fertilizer. Responses of Amaranthus to manure treatments in the Ntselamanzi experiment were essentially similar to those in the Gqumahashe field experiment, irrespective of the cropping system. Manure rates from 1.3 to 5.0 t ha^{-1} resulted in more N and P uptake when compared to unfertilized control, which could explain the biomass response to manure application.

However, fresh leaf matter and plant height of *Amaranthus* were higher in the intercrop than the sole crop at manure rates ≥ 2.5 t ha^{-1}, both at 30 and 60 DAT and this could be as a result of competition for light between maize and *Amaranthus*. Willey (1979) also observed that intercropped plants grew faster than sole cropped plants and as a result they used nutrients more efficiently. This suggests that, where the *Amaranthus* accession is grown as a leafy vegetable, with manure, intercropping it with maize could increase its leaf biomass quicker.

Fresh matter yield of sole cropped *Amaranthus* plants grown with ≤ 5 t ha^{-1} manure was comparable to unfertilized control while those fertilized with 10 t ha^{-1} manure compared well to NPK fertilizer at 30 and 60 DAT. Conversely, intercropped plants grown at all manure rates compared well to NPK fertilizer in terms of fresh matter yield and stem girth when compared to unfertilized control. However, fresh leaf and stem weight of intercropped plants fertilized with 1.3 t ha^{-1} manure compared well with unfertilized control while those fertilized with ≥ 2.5 t ha^{-1} manure compared well to NPK fertilizer at 30 DAT. The results suggested that the nutrients absorbed by fast growing intercropped *Amaranthus* plants were partitioned towards increasing number of leaves and stem thickening. Intercropping *Amaranthus* could therefore result in earlier harvests of the leaves as the crop is forced to grow faster as a result of competition.

Sole cropped *Amaranthus* grown with ≥ 5 t ha^{-1} manure had plant heights, leaf and stem, drymatter yieds that compared well to NPK fertilizer and higher than the unfertilized control. Intercropped *Amaranthus* plants grown with ≥ 2.5 t ha^{-1} had plant heights comparable to NPK fertilizer and greater than the unfertilized control, suggesting that the critical manure level was lower with intercropping. The results are in agreement with Elbehri *et al*. (1993), who reported increased *Amaranthus* plant height at higher nitrogen application rates. The results suggested that there were no negative effects on growth and yield of the *Amaranthus* accession grown with manure application as a result of intercropping with maize at least up to 60 DAT. The *Amaranthus* accession could thus be intercropped with maize up to 60 DAT without loss of yield especially when manured at a rate of > 2.5 t ha^{-1}.

Sole and intercropped plants grown with ≥ 2.5 t ha^{-1} manure had fresh and dry shoot yield comparable to NPK fertilizer whereas plants fertilized with 1.3 t ha^{-1} manure compared well to the unfertilized control. There were no cropping system effects across the manure treatments, which suggested that competition for nutrients between maize and *Amaranthus* was not evident at 30 DAT. Intercropped plants had thinner stem girth, lower fresh and dry shoot yields when compared to sole-cropped plants across the treatments and did not respond to manure rates at 60 DAT. Sole cropped maize grain yield increased with increase in manure application rates while intercropped maize grain yield did not respond significantly to manure application. Grain yield obtained from intercropped plants was far below the yield obtained from sole cropped plants and followed a similar trend observed for maize dry shoot yield at 60 DAT. These results suggested that intercropping will result in negative effects on the maize growth and grain yield and the effects become more apparent by 60 DAT.

Manure application resulted in increased fresh and dry shoot yield of sole cropped maize when compared to the unfertilized control and was comparable to plants fertilized with NPK fertilizer. Although fresh and dry shoot yield of intercropped plants increased as a result of manure application, there was no significant response observed. Lack of response of intercropped plants to manure rates could be associated with competition for nutrients between maize and *Amaranthus*. The sole cropped maize results agree with those observed by Mkile (2001) who reported that sole-cropped maize dry matter yield increased with increased kraal manure rates.

Sole-cropped maize grown with $\geq$ 5 t ha^{-1} manure had grain yield comparable to NPK fertilizer whereas when $\leq$ 2.5 t ha^{-1} manure was applied, grain yield compared well with unfertilized control. The results are consistent with those of Mkile (2001) who reported that when kraal manure is applied at the rate of 5 t ha^{-1}, maize yields were comparable to those obtained with the recommended inorganic fertilizer.

Application of manure increased residual soil pH from 5.0 to 5.4, while the NPK fertilizer had an acidifying effect. Both manure and fertilizer application did not have effect on residual soil N in both cropping system, suggesting that the crops exhausted most of the added N. This finding was consistent with the findings of the Gqumahashe field experiment and the glasshouse experiment, and it highlights the high N requirements of the leafy vegetable. In both sole and intercropped plots, residual extractable soil P was observed to be above the critical range which also agreed with the findings of the Gqumahashe field experiment. Although residual extractable P increased with increase in manure application in both cropping systems, however, there was higher residual extractable P in intercropped plots than in sole-cropped. The results are consistent with Eghball (1999) who reported accumulation of P as a result of manure application.

Manure application had no effect on residual soil K although intercropped plots were observed to have more residual K when compared to sole-cropped plots. This could be because the experimental field did not have K deficiency problem which agrees well with Laker (1976) who reported that most South African soils have sufficient K. Residual levels of Mg increased in fertilized plots as opposed to the unfertilized controls. Plots fertilized with ≤ 5 t ha^{-1} manure had residual Ca that compared well to the unfertilized control plots although the experimental field had Ca levels above the critical value of < 800 mg Ca/kg. Although Zn residual levels increased with application of manure and fertilizer, effects of cropping system was observed in manure rates 2.5 and 5 t ha^{-1} manure where sole cropping system had more residual Zn when compared to intercropping. Generally, the experimental field did not have Zn deficiency problem because all the treatments including control were above the critical range of 1.5 mg Zn kg^{-1} (Bornman *et al*. 1989).

Total land equivalent ratio (LER) in all treatment levels was observed to be greater than 1 at 30 DAT, which indicated that intercropping of *Amaranthus* and maize had an advantage over sole cropping at this stage of growth. However, at 60 DAT all treatments had a total LER of less than 1, an indication that intercropping had a negative effect on the yields of both crops. This suggests that the intercropping of *Amaranthus* with maize would be beneficial up to 30 DAT and negative effect would set in between 30 and 60 DAT.

5.2 CONCLUSIONS AND RECOMMENDATIONS

The findings of Gqumahashe experiment suggested that sheep kraal manure rates of 2.5 t ha^{-1} or higher could result in *Amaranthus* growth, yield and nutrient uptake, similar to those of the recommended NPK{2:3:4(30) + 0.5% Zn} fertilizer, applied at recommended rates for spinach, under dry land conditions of the Central Region of the Eastern Cape. In addition to improved growth, the crop was enriched with iron and crude protein, which are very important in human nutrition. The sheep manure had a liming effect and high residual fertility as indicated by high levels of P, K, Mg and Zn at harvest time. Therefore, *Amaranthus* need not be fertilized with mineral fertilizers where sheep kraal manure or other forms of manure are available. Organoleptic tests are needed to establish whether or not the yield increase observed with manure addition was at the expense of the good taste of the vegetable.

In glasshouse experiment, plants grown in Ntselamanzi soil had great plant height when compared to those grown in Gqumahashe soil. However, there was more positive response to manure application in plants grown in Gqumahashe soil than those in Ntselamanzi soil. As a result, plants grown in Gqumahashe soil accumulated more fresh and dry matter yield even when low manure rates ($\geq$ 2.5 t ha^{-1}) were applied. There was more accumulation of nutrients such as N, Ca and Fe in plants grown in Gqumahashe soil when compared to those in Ntselamanzi soil. There were also more residual nutrients (K, Mg and Ca) left in Gqumahashe soil than in Ntselamanzi soil. These nutrients could benefit the next crop.

In maize-*Amaranthus* intercropping, application of manure at the rates of 2.5 t ha^{-1} or higher improved growth and yield of both sole and intercropped *Amaranthus* in a similar way as the recommended NPK fertilizer at 30 DAT. More growth and yield of *Amaranthus* was obtained from intercrop when compared to mono-crop probably because the competition for water, nutrients and sunlight that existed in intercrops resulted in intercrops absorbing nutrients and water more vigorously. However, although *Amaranthus* yield was not affected by presence of maize at 60 DAT, maize shoot and grain yields in intercropped plants dropped significantly when compared to sole-cropped plants. Sole cropped maize responded significantly to applied manure rates and grain yield of plants fertilized with 5 t manure ha^{-1} compared well to inorganic NPK fertilizer. Sheep manure application at rates of $\geq$ 2.5 t ha^{-1} also improved leaf nutrient composition of *Amaranthus* while at the same time there were high levels of residual soil nutrients such as P, K, Mg, Ca and Zn. Based on results, it is therefore suggested that, if

Amaranthus is to be intercropped with maize under dry land conditions of the Central Region of the Eastern Cape, sheep manure should at least be applied at rate of ≥ 2.5 t ha^{-1} and *Amaranthus* be harvested at 30 DAT. Other possible options that need to be investigated include continuous harvesting of *Amaranthus* in intercropping system or *Amaranthus* should be planted as seeds at the same time as maize.

5.3 RECOMMENDATIONS FOR FURTHER STUDIES

All these studies were carried out using one-month old *Amaranthus* seedlings. It would be important to know how the crop would respond to manure application if it was grown from direct seeding.

In the intercrop, the *Amaranthus* seedlings already have a one month advantage. Therefore, it would be necessary to understand what would happen to growth and yield of maize if the *Amaranthus* was produced from seed sown at the same time as the maize. Another question that arises is "What would happen to the growth and yield of the two crops if *Amaranthus* was harvested continuously as a vegetable?"

It is important to include organoleptic tests in all future studies to establish whether the responses of *Amaranthus* to fertility management could be at the expense of taste.

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APPENDICES

APPENDIX 1

ANALYSIS OF VARIANCE TABLES FOR THE FIELD GQUMAHASHE EXPERIMENT (CHAPTER 2)

Plant Height 30 DAT

ANOVA TABLE

Source	Degrees of Freedom (df)	Sum of squares	Mean Square	F value	Probability
Replication	3	91.59	30.53	0.46	
Treatment	7	1140.72	162.96	2.45	0.05
Error	21	1397.66	66.56		
Total	31	2629.97			

Grand Mean = 39.53 Grand Sum = 1265.00

CV = 20.64% LSD (0.05) = 12.00

Plant Height 60 DAT

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	321.13	107.04	1.47	0.25
Treatment	7	1963.88	280.55	3.86	0.01
Error	21	1525.88	72.66		
Total	31	3810.88			

Grand Mean =48.69 Grand Sum =1558.00

CV = 17.51% LSD (0.05) = 12.53

Stem Girth 30 DAT

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.11	0.04	0.96	
Treatment	7	1.05	0.15	3.89	0.01
Error	21	0.81	0.04		
Total	31	1.98			

Grand Mean = 1.14 Grand Sum = 36.60

CV = 17.21% LSD (0.05) = 0.29

Stem Girth 60 DAT

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.23	0.08	0.96	
Treatment	7	1.30	0.19	2.31	0.07
Error	21	1.69	0.08		
Total	31	3.22			

Grand Mean = 1.80 Grand Sum = 57.60

CV = 15.75% LSD (0.05) = 0.47

Number of leaves (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	2535.75	845.25	0.80	
Treatment	7	11838.00	1691.14	1.60	0.19
Error	21	22206.25	1057.44		
Total	31	36580.00			

Grand Mean = 101.50 Grand Sum = 3248.00

CV = 32.04% LSD (0.05) = 47.82

Number of leaves 60 DAT

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	4788.38	1596.13	1.26	0.31
Treatment	7	23109.88	3301.41	2.61	0.04
Error	21	26531.63	1263.41		
Total	31	54429.88			

Grand Mean = 132.56 Grand Sum = 4242.00

CV = 26.81% LSD (0.05) = 52.27

Fresh weight of leaves (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	958.376	319.459	1.6336	0.2118
Treatment	7	3575.899	510.843	2.6123	0.0417
Error	21	4106.624	195.554		
Total	31	8640.889			

Grand Mean = 35.556 Grand Sum = 1137.800

CV = 35.556 LSD (0.05) =20.56

Fresh weight of leaves (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	1133.227	377.742	0.4249	
Treatment	7	14333.615	2047.659	2.3033	0.0657
Error	21	18668.902	888.995		
Total	31	34135.744			

Grand Mean = 64.839 Grand Sum = 2074.850

CV = 45.98 LSD (0.05) =43.84

Fresh weight of stems (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	3.884	1.295	1.4326	0.2615
Treatment	7	17.484	2.498	2.7636	0.0335
Error	21	18.980	0.904		
Total	31	40.349			

Grand Mean = 1.793 Grand Sum = 57.368

CV = 53.03 LSD (0.05) = 41.97

Fresh weight of stems (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	12.285	4.095	1.3637	0.2811
Treatment	7	69.768	9.967	3.3191	0.0154
Error	21	63.060	3.003		
Total	31				

Grand Mean = 3.565 Grand Sum = 114.067

CV (%) = 48.61% LSD (0.05) = 76.46

Fresh shoot weight (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	12.592	4.197	1.3525	0.2845
Treatment	7	42.097	6.014	1.9378	0.1138
Error	21	65.175	3.104		
Total	31				

Grand Mean = 3.525 Grand Sum = 112.807

CV = 49.97% LSD (0.05) = 77.70

Fresh shoot weight (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	9.877	3.292	0.7167	
Treatment	7	122.477	17.497	3.8091	0.0080
Error	21	96.460	4.593		
Total	31				

Grand Mean = 6.180 Grand Sum =197.760

CV (%) = 34.68% LSD (0.05) = 94.54

Dry weight of leaves (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.021	0.007	0.6547	
Treatment	7	0.183	0.026	2.3985	0.0570
Error	21	0.229	0.011		
Total	31				

Grand Mean = 0.350 Grand Sum = 11.211

CV = 29.82% LSD (0.05) = 4.61

Dry weight of leaves (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.361	0.120	7.7405	0.0011
Treatment	7	1.045	0.149	9.5943	0.0000
Error	21	0.327	0.016		
Total	31				

Grand Mean = 0.657 Grand Sum = 21.029

CV = 18.98% LSD (0.05) = 5.50

Dry weight of stems (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.050	0.017	1.3250	0.2928
Treatment	7	0.316	0.045	3.5753	0.0109
Error	21	0.265	0.013		
Total	31				

Grand Mean = 0.295 Grand Sum = 9.436

CV = 38.13% LSD (0.05) = 4.96

Dry weight of stems (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.482	0.161	3.2450	0.0425
Treatment	7	1.717	0.245	4.9540	0.0020
Error	21	1.040	0.050		
Total	31				

Grand Mean = 0.568 Grand Sum = 18.177

CV = 39.17% LSD (0.05) = 9.82

Dry shoot weight (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.041	0.014	0.1993	
Treatment	7	1.603	0.229	3.3719	0.0143
Error	21	1.426	0.068		
Total	31				

Grand Mean = 0.952 Grand Sum = 30.469

CV = 27.37% LSD (0.05) =11.50

Dry shoot weight (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	1.673	0.558	13.5171	0.0000
Treatment	7	4.330	0.619	14.9931	0.0000
Error	21	0.866	0.041		
Total	31				

Grand Mean = 1.298 Grand Sum = 41.535

CV = 15.65% LSD (0.05) = 8.96

APPENDIX 2

ANALYSIS OF VARIANCE FOR GLASSHOUSE EXPERIMENT (CHAPTER 3)

Plant Height

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	249.764	124.882	4.7848	0.0188
Soil type	1	519.460	519.460	19.9029	0.0002
Treatment	5	876.113	175.223	6.7136	0.0006
Interaction	5	149.488	29.898	1.1455	0.3665
Error	22	574.194	26.100		
Total	35	2369.0			

Grand Mean = 49.715 Grand Sum = 1789.750
CV = 10.3% LSD (0.05) = 7.49

Stem Girth

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	0.056	0.028	1.2421	0.30083
Soil type	1	0.002	0.002	0.1110	
Treatment	5	0.889	0.178	7.8902	0.0002
Interaction	5	0.188	0.038	1.6717	0.1833
Error	22	0.496	0.023		
Total	35	1.631			

Grand Mean =0.919 Grand Sum =33.100
CV = 16.33% LSD (0.05) = 0.22

Number of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	1037.722	518.861	6.8314	0.0049
Soil type	1	1156.000	1156.000	15.2201	0.0008
Treatment	5	2908.556	581.711	7.6589	0.0003
Interaction	5	295.667	59.133	0.7786	
Error	22	1670.944	75.952		
Total	35	7068.889			

Grand Mean = 74.444 Grand Sum = 2680.000
CV = 11.71% LSD (0.05) = 12.78

Fresh weight of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	83.678	41.839	6.4372	0.0063
Soil type	1	21.934	21.934	3.3746	0.0798
Treatment	5	272.808	54.562	8.3947	0.0001
Interaction	5	52.906	10.581	1.6280	0.1943
Error	22	142.990	6.500		
Total	35	574.316			

Grand Mean =16.002 Grand Sum =576.060

CV = 15.93 % LSD (0.05) =3.74

Fresh weight of stems

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	393.983	169.991	13.2747	0.0002
Soil type	1	2.045	2.045	0.1597	
Treatment	5	350.785	70.157	5.4786	0.0020
Interaction	5	91.882	18.376	1.4350	0.2511
Error	22	281.725	12.806		
Total	35	1066.420			

Grand Mean = 24.005 Grand Sum = 864.180

CV = 14.91% LSD (0.05) = 5.25

Fresh shoot yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	760.071	380.035	12.1605	0.0003
Soil type	1	37.251	37.251	1.1920	0.2867
Treatment	5	1180.853	236.171	7.5571	0.0003
Interaction	5	239.781	47.956	1.5345	0.2200
Error	22	687.537	31.252		
Total	35	2905.492			

Grand Mean =40.008 Grand Sum =1440.280

CV = 13.97 % LSD (0.05) =8.20

Dry weight of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	5.750	2.875	4.6223	0.0211
Soil type	1	0.000	0.000	0.0004	
Treatment	5	14.985	2.997	4.8181	0.0040
Interaction	5	2.107	0.421	0.6775	
Error	22	13.685	0.622		
Total	35	36.528			

Grand Mean = 3.158 Grand Sum = 113.700

CV = 24.97% LSD (0.05) = 1.16

Dry weight of stems

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	7.201	3.600	2.4192	0.1123
Soil type	1	15.668	15.668	10.5278	0.0037
Treatment	5	8.105	1.621	1.0891	0.3940
Interaction	5	3.938	0.788	0.5292	
Error	22	32.742	1.488		
Total	35	67.654			

Grand Mean =3.585 Grand Sum =129.050

CV = 34.03 % LSD (0.05) =1.79

Dry shoot yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	2	17.823	8.911	3.3310	0.0545
Soil type	1	15.933	15.933	5.9558	0.0232
Treatment	5	37.616	7.523	2.8122	0.0413
Interaction	5	11.358	2.272	0.8491	
Error	22	58.856	2.675		
Total	35	141.586			

Grand Mean =6.557 Grand Sum =236.050
CV = 24.94 % LSD (0.05) =2.40

APPENDIX 3

ANALYSIS OF VARIANCE FOR NTSELAMANZI EXPERIMENT (CHAPTER 4)

(a) Amaranthus growth and yield

Plant Height (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	301.322	100.441	5.6110	0.0032
Cropping System	1	95.909	95.909	5.3578	0.0270
Treatment	5	1322.554	264.511	14.7765	0.0000
Interaction	5	56.155	11.231	0.6274	
Error	33	590.724	17.901		
Total	47	2366.664			

Grand Mean = 50.964 Grand Sum = 2446.250 CV = 8.30%LSD (0.05) = 6.09

Plant Height (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	1031.201	343.734	1.1778	0.3331
Cropping System	1	7032.520	7032.520	24.0959	0.0000
Treatment	5	6221.934	1244.387	4.2637	0.0042
Interaction	5	1948.709	389.742	1.3354	0.2738
Error	33	9631.214	291.855		
Total	47	25865.579			

Grand Mean =145.646 Grand Sum =6991.000

CV = 11.73% LSD (0.05) = 24.58

Stem Girth (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	2.010	0.670	8.4549	0.0003
Cropping System	1	0.000	0.000	0.0038	
Treatment	5	4.434	0.887	11.1898	0.0000
Interaction	5	0.390	0.078	0.9844	
Error	33	2.615	0.079		
Total	47	9.449			

Grand Mean = 2.252 Grand Sum = 108.100

CV = 12.50% LSD (0.05) = 0.40

Stem Girth (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.649	0.216	3.0786	0.0409
Cropping System	1	0.238	0.238	3.3882	0.0747
Treatment	5	1.310	0.262	3.7297	0.0087
Interaction	5	0.521	0.104	1.4823	0.2221
Error	33	2.318	0.070		
Total	47	5.036			

Grand Mean =3.179 Grand Sum =152.580

CV = 8.34% LSD (0.05) = 0.38

Number of leaves (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	121.417	40.472	0.0929	
Cropping System	1	2028.000	2028.000	4.6564	0.0383
Treatment	5	48095.000	9619.000	22.0856	0.0000
Interaction	5	1966.250	393.250	0.9029	
Error	33	14372.583	435.533		
Total	47	66583.250			

Grand Mean = 196.625 Grand Sum = 9438.000

CV = 10.61% LSD (0.05) = 30.02

Number of leaves (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	8697.417	2899.139	0.7188	
Soil type	1	15052.083	15052.083	3.7321	0.0620
Treatment	5	273019.500	54603.900	13.5390	0.0000
Interaction	5	18094.167	3618.833	0.8973	
Error	33	133092.083	4033.093		
Total	47	447955.250			

Grand Mean =3.179 Grand Sum =152.580

CV = 8.34% LSD (0.05) = 0.38

Fresh weight of leaves (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	11114.258	3704.753	5.7951	0.0027
Cropping System	1	21476.134	21476.134	33.5936	0.0000
Treatment	5	36856.367	7371.273	11.5303	0.0000
Interaction	5	3345.932	669.186	1.0468	0.4071
Error	33	21096.674	639.293		
Total	47	93889.366			

Grand Mean = 124.941 Grand Sum = 5997.170

CV = 20.24% LSD (0.05) = 36.37

Fresh weight of leaves (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	20877.991	6959.330	1.3570	0.2729
Soil type	1	4294.082	4294.082	0.8373	
Treatment	5	94969.480	18993.896	3.7038	0.0090
Interaction	5	29588.444	5917.689	1.1539	0.3523
Error	33	169233.435	5128.286		
Total	47	318963.433			

Grand Mean =251.490 Grand Sum =12071.500

CV = 28.48% LSD (0.05) = 103.0

Fresh weight of stems (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	59071.099	19690.366	7.8944	0.0004
Cropping System	1	13662.340	13662.340	5.4776	0.0255
Treatment	5	187914.319	37582.864	15.0680	0.0000
Interaction	5	11719.840	2343.968	0.9398	
Error	33	82309.402	2494.224		
Total	47	354677.001			

Grand Mean = 209.016 Grand Sum = 10032.770

CV = 23.89% LSD (0.05) = 71.85

Fresh weight of stems (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	376470.324	125490.108	1.7014	0.1858
Soil type	1	329635.268	329635.268	4.4693	0.0422
Treatment	5	1298327.187	259665.437	3.5206	0.0117
Interaction	5	51312.892	10262.578	0.1391	
Error	33	2433920.930	73755.180		
Total	47	4489666.601			

Grand Mean =889.457 Grand Sum =42693.950

CV = 30.53% LSD (0.05) = 390.70

Fresh shoot yield (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	131435.190	43811.730	5.4387	0.0038
Cropping System	1	43036.347	43036.347	5.3424	0.0272
Treatment	5	161065.162	32213.032	3.9988	0.0060
Interaction	5	97470.147	19494.029	2.4199	0.0564
Error	33	265833.949	8055.574		
Total	47	698840.795			

Grand Mean = 330.462 Grand Sum = 15862.170

CV = 27.16% LSD (0.05) = 129.10

Fresh shoot yield (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	379218.293	126406.098	1.1960	0.3265
Soil type	1	258668.966	258668.966	2.4473	0.1273
Treatment	5	2068440.978	413688.196	3.9140	0.0068
Interaction	5	144310.251	28862.050	0.2731	
Error	33	3487903.644	105694.050		
Total	47	6338542.131			

Grand Mean =1140.953 Grand Sum =54765.750

CV = 28.49% LSD (0.05) = 467.70

Dry weight of leaves (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	58.329	19.443	0.9647	
Cropping System	1	27.135	27.135	1.3464	0.2542
Treatment	5	1240.104	248.021	12.3059	0.0000
Interaction	5	26.034	5.207	0.2583	
Error	33	665.102	20.155		
Total	47	2016.704			

Grand Mean = 20.814 Grand Sum = 999.090

CV = 21.57% LSD (0.05) = 6.46

Dry weight of leaves (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	655.356	218.455	1.6723	0.1910
Soil type	1	33.835	33.835	0.2590	
Treatment	5	3348.050	669.610	5.1261	0.0014
Interaction	5	86.127	17.225	0.1319	
Error	33	4310.750	130.629		
Total	47	8434.126			

Grand Mean =58.858 Grand Sum =2825.200

CV = 19.42% LSD (0.05) = 16.44

Dry weight of stems (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	158.726	52.909	1.9797	0.1362
Cropping System	1	87.615	87.615	3.2783	0.0793
Treatment	5	838.446	167.689	6.2744	0.0003
Interaction	5	71.425	14.285	0.5345	
Error	33	881.961	26.726		
Total	47	2038.173			

Grand Mean = 20.617 Grand Sum = 989.630

CV = 25.07% LSD (0.05) = 7.44

Dry weight of stems (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	21691.532	7230.511	4.6451	0.0081
Soil type	1	879.369	879.369	0.5649	
Treatment	5	53589.981	10717.996	6.8855	0.0002
Interaction	5	5299.406	1059.881	0.6809	
Error	33	51367.692	1556.597		
Total	47	132827.980			

Grand Mean =175.553 Grand Sum =8426.550

CV = 22.47% LSD (0.05) = 56.76

Dry shoot yield (30 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	317.261	105.754	1.8061	0.1653
Cropping System	1	39.331	39.331	0.6717	
Treatment	5	4303.163	860.633	14.6980	0.0000
Interaction	5	163.084	32.617	0.5570	
Error	33	1932.292	58.554		
Total	47	6755.130			

Grand Mean = 41.116 Grand Sum = 1973.570

CV = 18.61% LSD (0.05) = 11.01

Dry shoot yield (60 DAT)

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	26914.078	8971.359	4.0073	0.0155
Soil type	1	568.632	568.632	0.2540	
Treatment	5	83618.687	16732.737	7.4702	0.0001
Interaction	5	5759.524	1151.905	0.5145	
Error	33	73878.116	2238.731		
Total	47	190739.036			

Grand Mean =234.393 Grand Sum =11250.810

CV = 20.19% LSD (0.05) = 68.07

(b) Maize growth and yield (30 DAT)

Number of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	4.750	1.583	3.1194	0.0391
Cropping System	1	2.083	2.083	4.1045	0.0509
Treatment	5	2.000	0.400	0.7881	
Interaction	5	3.667	0.733	1.4448	0.2344
Error	33	16.750	0.508		
Total	47	29.250			

Grand Mean = 10.9 Grand Sum = 522.0 CV = 6.55% LSD (0.05) = 1.03

Stem girth

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	1.591	0.530	6.0385	0.0021
Soil type	1	0.008	0.008	0.0942	
Treatment	5	0.457	0.091	1.0407	0.4104
Interaction	5	0.328	0.066	0.7464	
Error	33	2.898	0.088		
Total	47	5.282			

Grand Mean =1.940 Grand Sum =93.130

CV = 15.27% LSD (0.05) = 0.43

Fresh shoot yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	29081.525	9693.842	13.1548	0.0000
Cropping System	1	775.136	775.136	1.0519	0.3125
Treatment	5	9336.707	1867.341	2.5340	0.0478
Interaction	5	1425.074	285.015	0.3868	
Error	33	24317.826	736.904		
Total	47	64936.269			

Grand Mean = 104.392 Grand Sum = 5010.830

CV = 26.00% LSD (0.05) = 39.05

Dry shoot yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	3475.317	1158.439	12.3958	0.0000
Soil type	1	161.187	161.187	1.7248	0.1981
Treatment	5	1755.442	351.088	3.7568	0.0084
Interaction	5	184.431	36.886	0.3947	
Error	33	3083.989	93.454		
Total	47	8660.366			

Grand Mean =34.095 Grand Sum =1636.560

CV = 28.35% LSD (0.05) = 13.91

Maize growth and yield (60 DAT)

Number of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	10.729	3.576	6.7360	0.0011
Cropping System	1	2.521	2.521	4.7479	0.0366
Treatment	5	2.354	0.471	0.8868	
Interaction	5	1.854	0.371	0.6985	
Error	33	17.521	0.531		
Total	47	34.979			

Grand Mean = 15.646 Grand Sum = 751.0 CV = 4.66% LSD (0.05) = 1.05

Stem girth

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	0.190	0.063	1.4246	0.2531
Soil type	1	4.078	4.078	91.4838	0.0000
Treatment	5	0.143	0.029	0.6421	
Interaction	5	0.867	0.173	3.8906	0.0070
Error	33	1.471	0.045		
Total	47	6.749			

Grand Mean =2.874 Grand Sum =137.950

CV = 7.35% LSD (0.05) = 0.31

Fresh weight of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	4694.642	1564.881	1.4331	0.2507
Cropping System	1	117978.588	117978.588	108.040	0.0000
Treatment	5	2292.281	458.456	0.4198	
Interaction	5	6269.919	1253.984	1.1484	0.3550
Error	33	36035.578	1091.987		
Total	47	167271.009			

Grand Mean = 218.044 Grand Sum = 10466.100

CV = 15.16% LSD (0.05) = 47.54

Fresh weight of stems

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	62375.712	20791.904	2.6379	0.0659
Soil type	1	2047154.268	20447154.268	259.722	0.0000
Treatment	5	54033.074	10806.615	1.3710	0.2603
Interaction	5	56298.537	11259.707	1.4285	0.2399
Error	33	260109.315	7882.100		
Total	47	2479970.906			

Grand Mean =341.329 Grand Sum =16383.810

CV = 26.01% LSD (0.05) = 127.7

Fresh shoot yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	209650.084	69883.361	4.5940	0.0085
Cropping System	1	2284292.312	2284292.312	150.166	0.0000
Treatment	5	231442.174	46288.435	3.0429	0.0229
Interaction	5	65660.645	13132.129	0.8633	
Error	33	501989.604	15211.086		
Total	47	3293034.819			

Grand Mean = 934.5 Grand Sum = 44854.3 CV = 13.20% LSD (0.05) = 177.40

Dry weight of leaves

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	732.251	244.084	5.9991	0.0022
Soil type	1	4984.744	4984.744	122.514	0.0000
Treatment	5	1206.122	241.224	5.9288	0.0005
Interaction	5	25.837	5.167	0.1270	
Error	33	1342.671	40.687		
Total	47	8291.625			

Grand Mean =65.943 Grand Sum =3165.250

CV = 9.67% LSD (0.05) = 9.17

Maize grain yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	105068.271	35022.757	0.4474	
Soil type	1	14859496.304	14859496.304	189.8339	0.0000
Treatment	5	1620804.873	324160.975	4.1412	0.0050
Interaction	5	438121.254	87624.251	1.1194	0.3693
Error	33	2583117.548	78276.289		
Total	47	19606608.250			

Grand Mean =1432.849 Grand Sum =68776.730

CV = 19.53% LSD (0.05) = 402.50

Dry weight of stems

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	25981.772	8660.591	3.1528	0.0378
Cropping System	1	126824.364	126824.364	46.1685	0.0000
Treatment	5	29170.179	5834.036	2.1238	0.0871
Interaction	5	13966.985	2793.397	1.0169	0.4235
Error	33	90650.629	2746.989		
Total	47	286593.928			

Grand Mean = 216.877 Grand Sum = 10410.100

CV = 24.17% LSD (0.05) = 75.40

Dry shoot yield

ANOVA TABLE

Source	df	Sum of squares	Mean Square	F value	Probability
Replication	3	98912	32970.799	4.0077	0.0154
Soil type	1	2623563.315	2623563.315	318.906	0.0000
Treatment	5	105607.827	21121.565	2.5674	0.0455
Interaction	5	54021.322	10804.264	1.3133	0.2824
Error	33	271483.319	8226.767		
Total	47	3153588.181			

Grand Mean =455.035 Grand Sum =21841.700

CV = 19.93% LSD (0.05) = 130.5

APPENDIX 4

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Effects of sheep kraal manure on growth, dry matter yield and leaf nutrient composition of a local *Amaranthus* accession in the central region of the Eastern Cape Province, South Africa[#]

S Mhlontlo, P Muchaonyerwa and PNS Mnkeni*

Department of Agronomy, Faculty of Science and Agriculture, University of Fort Hare, Private Bag X314, Alice 5700, South Africa

Abstract

Indigenous vegetables that supply abundant amounts of protein, vitamins, calories and minerals could alleviate problems of malnutrition, in developing countries. *Amaranthus* is one such vegetable that could be domesticated and cultivated but information on its fertility requirements is scanty. A dry-land field experiment was therefore conducted to study the effects of sheep kraal manure application rates on growth, fresh and dry matter yields, nutrient uptake and grain yield of one of the *Amaranthus* accessions that grow in the wild in the Eastern Cape. The treatments were sheep kraal manure rates ranging from 0 to 10 t/ha and an NPK {2:3:4(30) + 0.5% Zn} fertiliser as a positive control at 150 kg/ha. Low manure rates (≤2.5 t/ha) resulted in plant heights and fresh matter yields which were comparable to those in the unfertilised control, whereas higher rates (5 and 10 t/ha) and NPK fertiliser gave greater plant heights and higher yields at both 30 and 60 days after transplant (DAT) ($p<0.05$). At 30 DAT, manure application rates of ≥2.5 t/ha and the NPK fertiliser treatment, produced greater shoot dry-matter yields (≥29.35 g/plant) than the unfertilised control (17.11 g/plant). Uptake of N and P in the leaves increased with increase in manure application rate with N uptake reaching a maximum of 308 mg N /plant at a manure rate of 2.5 t/ha which corresponded with the maximum dry matter yield of 45.97 g/plant. There was no effect of manure rate or fertiliser on residual soil N and Ca, whereas P, K, Mg and Zn were increased ($p<0.005$). The findings suggested that ≥2.5 t/ha sheep kraal manure could result in growth, nutrient uptake and yield comparable to 150 kg/ha NPK fertiliser for the *Amaranthus* accession used in this work.

Keywords: *Amaranthus* accession, sheep manure, dry matter yield, nutrient composition, residual nutrients

Introduction

Hunger and malnutrition are mostly experienced in developing countries where they affect growth and development of children (Aphane et al., 2003). Foods of animal origin, which are major sources of vitamins and proteins, are often too expensive for poor households (Aphane et al., 2003; Wehmeyer and Rose, 1983). Vegetables that supply abundant amounts of protein, vitamins, calories and minerals, needed in a diet, could alleviate problems associated with malnutrition (Wehmeyer and Rose, 1983). However, the production of exotic vegetables is made difficult by harsh climatic and resource-poor conditions encountered in most rural areas, where problems of malnutrition occur.

More than 100 different indigenous species, including *Amaranthus* sp., *Corchorus* genera, *Cleome gynandra*, grow well in such areas (Jansen van Rensburg et al., 2004; Aphane et al., 2003). They are popular in communities such as in the former Transkei, South Africa, where their leaves are gathered from plants growing in the wild, chopped and mixed with maize meal to prepare a traditional meal known as '*imifino*' or '*isigwampa*' (Wehmeyer and Rose, 1983). *Amaranthus* could be cultivated in areas of Southern Africa where there is inadequate or unreliable rainfall (Jansen Van Rensburg et al., 2004) but information on its fertilisation requirements is limited (Elbehri et al., 1993). Moreover chemical fertilisers are expensive for the resource-poor farmers who often utilise those vegetables (Jansen Van Rensburg et al., 2004). Hence there is need to investigate cheaper sources of nutrients such as animal manures. According to Schippers (2000), the crop gives good yield when high levels of nitrogen are applied and it responds well to organic matter.

Farmers in the Eastern Cape use kraal manure in their maize-based cropping systems to address problems of declining soil fertility (Van Averbeke and De Lange, 1995). While guidelines exist on the use of kraal manure for crops such as maize (Van Averbeke and Yoganathan, 1997), no information could be found on the use of kraal manure on *Amaranthus* in the Eastern Cape. This article reports on effects of sheep kraal manure application rates on growth, fresh and dry matter yields, nutrient uptake and grain yield of a local *Amaranthus* accession in the central region of the Eastern Cape.

Experimental

The experiment was conducted between November 2002 and May 2003 in Gqumahashe village (32° 45' S; 26° 52' E), five km north of Alice town. The soil contained 0.026% K, 0.35% Ca, 0.044% Mg, 2.5 mg P/ℓ and 1.4 mg Zn/ℓ, with pH 5.3 (in KCl). Sheep kraal manure used in this study was collected from kraals in the village and contained 1.8% N, 3.7% Ca, 1.4% Mg, 0.37% P, 16 000 mg/kg Fe and 872 mg/kg Zn. It was applied to the soil at different rates (0, 0.3, 0.6, 1.2, 2.5, 5.0 and 10 t/ha). Inorganic NPK fertiliser {2:3:4(30) + 0.5% Zn} was applied at a rate of 150 kg/ha, the rate recommended for spinach by Makus (1984), as a positive control. The experiment

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* To whom all correspondence should be addressed.

☎ +2740 602 2139; fax: +2740 653 1730;
e-mail: pmnkeni@ufh.ac.za

was arranged in a randomised complete block design (RCBD) with four replications. Sheep kraal manure was broadcast in the designated plots after land preparation and incorporated into the soil, using a rotavator, two weeks before transplanting. Inorganic fertiliser was also applied by broadcasting and incorporated a day before planting.

One-month-old seedlings of an unclassified *Amaranthus* accession that grows in the wild in the Eastern Cape were transplanted on 17 December 2002, in 6 m rows (6 rows /plot) with an inter-row spacing of 1 m and intra-row spacing of 30 cm. The seedlings were then irrigated for the first week to aid establishment, whereafter they solely depended on rain. Other management practices, like weeding, were the same across the treatments. No pesticides were applied. Data collection and sampling for growth, fresh and dry matter yields, were done at 30 and 60 d after transplanting (DAT). Two plants were randomly selected from the two middle rows in each plot and uprooted. Stem girth, plant height, number of leaves and fresh mass (stems and leaves) were determined, before dry matter (leaves and stems) was determined after drying in an oven at 60°C to constant mass. All oven-dried leaf samples were ground, digested and analysed for total N, P, K, Ca, Mg, Fe and Zn as described by Okalebo et al. (2002). Nutrient uptake (N, P, K, Ca, Mg, Fe and Zn) was then calculated from the leaf dry matter and the composition of the nutrients in the leaves. Grain mass and residual soil nutrient composition were determined at 90 DAT. Analysis of variance (ANOVA) was done using the MStat C statistical software and least significant differences (LSD) at 5% significant level were used to separate the means.

Results and discussion

Effects of sheep manure application rate on growth of *Amaranthus*

Plant height, number of leaves and stem girth, increased significantly ($p<0.05$) with an increase in sheep kraal manure application rate (Table 1). At low manure rates (≤2.5 t/ha), the plants had comparable height to those in the unfertilised control, whereas higher rates (5 and 10 t/ha) and NPK fertiliser resulted in greater plant heights both at 30 and 60 DAT. Similar results were observed by Elbehri et al. (1993), who reported increased *Amaranthus* plant height at higher nitrogen application rate. At low manure rates (≤1.3 t/ha) the number of leaves were comparable to the unfertilised control, whereas higher rates (2.5 to 10 t/ha) and the NPK fertiliser treatments produced larger numbers of leaves both at 30 and 60 DAT. These responses could be ascribed to increased uptake of nutrients as a result of the availability of larger amounts of nutrients in the soil as the amount of manure increased.

Manure application resulted in larger stem girth when compared to the unfertilised control but there was no additional response to increased application from 0.3 to 10 t/ha, giving values similar to that obtained with the NPK fertiliser. These results appear to indicate that addition of manure at 0.3 t/ha provided sufficient nutrients for maximum stem girth at growth stages up to 60 DAT and the rest of the nutrients were partitioned towards stem elongation and leaf production.

Sheep manure application effects on fresh yield of *Amaranthus*

Fresh matter yield (leaf, stem and shoot) increased significantly ($p<0.05$) with an increase in sheep kraal manure application rate (Table 2). Where low rates of kraal manure (≤2.5 t/ha) were applied, leaf stem and shoot fresh matter yields were comparable to unfertilised control both at 30 and 60 DAT. Higher rates of sheep kraal manure (5 and 10 t/ha) produced higher fresh matter yields than the unfertilised control, giving values similar to that obtained with the NPK fertiliser. At the higher sheep kraal manure application rates, the results compared well with those reported by Makus (1984) for different accessions of *Amaranthus*, fertilised with mineral fertiliser at recommended rates for spinach. The values obtained in the present study were lower than those reported by Allemann et al. (1996) for different varieties of *Amaranthus* at ARC-Roodeplaat, the research station of the Vegetable and Ornamental Plant Institute, near Pretoria. This is logical, since in the latter experiment the crop was grown under irrigation, while in the present study it was grown under rain-fed conditions in an abnormally dry season. In the irrigated experiment of Allemann et al. (1996) fertiliser applications were also much higher than in the present experiment, as is normal for irrigated conditions. In the present study the highest leaf fresh matter yield at 30 DAT was obtained with an application of 5 t/ha sheep kraal manure, while at 60 DAT it was obtained with the inorganic NPK fertiliser treatment. These results indicate that a sheep kraal manure application rate of at least 5 t/ha is critical to maximise *Amaranthus* fresh matter yield if the crop is to be cultivated and used as a vegetable.

TABLE 1
Effects of sheep kraal manure application on growth of *Amaranthus*

Manure rates (t/ha)	Plant height (cm)		Stem girth (cm)		Number of leaves	
	30 DAT*	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
0	30.50c**	37.00d	0.75c	1.40b	67b	92c
0.3	34.00bc	42.25cd	1.00bc	1.68ab	86ab	111bc
0.6	33.75bc	41.50d	1.10ab	1.70ab	86ab	112bc
1.3	38.75abc	48.25bcd	1.18ab	1.73a	99ab	122bc
2.5	40.50abc	47.75bcd	1.25ab	1.90a	117a	140abc
5.0	45.00ab	54.25abc	1.35a	1.95a	118a	150ab
10.0	47.25a	61.00a	1.30a	2.03a	126a	153ab
NPK fertiliser	46.50a	57.50ab	1.23ab	2.03a	114ab	181a
CV (%)	21	17	17	16	32	27

** DAT = Days after transplanting*
***Means in each column followed by the same letter or none at all are not significantly different at $p < 0.05$.*

TABLE 2
Effects of sheep kraal manure application on fresh matter yield of *Amaranthus*

Manure rate (t/ha)	Leaves (g/plant)		Stems (g/plant)		Shoots (g/plant)	
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
0	18.88d*	28.50c	21.73d	45.76d	45.66c	97.16d
0.3	25.85cd	51.82bc	31.39cd	66.08cd	67.47bc	132.66cd
0.6	31.08abcd	56.05bc	43.33bcd	66.43cd	96.14abc	143.53cd
1.3	28.48bcd	54.06bc	43.93bcd	96.90bcd	103.27abc	154.70bcd
2.5	38.90abcd	68.21abc	51.55abcd	113.15abcd	106.54abc	194.85abc
5.0	50.45a	77.25ab	78.00ab	129.40abc	149.17a	239.05ab
10.0	48.88ab	78.73ab	90.28a	156.60ab	149.72a	262.45a
NPK fertiliser	41.95abc	104.10a	70.28abc	181.38a	127.94ab	258.80a
CV (%)	39	46	53	49	50	35

** Means in each column followed by the same letter or none at all are not significantly different at $p < 0.05$.*

TABLE 3
Effects of sheep kraal manure application rates on dry matter yield of *Amaranthus*

Manure rate (t/ha)	Leaves (g/plant)		Stems (g/plant)		Shoots (g/plant)		Grain yield (g/plot)
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	
0	6.17c*	10.26f	4.11d	5.69d	17.11c	19.35c	362
0.3	8.44bc	14.62ef	6.15cd	10.09cd	21.88bc	28.74b	402
0.6	9.79abc	16.63de	7.55bcd	12.65bcd	26.67abc	31.27b	405
1.3	9.75abc	18.32cde	7.71bcd	15.49bcd	27.03abc	36.69b	412
2.5	11.84ab	21.96bcd	9.30abc	18.28abc	29.35ab	45.97a	428
5.0	12.49ab	23.52abc	9.86abc	22.28ab	30.74ab	46.97a	443
10.0	13.44a	24.68ab	14.03a	25.35a	37.68a	49.77a	488
NPK fertiliser	12.16ab	27.72a	12.07ab	26.49a	38.09a	52.78a	532
CV (%)	30	19	38	39	27	16	33

** Means in each column followed by the same letter or none at all are not significantly different at $p < 0.05$*

Effects of sheep manure rate on dry matter and grain yield of *Amaranthus*

Dry matter (leaf, stem and shoot) yields increased with increasing manure application rate (Table 3). At 30 DAT, manure application rates of ≥2.5 t/ha and the NPK fertilised treatment, produced greater shoot dry-matter yields than the unfertilised control. The yields obtained in the present study were lower than those reported for the irrigated experiment by Allemann et al. (1996), which is logical. The unfertilised control produced yields which were comparable to those from manure rates ranging from 0.3 to 1.27 t/ha. Elbehri et al. (1993) reported improved forage yield of *Amaranthus* as a result of nitrogen addition. The findings suggested that 2.5 t/ha of sheep kraal manure would supply sufficient nutrients (compared to the recommended fertiliser application) for dried vegetable *Amaranthus,* especially when the leaves are to be harvested at a young age (30 DAT). This is recommended and is practised in the Eastern Cape (Wehmeyer and Rose, 1983; Bhat and Rubuluza, 2002). This critical manure rate is lower than the one based on fresh matter yield. This could be a result of differences in water uptake by the plants at the time of sampling. From the differences in fresh and dry matter responses to the two different kraal manure rates, the results indicated that the plants in the 5 t/ha manure treatment took up more water than in the 2.5 t/ha treatment. Since fresh material is normally consumed, a kraal manure application of 5 t/ha would seem the more logical rate at which to apply it. It is important to note that at the young growth stage at which the leaves are normally harvested (30 DAT) fairly moderate sheep kraal manure applications gave better results than inorganic NPK fertilisers. Grain yield did not respond to sheep kraal manure or fertiliser application when compared to the control (Table 3).

Sheep manure effects on nutrient concentrations and amounts in *Amaranthus* leaves

The concentrations of Ca, Mg, P, N and K in the *Amaranthus* leaves agreed very well with those reported for different accessions of the crop by Makus (1984) while Fe and Zn were much lower. There were no effects of rate of manure application on N, P, K, Ca, Mg, and Zn concentrations in *Amaranthus* leaves at 30 DAT (Table 4). These results agree with those of Ore-Oluwa et al. (1981) who reported no effects of nitrogen on accumulation of Ca, K, Na, Cu and Zn in *Amaranthus* leaves. However, uptake of N and P in the leaves increased with increase in manure application rate, with N uptake reaching a maximum at a manure rate of 2.5 t/ha, which corresponded with maximum dry matter yield (Table 5). Due to the close relation between N and protein, the same trend was observed for crude protein. Crude protein contents compared favourably with other indigenous vegetables used in the Eastern Cape, and thus could supplement the maize-based diets with protein (Wehmeyer and Rose, 1983). The findings indicate that 2.5 t/ha or higher rates of sheep kraal manure supplied adequate amounts of nutrients (especially N and P) for optimum yields.

Leaf Fe concentration results agreed with those reported by Jansen Van Rensburg et al. (2004). It varied with different

TABLE 4
Effects of sheep kraal manure application on nutrient concentrations in *Amaranthus* leaves at 30 DAT

Manure rate (t/ha)	Nutrient concentrations in *Amaranthus* leaves						
	N	P	K	Mg	Ca	Fe	Zn
	(%)					(mg/kg)	
0	2.17*	0.09	3.3	1.4	3.9	60.0bc	2.9
0.3	2.19	0.12	3.5	1.4	3.9	46.9c	3.2
0.6	2.57	0.09	3.8	1.3	3.6	132.3a	2.4
1.3	2.34	0.12	3.4	1.3	3.8	90.9abc	2.2
2.5	2.53	0.12	3.6	1.5	3.7	100.6abc	2.3
5.0	2.13	0.11	3.7	1.3	3.5	81.1abc	2.5
10.0	2.25	0.13	4.3	1.5	3.7	97.8abc	3.8
NPK fertiliser	2.47	0.14	4.7	1.3	3.7	116.5ab	2.3
CV (%)	17	14	16	13	12	43	49

**Means in each column followed by the same letter or none at all are not significantly different at p < 0.05.*

TABLE 5
Effects of sheep kraal manure rate on nutrient amounts in *Amaranthus* leaves at 30 DAT

Manure rate (t/ha)	Nutrient uptake (mg/plant)					Crude protein (g/plant)
	N	P	K	Mg	Ca	
0	134c	6.03d	207	82	240	0.84c
0.3	178bc	9.05cd	288	116	324	1.11bc
0.6	264ab	9.88bcd	360	138	352	1.65ab
1.3	262ab	11.88abcd	310	130	369	1.64ab
2.5	308a	13.10abc	482	176	436	1.93a
5.0	273ab	13.38abc	506	158	443	1.71ab
10.0	267ab	17.83a	520	182	503	1.67ab
NPK fertiliser	315a	16.80ab	565	154	452	1.97a
CV (%)	35	35	34	34	34	21

**Means in each column followed by the same letter or none at all are not significantly different at p < 0.05.*

manure and fertiliser applications, though no specific trend was observed (Table 4). Rates of manure application greater than 0.6 t/ha, however, generally resulted in levels of Fe that were higher than in the control treatment. Since Fe is an important element in human nutrition, these results suggest that in addition to improving yields, fertilisation of *Amaranthus* with sheep manure will have the added benefit of improving its nutritional value, including Fe.

Effects of sheep manure application rates on residual soil nutrient composition

Post cropping soil pH increased from 5.4 to 5.8 in response to increasing manure rate from 0 to 10 t/ha, whereas the NPK fertiliser depressed it (Table 6). Manure rates <2.5 t/ha had post-cropping pH values which were comparable to the unfertilised control, whereas higher rates had significantly higher pH values ($p<0.05$). The liming effect of manure could be of great significance in the Eastern Cape where manure is readily available and pH of most of the soils has been reported to be critically low (Mandiringana et al., 2005).

There was no effect of manure rate or fertiliser on residual soil N, suggesting that the crop had exhausted the soil N from manure or fertiliser. Lower manure rates (≤1.3 t/ha) resulted in lower residual soil P than the higher rates (2.5-10 t/ha). Although the latter gave lower plant-available soil P levels than the NPK fertiliser (Table 6), the increases were substantial, which agrees with the findings of Eghball and Power (1999), who reported an accumulation of soil P as a result of manure application. This could probably benefit the next crop grown on this soil but could over several seasons of application of high manure rates lead to the build-up of excessive soil P levels. This could eventually result in P/Zn imbalance, which could result in reduced Zn uptake if manure is applied at high levels over long periods (Brady and Weil, 1999).

Residual soil K from plots fertilised with NPK fertiliser, and low manure rates (0.3 to 1.3 t/ha), did not differ statistically significantly from that in the unfertilised control. At higher kraal manure rates (2.5 to 10 t/ha) sharp increases in soil K levels were observed. Soil K levels in all the treatments, even the unfertilised control, exceeded 200 mg K/kg. This is above the critical level of 80 to 120 mg K/kh (Bornman et al., 1989), which explains the lack of K uptake response to manure or fertiliser application. The results are in agreement with Laker (1976), who reported that, in general, South African soils do not have K deficiency problems. Although the uptake of Mg did not respond to manure and fertiliser application, its residual levels increased at manure rates of 5 and 10 t/ha (Table 6). Calcium ranged between 3 914 and 4 690 mg Ca/kg. The manure rate of 10 t/ha gave a significantly higher calcium level than all the other treatments (Table 6). Low manure rates (0.3 to 1.3 t/ha) did not increase residual Zn levels significantly above the unfertilised control, while higher manure applica-

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TABLE 6
Effects of sheep kraal manure application rates on residual soil nutrient composition

Manure rate (t/ha)	pH (KCl)	Total N (%)	OC (%)	Selected nutrients (mg/kg)				
				P	K	Mg	Ca	Zn
0	5.40c	0.07	1.70b	4.00d	212.00d	309.70c	3914b	1.61e
0.3	5.50c	0.09	1.93a	4.50d	203.28d	325.63bc	3943b	2.13cde
0.6	5.45c	0.09	1.74ab	4.87d	237.55d	344.83bc	3900b	1.88de
1.3	5.50c	0.10	1.88ab	6.21d	268.75d	359.75bc	3822b	2.02cde
2.5	5.55bc	0.10	1.89ab	15.28c	351.75c	350.50bc	4038 b	2.28bcd
5.0	5.70ab	0.09	1.92a	19.50c	433.61b	376.00b	4019 b	2.43bc
10.0	5.80a	0.09	1.87ab	28.00b	533.75a	456.50a	4690a	2.78b
NPK fertiliser	5.20d	0.09	1.78ab	36.23a	267.25d	362.63bc	3968b	6.04a
CV (%)	2.02	17.50	7.01	29.21	14.36	10.71	9.32	13.12

**Means in each column followed by the same letter or none at all are not significantly different at $p < 0.05$.*

tions (≥2.5 t/ha) significantly increased soil Zn levels. This indicates that the application of sheep manure can increase the zinc fertility of Zn deficient soils. In the present study, however, Zn was not a problem as levels in all treatments, including the control were within or above the critical range of 1.5 to 2 mg Zn/kg (Bornman et al., 1989). The inorganic NPK {2:3:4(30) + 0.5% Zn} fertiliser treatment gave the highest level of residual Zn (Table 6), because the fertiliser contained Zn in its formulation.

Conclusions

The findings of this study suggest that sheep kraal manure rates of 2.5 t/ha or higher could result in *Amaranthus* growth, yield and nutrient uptake, similar to those of the recommended NPK {2:3:4(30) + 0.5% Zn} fertiliser at 150 kg/ha under dry-land conditions of the Central Region of the Eastern Cape. In fact, at the young growth stage at which *Amaranthus* is normally harvested, fairly moderate sheep kraal manure applications gave better results than commercial inorganic NPK fertiliser. In addition to improved growth, the crop was enriched with iron and crude protein, which are very important in human nutrition. Sheep manure, at rates ≥2.5 t/ha, raised soil pH (liming effect) and had high residual fertility, as indicated by high levels of P, K, Mg and Zn at harvest time. Therefore, *Amaranthus* needs not be fertilised with mineral fertilisers where sheep kraal manure or other forms of manure are available. Organoleptic tests and other proximate analyses are needed to establish whether or not the yield increase observed with manure addition was at the expense of the good taste and high crop quality of the vegetable. Further research replicated over many sites and incorporating a comparative cost analysis is needed to establish the cost effectiveness of using kraal manure as a source of nutrients for *Amaranthus*.

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