Growth parameters, maize (*Zea mays* L.) silage and Bambara groundnut (*Vigna subterranea* L.) grain yield in an intercropping system.

Lumka September

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by the Agricultural Research Council (ARC) Collaborative Centre on Smallholder Farmer Development Research.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Professor Albert T. Modi

Date: 13 November, 2015

DECLARATION

I, Lumka September, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

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(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

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ABSTRACT

Intercropping is practised throughout the tropics with a range of different crop combinations. As sustainable agriculture includes the enhancement and management of natural resources while meeting the human and animal needs for food/feed and fibre, intercropping has been shown to conserve resources and produce more nutritious food and feed. Therefore, intercropping can contribute to the complex livelihoods of African smallholder farmers by improving their returns on minimal inputs and producing more and quality food per land area. The aim of the study was to evaluate productivity and efficiency of intercropping maize and bambara groundnut, an underutilised legume crop, as alternative dual purpose crops with potential to feed both humans and livestock. Maize (ZM 305) and bambara groundnut landraces were planted in a randomised complete block design (RCBD) consisting of three replications. The experiment consisted of three treatment combinations [sole maize (M), sole bambara groundnut (BG) and maize + bambara groundnut intercrop (MBG)]. Seed quality of both maize and bambara groundnut was determined prior to planting to establish field planting value of seed lots. Data collection included plant growth (leaf number and plant height), physiology (chlorophyll content index and stomatal conductance) and yield and yield components. Intercrop productivity was evaluated using the land equivalent ratio (LER). Maize and bambara groundnut were further analysed for silage properties. The results showed that both maize and bambara groundnut seeds had high seed vigour and viability. There were no differences with respect to growth and physiological parameters of the two crop species. Significant differences ($P<0.05$) were observed with respect to yield and yield components of bambara groundnut when intercropped with maize. The land equivalent ratio (LER) obtained for the biomass yield of maize was 1.016, which showed an advantage to intercropping. Intercropping increased soil fertility and improved water use efficiency. With respect to the nutrient composition of the two crops, the results obtained were within the range found in the literature. Protein and neutral detergent fibre contents obtained for maize sole crop and intercrop were 7.18% and 7.5% and 77.12% and 70.30%, respectively. For bambara groundnut sole crop and intercrop, the protein and neutral detergent fibre contents obtained were 19.47% and 20.45% and 43.21% and 60.68%, respectively. Despite low yields of bambara groundnut, these findings suggested that intercropping of maize and bambara is advantageous for resource poor smallholder farmers in South Africa.

Keywords: Intercropping, productivity and efficiency, maize, bambara groundnut, silage

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CHAPTER 1

INTRODUCTION

1.1 Background and Rationale

Livestock are an important asset within Sub-Saharan Africa (SSA) with 70% of the rural poor in the region partially dependent on it to sustain their livelihoods (Otte and Knips, 2005). Apart from its role in traditional rituals and showing wealth status, livestock contributes towards food security, directly and indirectly. According to the Food and Agriculture Organization (FAO, 2013), livestock products provide 6% of calorie intake and 19% of dietary protein consumed in developing countries. Animal products are the only reliable sources of vitamin B12, zinc and iron. In addition, livestock are the predominant source of draught power while manure from excreta is often used to fertilize agricultural land. According to Otte and Knips (2005), SSA has the largest area of permanent pastures; however, due to high carrying capacity, poor socio-economic structure, over grazing, increased scarcity for resources, namely water and land due to increased human population, pastures have become degraded and can no longer provide the much needed sustenance for livestock production. This has resulted in reduction in herd size, especially for cattle, poor livestock health, resulting in reduced availability of products and services (Muck and Shinners, 2001). Since livestock still remains an important livelihood strategy for rural farmers in SSA, its loss can trigger a further collapse into chronic poverty and malnutrition in a region already battling with food insecurity and poor nutrition (Chiba *et al.*, 2005). It is therefore in this context that this study aims to evaluate productivity and efficiency of maize and bambara groundnut intercropping as an alternative dual purpose crops with potentials to feed both humans as well as animals.

Ranum *et al.* (2014) and FAO (2012) reported that improved livestock production was key in alleviating malnutrition and subsequently food insecurity in many parts of the SSA. There is need to investigate options that will improve available feed for cattle in order to improve production and reproduction and ultimately food security and nutrition (Ranum *et al.*, 2014). According to the FAO (2013), there is also need to develop strategies to enhance adoption of forage conservation technologies by rural farmers, thus enabling them to increase animal production and enter expanding markets for livestock products. In this regard, silage was observed to be a sustainable alternative towards improving livestock productivity.

According to Gebrehawariat *et al.* (2010), silage is defined as a fodder converted into succulent feed for livestock through processes of anaerobic acid fermentation. An FAO report (2013) reported that maize as feed is often processed into silage. Otte and Knips (2005) reported that maize silage had 30-50% higher nutritive value compared to maize grain and maize straw. Therefore, feeding maize silage to livestock would greatly contribute to the alleviation of malnutrition or malnourishment through increased reproductive efficiency, size, and weight of livestock. The production of silage in rural farming communities is not very common owing to agricultural land being primarily used for human crop production. Farmers are not willing to sacrifice their arable land for animal feed production. Thus, Auerswald *et al.* (2003) mentioned that developing methods and technologies such as cropping systems which use the limited land and the available resources such as water, nutrient, and radiation more efficiently could help increase agricultural productivity and subsequently reduce food insecurity.

Intercropping also known as mixed cropping or poly-culture, involves the growing of two or more crop species in proximity to promote interaction between them (Ghosh *et al.*, 2006). According to Jensen (2005), intercropping is the simultaneous cultivation of more than one species or cultivar on the same piece of land. Advantages to intercropping include the more efficient utilization of the available resources which leads to improved productivity compared to sole cropping. Intercropping is also known to increase grain yields and stability, reduce weed pressure and sustain plant health, thus implying reduced labour and management costs (Sullivan, 2003; Thobatsi, 2009). Within South Africa, the most frequently practiced intercropping systems include intercrops of a cereal and a legume because they have long been proven to increase yields and stability (Thobatsi, 2009). These typically feature the major legumes. However, there has also been interest on including minor or underutilised legumes in rural cropping systems (Mabhaudhi *et al.*, 2014).

Underutilised crops hold a significant potential for improving food security and achieving more balanced nutrition for the rural and urban poor, conserving biodiversity and stabilizing agro-ecosystems, as well as generating income for the rural poor (Jensen, 2005). However, Akpalu (2010) argued that it is always difficult for the rural and urban poor to achieve a balanced nutrition because animal protein is very expensive and therefore not easily affordable by majority of them whose income is very low. Will (2008) and Gqaleni (2014) reported that underutilised crops could be used for animal feed production because of their nutritional status, particularly as a source of protein. The seeds of bambara groundnut have been successfully used in poultry feeds and the leaves for animal grazing because they have high levels of nitrogen and phosphorus (Gqaleni, 2014). The bambara groundnut leaves and by-products could also be used as feed ingredients in animal feeds, thus reducing costs of buying artificial nutrient formulated feeds from animal industries.

According to Otte and Knips (2005), pastures have become degraded over the years and can no longer provide the much needed sustenance for livestock production. This has resulted in reduction in herd size and in reduced availability of products and services (Muck and Shinners, 2001). This suggests that South African agriculture needs to put more effort in increasing output in order to meet food demand from an ever increasing population. Thus the study aims to evaluate the combined productivity of maize and bambara groundnut in an intercrop system as alternative feed sources of the slowly degrading pasture lands.

1.2 Hypothesis

It was hypothesized that intercropping maize with bambara groundnut under rainfed conditions have no effect on crop growth parameters, yield and nutritional status of maize and bambara groundnut compared to sole crops.

1.3 Specific Objectives

- To determine growth and development of maize and bambara groundnut under rain-fed conditions
- To evaluate productivity of intercropping maize and bambara groundnut for silage making
- To determine grain yield of maize and bambara groundnut
- To evaluate the effect of intercropping on soil nutrients
- To evaluate the effect of intercropping on the nutritional status of bambara groundnut and maize

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Many farmers generally rely on a wide range of neglected and underutilized species (NUS) such as bambara groundnut, for their livelihoods (Padulosi, 2002). Neglected and underutilized species are domesticated plant species that have been used for centuries as sources of food, fibre, feed, oil and medicinal properties, hence are considered useful species that contribute consistently to the well-being of mankind (International Plant Genetic Resources Institute (IPGRI), 2002). Underutilized crops exhibit an agronomic advantage in terms of adaptability to low input agriculture and rain-fed agricultural systems, thus hold a significant potential for improving food security especially in rural areas (Osewa *et al.*, 2013).

According to the Department of Agriculture, Forestry and Fisheries (DAFF) (2011), underutilized crops are one of the cheaper and more affordable alternative sources of protein to the rural and semi-urban poor because they offer a lot in terms of their nutritional value. For example, Akpalu (2010) and Mabhaudhi *et al.* (2013) mentioned that the seeds of bambara groundnut, also a neglected and underutilized crop, are high in both protein (14-24%) and carbohydrate content (60%). Thus NUS hold a significant potential for achieving more balanced nutrition for the rural and semi-urban dwellers (Osewa *et al.*, 2013). Akpalu (2010) argued that it is always difficult for the rural and urban poor to achieve a balanced nutrition because animal protein is very expensive and therefore not easily affordable by majority of them whose income is very low. Therefore, as means of improving the availability of animal protein, farmers have been intensively cultivating staple food crops such as maize, also adapted to low-input and rain-fed agricultural systems, for the purpose of generating livestock feed out of the crops (Ranum, 2014). According to Campbell (2014), maize is high in energy, low in fibre and easily digestible, thus more nutritious and palatable to livestock. Recent publications have shown that the quality and quantity of livestock and livestock products increases when livestock is fed maize based feed (NRC, 2001; Van de Vyver *et al.*, 2013). Thus the increase in quantity and quality of livestock and its products implies more availability and accessibility of healthy meat and other animal based products which mainly supply protein to human diets, hence alleviating food security (FAO 2008).

2.2 Maize

2.2.1 History and Origin

Maize (*Zea mays*, L.) also known as umbona (Xhosa) and umbila (Zulu) in South African vernacular (du Plessis, 2003), is one of the most important food crops recognized as a staple in many developing countries especially in sub-Saharan Africa (SSA) (FAO, 2012). As a cereal crop, maize belongs to the family Poaceae, which is a family of grasses (du Plessis, 2003). It is believed to have originated from Mexico in South America, and was later introduced to Africa in the 1500s by Portuguese and Arab explorers in West and East Africa (Matsuoka *et al.,* 2002; Ristanovic, 2001). Maize is found across the whole world and its domestication began at least 6 000 years ago, hence is categorised as one of the most adaptable staple food crops in the world (Piperno and Flannery, 2001).

According to Setimela and Kosina (2006), maize varieties may be either hybrid or open-pollinated (OPVs). Hybrid varieties are made by crossing selected parents with desired traits in the field, while open-pollinated varieties are broad populations of many parents. The parents of hybrid varieties are known as inbred lines and are chosen based on characteristics such as early maturity, disease resistance, drought tolerance and yield potential (Banziger and Long, 2002). Hybrid plants are uniform in colour, plant height, maturity and other plant characteristics. Setimela and Kosina (2006) reported that the uniformity of hybrid plants enables farmers to carry out certain operations, such as harvest, at the same time, which is of great advantage for farmers using combine harvesters. Hybrids are usually higher yielding than open-pollinated varieties due to their biological effect known as heterosis, but they generally require much higher standards of field management than open-pollinated varieties in order to achieve their yield potential (du Plessis, 2003). Open-pollinated varieties show greater variability and are more stable in low-yielding or stress environments than hybrids and their grain, if isolated from other maize varieties or harvested from the middle of the field, may be recycled for a maximum of three seasons without significant yield loss (Kutka, 2011), hence is of great advantage to the resource poor famers. Nevertheless, hybrids, due to their high yielding potential, are most preferred for feed production purposes than open-pollinated varieties (Setimela and Kosina, 2006).

2.2.2 Botany and Ecology

According to du Plessis (2003) maize is an annual, determinate, monoecious, C4 plant that has a profusely branched, fine root system. The root system is known to provide support to the growing plant through increased water and nutrient uptake as a result of an increased surface area (Ristanovic, 2001). The length of a mature root grows up to about 1.5 m which implies deep penetration into the soil profile. Generally, the height of the plants varies from less than 0.6 m to 5.0 m depending on variety (Hoopen and Maiga, 2012; du Plessis, 2003). The plants have cylindrical, solid stems divided into nodes and internodes. According to Matsuoka *et al*. (2002) and Ristanovic (2001), the first four internodes do not lengthen, whereas the ones below the sixth, seventh and eight leaves lengthen to approximately 25, 50 and 90 mm, respectively. However, the elongation depends on variety. Matsuoka *et al*. (2002) further reported that the total number of nodes and internodes can vary from as low as eight for short varieties to 21 for taller varieties. The plant forms about eight to 20 leaves arranged spirally on the stem. The leaves can grow up to 10 cm wide and 1 m long (du Plessis, 2003). The leaf on its own consists of a sheath, ligules, auricles and a blade (Matsuoka *et al*., 2002). As a monoecious plant, maize has male and female flowers borne on the same plant as separate inflorescences (Hoopen and Maiga, 2012). The male flowers are borne on the tassel while female flowers are borne on the ear (du Plessis, 2003). The ears are enclosed by bracts and they grow silks that remain receptive to pollen for approximately three weeks. However, the receptivity decreases after the tenth day of emergence. The pollination is therefore followed by the development of kernels (dent or flint) which consists of an endosperm, embryo, a pericarp and tip cap (Setimela and Kosina, 2006). As a C4 plant, maize uses resources such as solar radiation, carbon dioxide (CO_2) and water during photosynthesis more efficiently than C3 plants, resulting in higher yields (du Plessis, 2003).

Maize is a short-day plant and has less than 12 hours/day of photoperiodism (Buckler and Stevens, 2005). Even though it is produced under diverse environments, it requires a frost-free period during all growth stages to prevent damage. Its optimum temperature for growth and development ranges between 18 to 32 °C (Belfield and Brown, 2008). According to du Plessis (2003), maize is most suitable cultivated in soils with a good effective depth, favourable morphological properties, good internal drainage, and sufficient, balanced quantities of plant nutrients and chemical properties. Maize requires an annual rainfall of 500 to 750 mm during growth and development which is higher than the average rainfall received in South Africa per annum. Thus, for optimum production it often requires supplementary irrigation especially during its critical stages of growth because like in any other agronomic production practice, water deficiency is usually the most yield-limiting factor (Matsuoka *et al*., 2002). In maize, water deficiencies at grain filling stage result in shrivelled grains, thus poor seed quality and compromised yields. However, too much rainfall at maturation stage can also cause yield losses (du Plessis, 2003).

2.2.3 Socio-Economic Importance

Maize is the most important grain crop in South Africa. It is mostly used as a grain crop for both human and animal consumption. According to du Plessis (2003), maize is the third most important cereal crop in the world after wheat and rice. Nutritionally, the crop plays a vital role as a staple diet especially in developing countries. Kutka (2011) and du Plessis (2003) stated that almost all the plant parts of maize can be utilized into edible or non-edible products. The kernels consist of an endosperm, embryo, a pericarp and tip cap. The endosperm contains about 80% of the carbohydrates, 20% of the fat and 25% of the minerals, while the embryo contains about 80% of the fat, 75% of the minerals and 20% of the protein (du Plessis, 2003). Robertson *et al*. (2011) reported that part of the kernels contains starch which is used in food and many other products such as adhesives, clothing, paper production and pharmaceuticals. The starch can also be converted into sweeteners and used in products such as sweets, bakery products and jams (Ristanovic, 2001). Oil is generated from the fat found in both the endosperm and embryo. It is then used in cooking oils, margarine and salad dressings (du Plessis, 2003). Recently, the crop has been receiving more and more attention since it was found capable of being used to generate bioethanol which in turn can be used as a biofuel (Robertson *et al*., 2011).

2.3 Bambara Groundnut

2.3.1 History and Origin

Bambara groundnut (*Vigna subterranea* L. Verdc.) is an underutilized African indigenous crop that is grown mainly at subsistence level. It is also known as phonda (Venda), ditloo-marapo (Sepedi), and tindhluwa (Tsonga) in South African vernacular (Department of Agriculture, Forestry and Fisheries (DAFF), 2011) and as nyimo in Zimbabwe (Mabhaudhi, 2012). According to DAFF (2011), bambara groundnut originated from North Africa and through migration of indigenous people, moved as far south as KwaZulu-Natal. Masindeni (2006) stated that bambara groundnut belonged to the *Vigna subterranea* botanical Family (Fabaceae) which is a family of leguminous plants. Today, the main producing areas of bambara groundnut in SA are Limpopo, Mpumalanga and KwaZulu-Natal (DAFF, 2011). However, according to Masindeni (2006), the crop is also cultivated in the Eastern Cape and Northwest provinces.

There are two botanical varieties of bambara groundnut namely *Vigna. subterranea* var. *spontanea* which mainly includes the wild species type and *V. subterranea* var. *subterranea* which includes the cultivated type (Ijoyah, 2012; Masindeni, 2006). The Department of

Agriculture, Forestry and Fisheries (2011) further reported that there are at least seven types of bambara groundnut varieties which include plain black, plain red, plain cream, plain brown, cream with black eye, cream with brown eye, and speckled varieties. The plain black varieties are early maturing, usually with small to medium-sized kernels and are mainly one-seeded. The plain red varieties are late maturing, usually with large kernels and have a high yield potential. The plain cream varieties have very small pods and kernels and they mainly produce one seed and have low yield potential. The plain brown varieties have kernels that are of medium to large size and there is a continuous variation between light and dark brown. The cream with black eye varieties have large kernels with a high yield potential while the cream with brown eye varieties have moderate kernels with high yield potential. The speckled varieties have small kernels and are mainly one-seeded. According to a study conducted by Chibarabada (2014), the seed coat and speckling colour in bambara groundnut affects the quality of the seeds. She further mentioned that black speckled landraces had the highest germination of 87% and the plain cream landraces had the lowest final germination of 67%.

2.3.2 Botany and Ecology

According to Akpalu (2010), bambara groundnut is an annual herbaceous, grain legume crop with creeping stems at ground level. The plant generally appears bushy as a result of bunched leaves arising from branched stems which form a crown on the soil surface (Brink *et al.,* 2006). DAFF (2011) pointed out that bambara groundnut had a growth habit that was either spreading or bunched type. The spreading types are cross-pollinating while the bunched types are self-pollinating (Akpalu, 2010; Masindeni, 2006). The plants consist of about ten lateral stems which develop from a strong well-developed tap root with profuse lateral roots. The Department of Agriculture, Forestry and Fisheries (2011) reported that the roots formed nodules for nitrogen fixation, in association with appropriate rhizobia. The stems have very short internodes. However, the length of the internodes differs for bunched, semi-bunched (intermediate), and spreading types (Akpalu, 2010). Akpalu (2010) further reported that stem branching began very early, about one week after germination. Each branch is made up of internodes and the plant can produce as many as 20 branches. According to several authors (Masindeni, 2006; DAFF, 2011; Mabhaudhi, 2012), bambara groundnut has trifoliate leaves borne on the stems. The leaves are made up of leaflets, the oval leaflets and terminal leaflet. The oval leaflets are attached to the ranchis with marked pulvini and the terminal leaflet has an average length of 6 cm and an average width of 3 cm (Brink *et al.,* 2006; DAFF, 2011). The leaves are ± 5 cm long with a petiole approximately 15 cm long. Brink *et al.* (2006)

reported that the petioles are stiff and grooved with a base that is green or purple in colour. According to Akpalu (2010), the leaves and flower buds arise alternately at each node. The flowers are borne on hairy peduncle which arises from the nodes of the stem. The Department of Agriculture, Forestry and Fisheries (2011) reported that flowering starts 30 to 35 days after sowing and may continue until the end of the plant's life cycle. The fruit then develop above or just below the soil surface once sepal enlarges and may reach up to 3.7 cm long; depending on the number of seeds they contain (Akpalu, 2010). At maturity, the seeds (round in shape and ±1.5 cm in diameter) vary considerably in colour and size and they become smooth and extremely hard when dry. The seed colour varies from cream white, brown, yellowish brown, red, spotted, purple and black (Masindeni, 2006).

There are two main factors affecting the development of many annual crops in crop production, namely photoperiod and temperature (Masindeni, 2006). Brink *et al.* (2006) reported that both the onset of flowering and podding of bambara groundnut were photoperiod sensitive. The Department of Agriculture, Forestry and Fisheries (2011) reported that photoperiod played a role in the determination of pod number per plant. However, Akpalu (2010) stated that this phenomenon depended on the type of variety. The crop is a typical short-day plant that requires bright sunshine, high temperatures, and frequent rain during its growth and development (Akpalu, 2010; DAFF, 2011). Research has shown that bambara groundnut does not tolerate freezing temperatures at any stage of growth and extreme temperatures seem to trigger leaf senescence, resulting in reduction of biomass yield (Brink and Belay, 2006). According to DAFF (2011), the optimum temperature for germination of the crop is between 30 C to 35 °C. Germination is retarded when temperatures go below 15 °C and above 40 °C (DAFF, 2011). Generally, the crop grows well at average temperatures of 20 to 28 °C (Akpalu, 2010; DAFF, 2011). Bambara groundnut is highly adaptable and tolerates harsh conditions better than most crops (Brink and Belay, 2006). Except at maturity, the crop can tolerate heavy rainfalls and requires an annual rainfall of 500 to 600 mm during its growing season (DAFF, 2011). The crop grows well on well-drained soil, with a soil pH within the range of 5.0 to 6.5. However, it can also grow on poor soils that are low in nutrients. Soils that are rich in nitrogen tend to encourage vegetative growth at the expense of grain seed production (Akpalu, 2010).

2.3.3 Socio-Economic Importance

Bambara groundnut is rated the third crop among the grain legume crops of the African lowland tropics after the popular groundnut and cowpea (DAFF, 2011). As a legume, bambara groundnut has the ability to fix atmospheric nitrogen through a symbiotic relationship with bacteria, resulting in reduced levels of nutrient application (Zondi, 2013). According to Brink and Belay (2006), bambara groundnut has long been used for both human and animal consumption because it has high nutritional value. According to Akpalu (2010), the crop can be used to cure nausea suffered by pregnant women.

Bambara groundnut makes a complete food, containing sufficient quantities of protein, carbohydrate, and fat. Its seeds contain 63% carbohydrate, 14- 24% protein, and 6.5- 12% oil. The protein is reported to be higher in the essential amino acid methionine than in other grain legumes. According to DAFF (2011), immature seeds of bambara groundnut are more palatable than the hard (fully matured) seeds. Normally, the immature seeds are eaten fresh, boiled or grilled while the mature seeds are mixed with oil or butter into flour to form porridge. Brink and Belay (2006) reported that the flour may be prepared from roasted or unroasted seeds which can be used for livestock feeding after being soaked in water. The Department of Agriculture, Forestry and Fisheries (2011) stated that the roasted ground meal can be used as a coffee substitute. According to Akpalu (2010), the ripe seeds are broken into pieces, boiled, crushed, and eaten as a relish with maize-meal porridge. They may also be mixed with other foods, such as meat stew, rice, spinach, maize and sorghum.

Bambara groundnut leaves can be used for animal grazing because they are rich in nitrogen and phosphorus. According to Brink and Belay (2006), the leaves can also be pounded with those of *Tagetes minuta* then added into water to make a solution which is used to wash livestock as a preventative (insecticide) against ticks. Gqaleni (2014) reported that the seeds of bambara groundnut have been successfully used in poultry feeding. In weaner pig diets, an addition level of up to 10% bambara groundnut was found economical for producing affordable and cheaper pork (Oyeleke *et al.*, 2012). According to Belewu *et al.* (2008), bambara groundnut has high crude protein content (17-25%) which can be a good protein supplement for maize diets prepared for animal consumption. The Department of Agriculture, Forestry and Fisheries (2011) reported that more experiments have recently been conducted to make milk out of the bambara groundnut.

2.4 Silage

Silage is the product from a series of processes by which cut forage of high moisture content is fermented to produce a stable feed which resists further breakdown in anaerobic storage (Maasdorp *et al.*, 2002; Meskee *et al.*, 2003). Campbell (2014) defined silage as fodder, typically fed to ruminants, consisting of undried vegetation stored in an airtight environment, which leads to its fermentation. According to Pioneer (2012), silage has more benefits over both grain and hay feeds and it has been preferred mostly over other types of feed because its storage period can last up to 3 years without deterioration. It also has fewer weather-related harvesting restrictions, loses less than 10% dry matter and has less desirable vegetation like maize stover, thus more suitable and reliable for silage production (Cheeke, 2005).

Silage is typically a high-quality feed and it is usually fed to livestock that have high nutrient requirements such as young animals and dairy animals. However, other livestock can also profitably utilize silage, if elements of their normal ration have become more expensive, or have it to avoid health problems related to low quality forage (Campbell, 2014). To avoid health problems, livestock must not be fed any portion of silage that is spoiled or mouldy. Usually the spoiled portion in any silage silo is the layer most exposed to air (Givens *et al.*, 1995). The portion must be removed and thrown away. For optimum consumption, silage should be fed within hours of opening the silo but, if it is to be fed out over several days, the silo should be resealed as best as possible to minimize drying, air exposure and the corresponding dry matter losses (Seglar, 2003). During feeding, the feed bunks must be cleaned out regularly to prevent any remaining silage which can spoil and contaminate the next feed out (Grant and Stock, 1994). Yami (2008) reported that livestock may not initially consume silage as a result of its odour just after opening. In such cases, the silage is usually left until its odour is weakened.

Cereal silages as a feed source have demonstrated over time to be dependable and economic (Titterton and Bareeba, 2002). They are easily ensiled because they have high levels of water-soluble carbohydrates, relatively low buffering capacity and easily controlled moisture content. For silage, cereals are usually harvested before they complete maturity because they have relatively low protein content (Eltayeb *et al.*, 2011). In most cases, the maximum total energy and protein yield is obtained by harvesting at, or before, the hard dough stage, depending on the species. For example, maize is normally harvested at half milk line stage while the moisture content is still high, approximately between 60- 70% (Campbell, 2014).

Harvesting at optimum stage of maturity, i.e. grasses at boot, legumes at bud, and maize silage at half milk line, is important to maximize both yield and quality of silage including neutral detergent fibre (NDF) digestibility. In general, the quality of different feed products is determined in terms of dry matter, crude protein, crude fibre, crude fat, crude ash, minerals, tannins and other parameters (Kim and Adesogan, 2006). The dry matter (DM) is defined as the percentage of the sample that is not water. The crude protein is a measurement of true protein and non-protein nitrogen (NPN) such as urea nitrogen and ammonia nitrogen. The crude fibre is divided into two categories, the neutral detergent fibre (NDF) and the acid detergent fibre (ADF). The neutral detergent fibre is a measurement of the total fibre content of forage and is composed of cellulose, hemicellulose, and lignin while acid detergent fibre is a measurement of the cellulose, lignin, and pectin fibre fractions of forages and is commonly used to predict energy content of maize silage and other forages. The crude fat also known as ether extract (EE) comprises all substances that are soluble in ether. Although it mainly contains lipids, it also includes other fat-soluble substances such as chlorophyll and fat-soluble vitamins, and it is high in energy when the fraction represents primarily lipids. The crude ash is the remaining residue after all organic matter present in a sample is completely burnt. It comprises all inorganic matter in the feed, as well as inorganic contaminants, such as soil or sand. The minerals include calcium (Ca), phosphorus (P), magnesium (Mg), and potassium (K) values expressed as a percentage of each in the feed (Jung *et al*., 1998; Summers, 2001; Mlynar *et al*., 2004; Kim and Adesogan, 2006).

Feed products from maize are characterized by high energy nutrients and relatively low content of crude protein with low biological value (Summers, 2001). However, from a nutritional standpoint, the issue with maize silage is that it is a very heterogeneous material consisting of starch (grain) and fibre (fodder). According to Mlynar *et al*. (2004), the energy values of maize silage ranges from 0.5 to 0.7 Mcal/lb dry matter. Jung *et al*. (1998) reported that the concentration of NDF in maize silage ranges from 36 to 50%. However, Ondarza (2008) reported that the measurements of NDF digestibility in the laboratory range from 30 to 74.3%. The concentration of maize silage ADF ranges from 18 to 26%. In general, maize silages with lower NDF and ADF values are more desirable because of digestibility and higher energy content, respectively. Summers (2001) reported that maize silage with lower values of ADF and NDF digestibility increases dry matter intake and thus could result in an increase in livestock production, particularly milk production.

2.4.1 Silage Making

Silage can be successfully made from any green crop that has sufficient water-soluble carbohydrates and appropriate moisture content (Jennings, 1995). The purpose of silage making is to preserve the harvested crop by anaerobic fermentation. The process uses bacteria to convert soluble carbohydrates into acetic and lactic acid, which pickles the crop. In a well-sealed silo, silage can be stored for long periods of time without losing quality (Mlynar *et al*., 2004). Although almost all crops can be used as silage, cereal crops are the most commonly used crops in silage making because they tend to yield higher than other crops when grown under adequate availability of nutrients especially nitrogen (N) (Wilkins, 1996). According to Campbell (2014), some of the mainstream silage crops include maize (*Zea mays*), sorghum (*Sorghum bicolor*), small grains such as oats (*Avena sativa*), rye (*Secale cereale*), wheat (*Triticum* spp.), pearl millet (*Pennisetum glaucum*) and triticale (*Triticosecale*). The legume crops include alfalfa (*Medicago* spp.), peas (*Pisum sativum*), fava beans (*Vicia faba*) and clover (*Trifolium* spp.). The storing of these crops as silage provides a number of benefits such as improving production and reproduction of livestock, alleviating malnutrition and subsequently food insecurity, as well as minimising the effect livestock has on the environment through overgrazing of natural vegetation which leads to soil erosion, and ultimate desertification (Titterton and Bareeba, 2002). Compared to other crops commonly grown for silage, maize, under conditions of adequate moisture, heat and nutrients, produces the greatest silage yields of high energy (Table 2.1).

Table 2.1: Crude protein, energy (Total Digestible Nutrients), Acid Detergent Fibre, Neutral Detergent Fibre, Calcium and Phosphorus contents of selected legume and cereal crops. Source: Campbell (2014)

Crop	Crude Protein	Estimated Energy TDN	Calcium	Phosphorus	ADF	NDF
Barley	14.1	53.0	0.46	0.32	37.7	56.7
Wheat	12.5	57.8	0.30	0.27	38.7	58.4
Oats	12.5	49.0	0.37	0.26	38.7	58.5
Alfalfa	26.1	58.6	1.54	0.24	26.1	33.5
Clover	16.2	58.1	1.28	0.22	36.1	43.6
Maize	8.34	68.2	0.20	0.23	28.6	50.5

2.4.1.1 Hybrid Selection

Hybrid selection is a vital decision in silage production because it determines the success of production. According to Jung *et al*. (1998), the selection of hybrids must be done capitalizing on high-yielding hybrids with good forage quality and adequate disease tolerance for maximum economic returns. Hall (2000) mentioned that selected hybrids must be evaluated for several times at different locations for hybrid performance test. The test ranks yields and provides a stronger comparison for how long a hybrid will perform in multiple environments and conditions. Many publications have shown that the overall feed value is improved when the selected hybrids are insect resistant hybrids, disease tolerant hybrids and herbicide resistant hybrids (Hoffman and Taysom, 2005).

Among the types of maize hybrids commonly grown for silage is waxy, nutridense, leafy and brown midrib types (Aioanei and Pop, 2013). The waxy hybrids have a higher concentration of more easily digested long chain starches. The nutridense hybrids have approximately 2% more of protein and starch than dual-purpose hybrids. A dual-purpose hybrid is one that is grown both for grain and silage (Adesogan, 2006). The leafy hybrid types have more leaf production above the ear than dual-purpose hybrids. The brown midrib hybrids have less lignin concentration than dual-purpose hybrids, making brown midrib forage more digestible (Martin *et al.*, 2004; Muck, 2000).

2.4.1.2 Crop Management

Generally, maize grown for silage requires good soil moisture levels throughout the growing season in order to avoid stress which in turn could affect the quality of silage (Pioneer, 2012). The field preparation must be completed prior to planting to obtain a moist, firm, weed-free seedbed, thus minimizing chances of uneconomical production. The soils must be fine textured with a good internal and surface drainage for satisfactory production and the temperature of the soil for germination should be warm enough to trigger the germination process (Osewa *et al.*, 2013). Meeske and Basson (1998a) reported that maize has high silage yield potential compared to other silage crops. However, the economics of its production requires more specialized equipment, higher inputs and more favourable growing conditions than wheat.

2.4.1.3 Harvest Stage

Silage is often harvested at relatively high moisture content and wilted in the field for short periods of time (Christensen, 1993). In the case of cereal grain crops, the correct stage to harvest whole-crop cereal silage (crops harvested when grain has reached full size but still soft) is when the grain has reached its full size and weight, but before it becomes hard and the green-chop cereal silage is harvested at the boot stage and thereafter wilted (Ewing, 1998). At the time of harvest for the whole-crop cereal silage, the grain will have changed from a green colour, to a yellow-golden colour. According to Jennings (1995), silage crops should be harvested at an appropriate stage of growth to avoid loss of quality and palatability.

The methods commonly used to determine the levels of optimal whole plant moisture at harvest in maize silage include black layer method, milk-line method, calendar method, electronic method and grab test method (Barnhill *et al*., 2009). Over the past decade, it was recommended that maize silage should be harvested at the black-layer stage of maturity. However, recent research and field experience has shown that harvesting maize at black-layer stage of maturity usually results in silage that is too dry to be well utilized by dairy cows (Shaver, 1999) because by the time the kernels in the centre of the ear have all developed a black layer, the moisture of the whole maize plant is said to be between 55 and 60% (Barnhill *et al*., 2009). Thus nowadays, the black layer method is no longer considered a reliable method for determining harvest dates for maize silage since the early 80s when evidence suggested the relationship between whole plant moisture and black layer is too variable (Campbell, 2014).

Recent publications have therefore proved that harvesting maize when the entire plant is between 60 – 70% moisture provides the best combination of dry matter yield, digestibility and is the most suitable moisture level for best silage fermentation (Barnhill *et al*., 2009). Therefore, the most widely used method that has its whole-plant moisture levels between 60 – 70% at harvest is the milk-line method. The milk-line method is used as an indicator of when to harvest whole-plant maize for silage (Shaver, 1999). The milk-line is the interface between the solid and liquid portions of a maize kernel. According to Barnhill *et al*. (2009), the optimum stage for harvest (soft dough) is from one fourth to two thirds milk-line. The line appears about the time the kernel starts to dent and will move from the top of the kernel toward its base as it matures and dries (Figure 2.1). The crop is therefore said to be close to physiological maturity when the milk-line is gone.

Barnhill *et al*. (2009) and Shaver (1999) reported that agronomists believe that silage moisture is approximately 68%, a good moisture level for packing and fermentation, when the milk-line is half way down the kernel. Barnhill *et al*. (2009) stated that the time the milk-line gets three fourths of the way down the kernel the whole plant moisture will have dropped to around 64%, the dry end of the recommended harvest window.

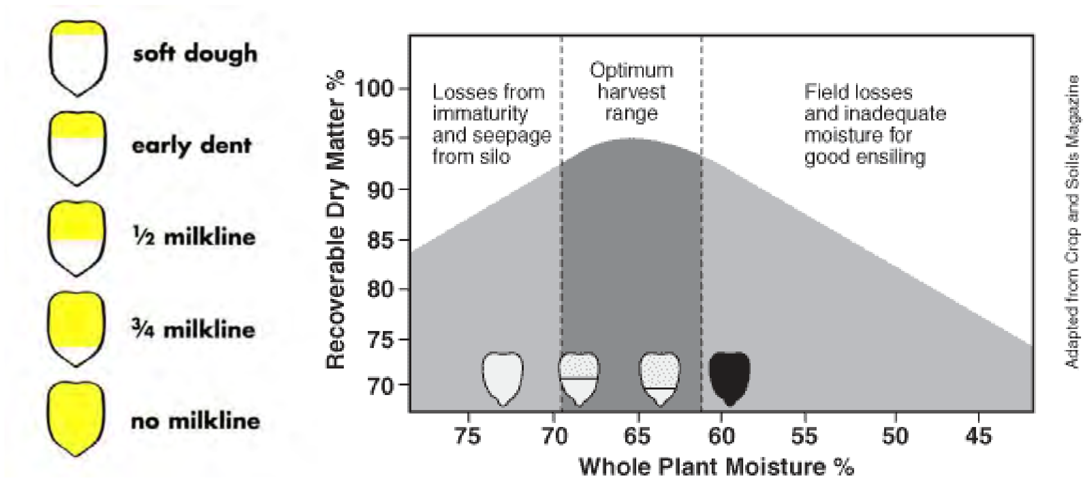

Figure 2.1: Maize seeds showing the level of the milk-line at different stages and the optimum range of harvest based on the recoverable dry matter. Source: Barnhill *et al*. (2009).

2.4.1.4 Chopping length

According to Meeske *et al.* (2003), the chopping length for maize silage may vary from 5 to 15 mm in order to provide sufficient saliva production and dietary fibre (Seglar, 2003). According to a study done by Shaver (1999), the recommended chop length for maize silage harvested with a conventional harvester without a crop processor is ⅜" theoretical length of cut (TLC) while it is ¾" TLC for maize silage harvested with a conventional harvester fitted with a crop processor. The ¾" TLC normally means that 20% to 30% of the processed silage will be in the coarse particle fraction but Meeske *et al.* (2003) concluded that only about 5% to 10% of the silage should be in the coarse particle fraction because unbroken kernels tend to pass through the cow undigested and large pieces of cobs or whole cobs are prone to sorting in the feed bunk. Grant and Stock (1994) reported that the particle size of silage determined by the chopping length affects both consumption and animal health. Seglar (2003) and Campbell (2014) reported that the recommendation for maize silage may vary between ¼" to ½" TLC depending upon whole-plant and kernel moisture content, hybrid, and forage harvester.

2.4.1.5 Moisture Content

Among the major factors affecting the fermentation process is the moisture content of the silage. Generally, the optimum moisture content for precision chopped silage is about 65%. This degree of hydration facilitates the fermentation process and usually helps to eliminate oxygen from the silage mass during packing (Sewell and Wheaton, 1993). Shaver (1999) reported that the best range in whole-plant moisture content that works well for achieving good preservation in horizontal silos is 65% to 70%. Muck (2000) reported that the whole plant maize harvested for storage in upright silos may need to be chopped a bit drier than 65% moisture to minimize seepage. Harvesting whole plant maize with more than 70% moisture increases seepage losses, increases acidity which can lower dry matter intake, and reduces dry matter yield per acre. Research has consistently shown reduced fibre and starch digestion along with reduced lactation performance for maize silage harvested at 60% moisture or less (Jennings, 1995). Maize silage harvested at 60% moisture or less will need to be either chopped fine or processed to minimize losses in starch digestion and lactation performance. Silages with less than 50% moisture content require supplemental water because the overall moisture content should be between 60 and 65% to prevent the formation of tobacco-brown silage (Sewell and Wheaton, 1993). Seven gallons of water, distributed evenly throughout the silage, are needed per ton of silage for each 1% increase in moisture content (Grant and Stock, 1994). Muck (2000) reported that the water used in silage must not be chlorinated, as chlorine can kill off desirable bacteria. Shaver (1999) in their study concluded that the best lactation performance by dairy cows has been shown to occur at 65% to 70% whole-plant moisture.

2.4.2 Ensiling

The quality and palatability of any silage will depend upon the stage of growth of the forage when it is ensiled. The first essential objective of the ensiling is to achieve anaerobic conditions under which natural fermentation can take place. In practice this is achieved by combining and compacting the material and the sealing of the silo to prevent air from re-entering (Meeske and Basson, 1998b). During ensiling, the air that is trapped in the herbage should be removed rapidly by respiratory enzymes (McDonald *et al.*, 1991). In cases where oxygen is in contact with herbage for a period of time, aerobic microbial activity occurs resulting in yeast and mould formation. This causes the material to decay to a useless, inedible and frequently toxic product (McDonald *et al.*, 1991). Campbell (2014) stated that chopping of plant material into finer pieces results in improved compaction and fermentation of silage thus improves palatability and intake of silage.

The second objective is to discourage the activities of undesirable microorganisms such as *Clostridia* and *Enterobacteria*. *Clostridia* are present on crops and in the soil in the form of spores. They multiply under anaerobic conditions, produce butyric acid and break down amino acids resulting in silage with a poor palatability and lower nutritional value (Campbell, 2014). The *Enterobacteria* are no-spore forming, facultative anaerobes, which ferment sugars to acetic acid and other products. *Enterobacteria* also have the ability to degrade amino acids

(McDonald *et al.*, 1991). According to Campbell (2014), the growth of *Clostridia* and *Enterobacteria* can be inhibited by lactic acid fermentation. Lactic acid bacteria are normally present on harvested crops and they ferment naturally occurring sugars like glucose and fructose to mainly lactic acid.

Maize is easy to ensile and compact because it has high sugar content. However, the biggest challenge is to improve its aerobic stability. Aerobic stability results in a higher silage intake and may improve animal production. In a study conducted by Meeske *et al*. (2003), they found that adding an inoculant during ensiling showed an improvement in aerobic stability, higher silage intake and less protein breakdown in maize silage. They further mentioned that milk production was, however, not increased. Hall (2009) reported the results of a study by Meeske and Basson (1998b) where they found that the intake of lambs fed inoculated maize silage was 10.7% higher and growth tended to be 6.6% higher. According to Muck (2000), less than 50% of studies with inoculants added to whole crop maize at ensiling resulted in a more rapid drop in pH. This is to be expected as the pH in maize silage often drops to 4 within the first 48 hours of ensiling leaving very little room for improvement in rate of preservation (Muck, 2000).

2.5 Intercropping

Intercropping is the growing of two or more crop species in proximity to promote interaction between component crops (Sullivan, 2003). Jensen (2005) defined intercropping as the simultaneous cultivation of more than one species or cultivar on the same piece of land. Intercropping, also known as mixed cropping or poly-culture, normally has one main crop and one or more added crops, with the main crop being of primary importance for economic or food production reasons (Masindeni, 2006). Ghosh *et al.* (2006) and Mondal *et al.* (2012) indicated that the other two or more crops in an intercrop were normally from different species and different plant families. However, they may be simply different varieties or cultivars of the same crop (Thayamini and Brintha, 2010). According to Andersen *et al.* (2004), the component crops of an intercropping system do not necessarily need to be planted at the same time nor be harvested at the same time, but should be grown simultaneously for a greater part of their growth periods.

Intercropping involves mixtures of annual crops with other annual crops or perennials with other perennial crops (Hugar and Palled, 2008). It has been receiving more attention lately because it offers potential advantages for resource utilization, decreased inputs and increased sustainability in crop production. Egbe and Kalu (2010) reported that there is very limited understanding of the interactions among intercropped species. However, the basic physiological and morphological differences between non-legume and legume species benefit their mutual association (Akunda, 2011). Ghanbari and Lee (2003) argued that the differences in rooting depth, lateral root spread and root densities are some of the factors of competition between the component crops in an intercropping system for water and nutrients, and hence input use efficiency. Alhassan and Egbe (2014) reported that the primary purpose of intercropping is to increase productivity per unit area of land.

2.5.1 Types of Intercropping

There are at least four main types of intercrops namely; strip intercropping, row intercropping, relay intercropping and mixed intercropping (Sullivan, 2003). Strip intercropping is when growing two or more crops together in strips that are wide enough to permit separate crop production using machines but close enough for the crops to interact. Row intercropping involves growing two or more crops at the same time with at least one crop planted in rows. Relay intercropping is when a second crop is planted into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting. Mixed intercropping is when growing two or more crops together in no distinct row arrangement (Thayamini and Brintha, 2010). Ghanbari and Lee (2002) reported that intercropping systems had, in general, a higher productivity than sole cropping systems.

2.5.2 Cereal - Legume Intercropping

Growing cereals and legumes together for food is a popular practice among subsistence farmers in the tropics (Egbe, 2005). The practice is old and it dates back to ancient civilizations. The system (cereal-legume intercropping system) has been proposed as a cropping strategy to enhance ground cover, thereby reducing weed competition, suppressing soil erosion, and providing nitrogen (N) for use by subsequent crops (Tsubo *et al.*, 2003). Therefore, with such intercropping systems, synthetic N-fertilizer and herbicide use might be reduced (Evans *et al.*, 2001; Egbe and Adeyemu, 2003; Tsubo *et al.*, 2003). Generally, in cereal-legume intercropping systems, the cereals are normally used as main crops, i.e. being of primary importance for economic or food production reasons. The common cereal-legume intercropping crop combinations include maize-beans, maize-cowpea, maize-soybean, maize-groundnuts, millet-groundnuts, sorghum-cowpea, wheat-soybean, and rice-pulses (Tsubo *et al.,* 2003; Mucheru-Muna *et al.,* 2010; Makgoga, 2013). Evans *et al*. (2001) stated that legume intercropping systems played a vital role in the efficient utilization of resources. The system is able to fix atmospheric nitrogen in a symbiosis relationship with rhizobium bacteria (Lemlem, 2013). Tsubo *et al.* (2003) also reported that cereal-legume intercropping systems are able to lower the amount of nutrients taken from the soil in comparison to sole crops. Rose and Matusso *et al.* (2013) reported that in Africa, legumes when intercropped with maize have been found to provide a stabilizing effect on food security of small scale farmers. They further mentioned that the systems provide a more stable production that is less variable under varying climate conditions.

2.6 Resource Use Efficiency in Intercropping Systems

When plants occupy the same space, there is always a possibility of competition for limiting resources such as water, nutrients and radiation (Lithourgidis *et al.*, 2011). According to Brisson *et al.* (2004), the competition in sole cropping, where all the plants are of the same species, is most likely to occur during times of peak demand. In intercropping, there is an advantage in resource competition since the component crops have different requirements for resources (Brisson *et al.*, 2004). Malezieux *et al.* (2009) reported that the competition in mixtures becomes more severe with similar plants than with plants differing in growth habit. However, Lithourgidis *et al.* (2011) argued that the efficient use of basic resources in a cropping system depended partly on the essential efficiency of the component crops that make up the system and partly on the complementarity effect between the crops. Thus, better resource use efficiency can be achieved through minimizing competition and maximizing complementarity between the different crops. Malezieux *et al.* (2009) reported that a factor that may be complementary at one stage of the growing cycle may become competitive at a later stage. Likewise, a competitive factor at one stage could become complementary at another. Therefore, Malezieux *et al.* (2009) concluded that it was necessary to prolong complementarity for as long as possible, and that could be archived by manipulating inputs, planting dates, planting methods and arrangements (Lithourgidis *et al.*, 2011).

2.6.1 Water Use Efficiency (WUE)

Water availability is one of the most important factors that determine productivity in cropping systems. Intercropping of two crop species such as legumes and cereals has been found to use water more efficiently than monocultures of either species through exploring a larger total soil volume for water, especially if the component crops have different rooting patterns (Alhassan *et al.*, 2012). The behaviour is due to the fact that intercropped species explore a larger total of soil volume because of different rooting patterns (Thobatsi, 2009). Water use efficiency can be defined as yield per unit area divided by water consumed to produce the yield. It is calculated using two components or factors, i.e. yield and water use (Walker and Ogindo, 2005; Makgoga, 2013). There are several possible ways in which intercropping can improve water use compared to sole cropping (Willey, 1990; Liebenberg, 1997; Carlson, 2008). These include increased water availability to plants, increase in the total amount of water withdrawn from the soil in the form of evapotranspiration, increased transpiration without increasing the total evapotranspiration, and increased water use efficiency.

Generally, water availability to plants can be increased through increased canopy cover that protects the soil against capping, leading to improved infiltration and reduced soil erosion. The availability can also be increased by a reduction in weeds due to intercropping (Thobatsi, 2009). The increase in the total amount of water withdrawn from the soil in the form of evapotranspiration increases with increased canopy cover. An increase in transpiration without increasing the total evapotranspiration is likely to occur under lower soil temperatures due to better canopy cover, thus reduced evaporation (Carlson, 2008). According to Liebenberg (1997), intercropping increased water use efficiency by more than 18% and by as much as 99% in some cases. Ghanbari and Lee (2003) reported that in an intercrop, surplus water early in a crop's life cycle could be utilized by another crop. Usually, the short season crops use water early in the season and get past their peak demand period before the onset of the peak demand period of the long season crops (Carlson, 2008). Many studies have proven that intercropped species out-yield sole crops. In a study of a sunflower-mustard strip intercrop, both components out-yielded the sole crops (Liebenberg, 1997). Launay *et al.* (2009) also observed that paired rows of sorghum with two rows of intercrops (groundnut, cowpea and soybean) yielded more compared to other planting combinations. Thus water use efficiency can be increased by means of an improved distribution of roots which helps reduce runoff during periods of rainfall (Carlson, 2008).

2.6.2 Nutrient Use Efficiency (NUE)

Crops require varying amounts of nutrients during their life cycle. The uptake depends on how much distributed and concentrated the roots are in the soil (Zhang and Li, 2003). Generally, nutrient uptake is increased with an improved distribution and concentration of the roots in the soil. In intercropping systems, nutrient use efficiency occurs spatially or temporally (Eskandari, 2011). The spatial nutrient uptake increases with increasing root mass, while the temporal nutrient uptake occurs when crops in an intercropping system have peak nutrient demands at different times. According to Thobatsi (2009), intercrops which differ in rooting and nutrient uptake patterns result in efficient use of nutrients, especially nitrogen uptake. This is due to the state of mobility of nitrogen over other mineral elements. The effect of nitrogen fixation is also a common research topic. Many studies demonstrate that non-legumes intercropped with legumes benefit from nitrogen recently fixed by the legumes (Mucheru-Muna *et al.*, 2010). The only clear route of nitrogen transfer is indirectly through the death and decomposition of the plant or plant material. Liebenberg (1997) reported that it is very unlikely that a non-legume will benefit from nitrogen fixed by a legume in that same season unless the non-legume grows actively for a considerably longer time than the legume. Zhang and Li (2003) and Liebenberg (1997) reported that under South African conditions, the effect of atmospheric nitrogen fixation by beans was found to be negligible because indigenous inactive *Rhizobium* is too competitive for inoculated active *Rhizobium*, implying reduced amounts of fixed nitrogen for plant uptake.

2.6.3 **Radiation** *Use Efficiency (RUE)*

Solar radiation is a resource which cannot be stored easily, therefore, must be used immediately. Its importance lies in the vital role it plays in photosynthesis and it determines water use by the process involved in evaporation and transpiration (Sinoquet *et al.*, 2000). For optimum plant growth and production, sufficient amounts of radiation for photosynthesis are required. Awal *et al.* (2006) defined radiation use efficiency (RUE) as the ability of a crop to produce dry matter or yield per unit of radiation intercepted and/or absorbed. Thus radiation interception is perhaps the most important factor affecting productivity of intercrops (Khan *et al.*, 2002). According to Liebenberg (1997), the crop that intercepts the radiation first shades the other, and is usually the dominant crop. The neighbouring plants compete with each other for direct interception (Khan *et al.*, 2002). The increase in interception and/or increase in solar radiation use efficiency can lead to greater productivity (Liebenberg, 1997; Tsubo *et al.,* 2003; Zanjan and Asli, 2012). Tsubo *et al.* (2003) stated that greater efficiency could be achieved through better distribution of leaf area over time and space. Liebenberg (1997) and Sinoquet *et al.* (2000) listed radiation and nitrogen as the two major resources for which cereal and legumes compete when intercropped in the humid subtropics.

Intercropping systems generally use light more efficiently than by sole crops (Pridham and Entz, 2008). According to Khan *et al.* (2002), short season crops usually exhibit a rapid increase in leaf area per unit of thermal time while the long season crops exhibit a slow increase in leaf area per unit of thermal time. Thus, for a short season crop, radiation may be poorly utilized during the end of the season, whereas a long season crop poorly use radiation at the beginning of the season (Liebenberg, 1997). Therefore, combining a short and long season crop can enhance temporal capture of radiation energy (Tsubo *et al.*, 2003). Many publications have proved the efficient use of light in a long/short season intercropping. Liebenberg (1997) reported that light conversion efficiency was greater in a sorghum/pigeon pea intercropping trial than in sole crops. Khan *et al.* (2002) reported that climbing beans, using maize plants as structural support, achieved an improved distribution of leaves through the canopy, thereby increasing light interception. However, there have also been reports that the benefit in intercropped trials was not always due to increased light interception; some crops have been found to benefit greatly from shading (Sinoquet *et al.,* 2000; Awal *et al.,* 2006; Mazaheri and Oveysi, 2004). Liebenberg (1997) stated that under agro-forestry, shading of potatoes during the first four weeks after planting and last two weeks before harvest increased tuber yield by 20%. According to Tsubo *et al.* (2003), shading effects are influenced by changing the spatial arrangement and density of component crops. Row orientation can also have an influence on shading but its influence is often determined by the topography of the field (Awal *et al.*, 2006). As previously mentioned, it can be seen that crop sensitivity to shade, amount of shading, growth cycles, cultivar choice and time of planting have an effect on light use efficiency (Liebenberg, 1997; Awal *et al.*, 2006).

2.7 Assessment of Intercropping Productivity

According to Sullivan (2003), researchers have designed methods for assessing intercrop performance as compared to pure stand yields. Such methods include land equivalent ratio (LER), area time equivalent ratio (ATER) and staple land equivalent ratio (SLER) (Thobatsi, 2009). In research trials, crop mixtures and pure stands are grown in separate plots. Yields from the pure stands and from each separate crop from within the mixture are then measured (Mazaheri and Oveysi, 2004). Of the three methods, LER is the most widely used method to determine the yield advantage the intercrop has over the pure stand, if any (Mazaheri and Oveysi, 2004; Sullivan, 2003).

2.7.1 Land Equivalent Ratio (LER) method

Land equivalent ratio (LER) is the ratio of the area needed under sole cropping to one of intercropping at the same management level to give an equal amount of yield. In short, LER is the sum of the fractions of the yields of the intercrops relative to their sole crop yields (Dariush *et al.*, 2006). It is calculated through dividing the intercrop yields by the pure stand yields for each component crop in the intercrop. The two figures obtained are then added together (Sullivan, 2003). According to Andrews (1979) LER can be mathematically expressed as:

$$LER = \frac{intercrop\ maize}{sole\ maize} + \frac{intercrop\ legume}{sole\ legume}$$ **Equation 2.1**

Yield advantages from intercropping, as compared to sole cropping, are often attributed to mutual complementary effects of component crops, such as better total use of available resources. Generally, sole cropping legumes have higher yields compared to yields in an intercropping system. However, in most cases, land productivity measured by LER shows the advantage of mixed cropping of cereals and legumes (Mandal *et al*., 1996). According to Sullivan (2003), LER gives an indication of magnitude of sole cropping required to produce the same yield on a unit of intercropped land. The research results indicate that response of nitrogen to intercropping generally results in reduced LER values (Mazaheri and Oveysi, 2004). Basically, when an LER measures 1.0, it means there was no advantage to intercropping over pure stands (Sullivan, 2003). Dariush *et al.* (2006) reported that LER values above 1.0 show an advantage to intercropping, while values below 1.0 show a disadvantage to intercropping. For example, an LER of 1.20 indicates that the yield produced in the total intercrop would have required 20% more land if planted in pure stands while an LER of 0.75 indicates that the yield produced in the total intercrop was only 75% of that of the same amount of land that planted pure stands (Sullivan, 2003). Income Equivalent Ratio (IER) is a term used to define LER when converted into economic terms. IER is defined as the ratio of the area needed under sole cropping to produce the same gross income as one hectare of intercropping at the same management level (Dariush *et al.*, 2006; Sullivan, 2003).

Sullivan (2003) reported that there were limitations to the use of the LER concept that should also be realized, particularly when used to compare the productivity of an intercrop and sole crop. Willey (1979) stated that one major problem is that the computation of LER needs maximum yields of sole crops obtained at optimum plant densities. Another problem is that LER does not give the production of biomass or the exact value of yields but instead represents the yield advantage or disadvantages of intercrops compared to sole crops (Thobatsi, 2009).

2.7.2 Area Time Equivalent Ratio (ATER)

Since the concept of LER does not include a time factor, it seems to over-estimate the advantage of intercropping particularly when component crops differ greatly in maturity. The estimation of LER assumes that land occupied by early maturing crops will not be utilized after harvest until harvesting of the late maturing crop (Sullivan, 2003). Thobatsi (2009) reported that it is very common in intercropping systems that the canopy of late maturing crops would spread to occupy the whole area, but in the case of a sole crop another crop may be planted immediately after the harvest of the early maturing crop. One way to overcome this limitation is by calculating yield production per day as an area time equivalent ratio (ATER) (Hiebsch and McCollum, 1987):

$$ATER = (Liti + Ljtj)/ T \qquad \textbf{Equation 2.2}$$

where Li and Lj are relative yields of partial LER's for component crops i and j, while ti and tj are durations (days) for crops i and j and T is the duration (days) of the whole intercrop system. Area time equivalent ratio might also underestimate the advantage of intercropping especially when component crops differ in their growth duration. This is because in the semi-arid areas it is not possible to plant another crop after harvesting like in the humid tropics where the growing season is continuous (Thobatsi, 2009). The growing season might not be long enough to have double sole croppings but it may be possible to have a long duration crop. Therefore, it appears that in semi-arid areas where double cropping is not possible, LER may be used for comparison, whereas in the humid tropics with continuous growing conditions ATER may be more appropriate (Sullivan, 2003).

2.7.3 Staple Land Equivalent Ratio (SLER)

The staple land equivalent ratio (SLER) mostly applies where the primary objective is to get the fixed yield production of one component crop, which in most cases is a cereal staple crop (Sullivan, 2003). Staple land equivalent ratio is an extension from LER which was proposed by Chetty and Reddy (1984). It is based on the assumption of a basic requirement for minimum supply of a major staple crop such as the cereal. The SLER has been used partially in India and does not appear to have been used widely elsewhere. Chetty and Reddy (1984) used the following formula to calculate SLER:

$$SLER = (Yi/Yii) + Pij\ (Yji/Yjj) \qquad \textbf{Equation 2.3}$$

where Yi/Yii is "the desired standardized yield" of staple i, Pij is the proportion of land devoted to intercropping and Yji/Yjj is the relative yield of crop j.

2.8 Conclusion

At a local level, South Africa is still faced with a global issue of food insecurity. As a result about 14 million people within the country suffer from poverty. The majority of these people are in rural and semi-urban areas of the country and most of them do not afford input resources such as fertilizers. Therefore, as means of alleviating the rate of poverty through agricultural projects, the resource poor farmers in rural areas of the country have been practising traditional cropping systems such as intercropping of cereal-legume crops such as maize and bambara groundnut. Maize and bambara groundnut play an important role in the subsistence and economy of poor people throughout the developing world because of their potential for dietary diversification and the provision of micronutrients such as vitamins and minerals, hence reduced rate of poverty and an increased overall general well-being.

CHAPTER 3

MATERIALS AND METHODS

3.1 Plant Material

Seeds of two different crops, maize and bambara groundnut, were obtained from different locations for the purpose of the study. The maize seed (ZM 305) was an open-pollinated variety (OPV) obtained from Zimbabwe. It is a small statured, early maturing variety with a yield potential of 2 – 5 t ha^{-1} (Chimonyo *et al*., 2014). The bambara groundnut seed was obtained from local subsistence farmers of Jozini (27°26'S; 32°4'E) in KwaZulu-Natal. The seeds were a mixture of three distinct colours including dark red, brown and cream, however, the colour of the seed coat was not considered a factor in this study.

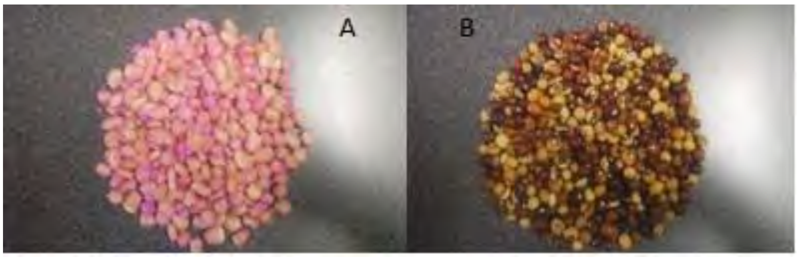

Figure 3.1: Illustration of maize variety ZM 305 (A) and bambara groundnut seeds (B).

3.2 Site Description

A field trial was conducted at Swayimane High School, Wartburg (29°25'S; 30°34'E) in KwaZulu-Natal. The area receives a mean annual rainfall of about 732 mm, with most rainfall (80 % of the total annual rainfall (592 mm)) occurring mainly between November and April. The area receives the lowest rainfall of 5 mm in June and the highest rainfall of 116 mm in January. Thus Wartburg can be classified as a semi-arid environment. The average midday temperatures for the area range between 19.7°C in winter to 26.2°C in summer (Jensen, 2015).

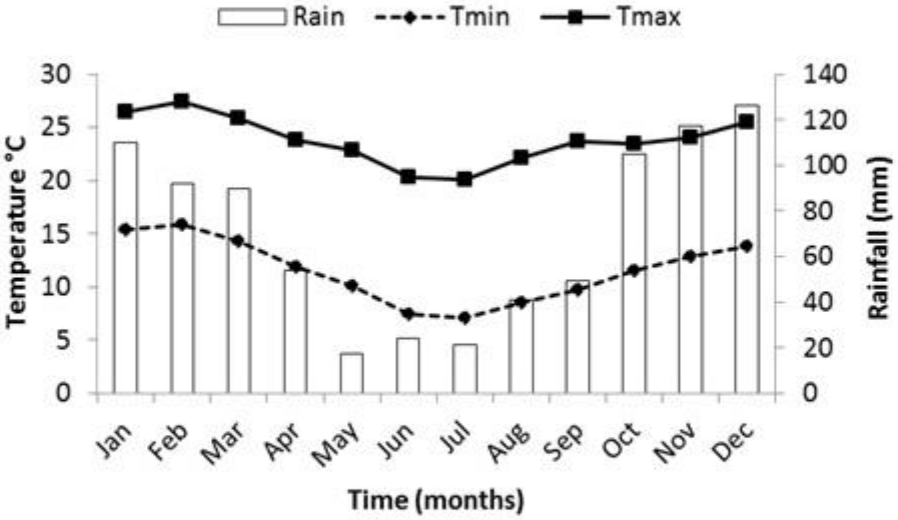

Figure 3.2: Average monthly temperatures (maximum and minimum) and rainfall distribution for Wartburg over a period of ten years. Source: Louis Botha weather station (2015).

3.3 Soils

Random soil samples were taken from the topsoil (0-30 cm) for soil analysis prior to planting at Swayimane High School in Wartburg, Pietermaritzburg. Based on fertiliser recommendations for the main crop, maize, 20 kg of 2:3:2 (N:P:K) (22) fertilizer was applied to the field six weeks after planting (26th of February 2015).

3.4 Laboratory Germination Test

For determination of seed quality for seed viability, the standard germination test was carried out under laboratory conditions. Three replicates of 25 seeds from each crop (maize and bambara groundnut) were germinated at 25 °C. The seeds were first rinsed with ethanol for the purpose of sterilization. Thereafter, the seeds were placed between moist double layered brown paper towels. The towels were moistened using distilled water. They were then rolled and sealed with rubber bands at each end. Thereafter, the rolled paper towels were put in plastic zip lock bags so as to minimize moisture loss. The bags were incubated in a germination chamber set at 25 °C for 8 days according to Association of Official Seed Analysts (AOSA 1992) guidelines.

3.5 Experimental Design

The field trial was established in January 2015 under rain-fed conditions. The experiment was a one way designed as a randomized complete block (RCBD) consisting of three replications. The experiment consisted of 3 treatment combinations (sole maize (M), sole bambara groundnut (BG) and maize + bambara groundnut intercrop (MBG)). Each block was replicated three times making a total of nine units. The size of individual plots was 9 m^2 and the whole trial was 121 m^2. The inter-row and intra-row spacing was 0.75 m and 0.375 m, respectively. The attained plant population for maize in each experimental plot was 33333.33 plants ha^{-1} while for bambara groundnut it was 83333.33 plants ha^{-1}.

3.6 Data Collection

3.6.1 Laboratory Data Collection

Germination counts were taken at 24 hour intervals. A seed was said to have germinated if radicle protrusion (2 mm) was observed. On the final day, measurements of root length (cm); shoot length (cm); fresh mass (g); dry mass (g) and root: shoot ratio, were taken. Germination percentage, mean germination time (MGT), germination index (GI) and time to 50% germination (T50) were calculated using the following equations:

The germination percentage (GP) was calculated according to the formula used by Zanjan and Asli (2012):

$$\text{Germination percentage} = \frac{\textit{Number of germinated seeds}}{\text{Total number of seeds incubated}} \times 100 \quad \textbf{Equation 3.1}$$

The mean germination time (MGT) was calculated by using the formula of Van Staden and Street (2007) and Muhammed and Amusa (2003):

$$\text{MGT} = \frac{\Sigma\ (\text{n x d})}{N} \quad \textbf{Equation 3.2}$$

where, n = number of seeds germinated on each day, d = number of days from the beginning of test, and N = the total number of seeds germinated at the termination of the experiment.

The germination index (GI) and time to 50% germination (T50) were calculated according to the formulae used by Zanjan and Asli (2012):

$$\text{Germination index (GI)} = \frac{\sum TiNi}{S} \quad \textbf{Equation 3.3}$$

where, Ti = number of days after planting, Ni = number of seeds germinated on day I, and S = the total number of planted seeds:

$$T_{50} = t_i + \frac{\left(\frac{N}{2} - ni\right)(ti - tj)}{ni - nj} \qquad \textbf{Equation 3.4}$$

where, N = final number of germination and ni and nj = cumulative number of seeds germinated by adjacent counts at times ti and tj. However, in this current study, T_{50} was read from the germination percentage graphs.

3.6.2 Field Data Collection

Data collected included weather data, emergence, plant height, leaf number, photosynthetic active radiation (PAR), chlorophyll content index, stomatal conductance and soil water content (SWC). The average midday temperatures for the area range from 19.7°C in winter to 26.2°C in summer (Jensen, 2015).

Weather data, mean annual rainfall of 732 mm and average midday temperatures of 19.7°C in winter to 26.2°C in summer were obtained from the nearest weather station in Wartburg (29°25'S; 30°34'E). Emergence was determined by counting the number of emerged seedlings in the field from seven days after planting until 49 days after planting. Plant height was measured from 22 days after planting using a 30 cm ruler and tape measure for bambara groundnut and maize, respectively. Leaf number was determined by counting the number of fully developed leaves with at least 50% green leaf area (Mabhaudhi and Modi, 2013). For bambara groundnut, a trifoliate was considered as one leaf. Photosynthetically active radiation (PAR) was measured using the AccuPAR LP80 ceptometer (Decagon Devices, USA). Two readings were taken in each plot, one from above the canopy where the sensor was not shaded, and another below the canopy. Thus the difference between the above and below values was a measure of intercepted PAR. Chlorophyll content index (CCI) was measured from the leaf adaxial surface using the SPAD 502 Plus chlorophyll content meter (Konica Minolta, USA). Stomatal conductance (SC) was measured from the abaxial surface of leaves using a steady state leaf porometer (Model SC-1, Decagon Devices, USA).

Changes in soil water content (SWC) were measured using a PR2/6 profile probe connected to an HH2 handheld moisture meter (Delta–T, UK). The PR2/6 profile probe has sensors positioned at 0.10, 0.20, 0.30, 0.40, 0.60 and 1.00 m along the probe. Soil water content (SWC) was measured at these corresponding six depths.

3.6.3 Harvest and Postharvest data

Maize was harvested at 105 days at soft dough stage. In each plot, six experimental plants were harvested. Fresh mass (g) was determined by weighing each plant together with its cob(s) using a Mettler TE 15 scale. The plants were dried in a glasshouse and weighed after every four days. When there was no loss in mass at two consecutive weighing's, maize plants were considered dry and final biomass was measured. Data also measured included, cob number cob length, and cob mass.

Bambara groundnut was harvested at 126 days after planting when about 80% of the leaves had senesced. In each plot, 10 experimental plants were harvested. Mass of biomass at harvest (g) was determined by weighing the whole plant with its fruits using an OHAUS® scale. The plants were further dried in a glasshouse for 30 more days until no further loss in mass was observed. After which, bambara ground nuts were considered dry and the final biomass yield was then measured. Thereafter, data of pod number per plant; pod mass per plant; number of seeds per plant and mass of the shells per plant were measured.

3.6.4 Proximate Analyses

To analyse for nutrient content, plant material for bambara groundnut was first ground to powder using a milling machine (Retsch KG). For maize, stems were initially chopped into smaller bits with a VIKING® GE 110 chopping machine then, leaves and stem were fed into Retsch KG milling machine. The crude protein was analysed using a Leco Trumac instrument following the Dumas combustion method. The method is an absolute method for the determination of the total nitrogen content in a usually organic matrix. The sample was combusted at high temperature in an oxygen atmosphere. Using the subsequent oxidation and reduction tubes, nitrogen was quantitatively converted to N_2. Results were given as % nitrogen, and were later converted into protein using a conversion factor of 6.25 (Muller, 2014). The chemical analysis of ash and fat was done following the Association of Official Analytical Chemists standard procedures (AOAC, 1980) described by Horwitz (1980). The detergent fibres (NDF and ADF) were analysed using a digestion block machine according to the method described by Goering and Van Soest (1970).

3.7 Description of Statistical Analyses

Data collected were analysed using analysis of variance (ANOVA) from GenStat® Version 16 (VSN International, UK) statistical package.

CHAPTER 4

SEED QUALITY OF MAIZE AND BAMBARA GROUNDNUT

4.1 Introduction

Seed quality is a critical factor affecting the early performance and growth of agricultural crops (Goggi *et al*., 2008). It is defined as the genetic, physical, phytosanitary and physiological attributes of a seed (International Seed Testing Association (ISTA), 2005). The genetic attributes focus on varietal identity and purity of seeds with its primary objective on producing and multiplying certified seeds of new cultivars. The physical attributes are defined based on the structure and size fraction of seeds hence Ogutu *et al.* (2012) and Sulewska *et al*. (2014) stated that well-developed and high density seeds have higher quality. The phytosanitary attributes focus on the health of seeds with its main focus on disease-causing organisms such as fungi, bacteria, viruses and insects. The physiological attributes define seed quality as the viability and vigour traits of a seed that make possible the emergence of normal seedlings under a wide range of environments (ISTA, 2012). Seed viability refers to the capacity of a seed to germinate in time and produce a normal seedling while seed vigour refers to seed properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions (ISTA, 2006; Setimela and Kosina, 2006; Goggi *et al*., 2008). Sulewska *et al*. (2014) reported that germination and seedling vigour were greatly influenced by seed size.

Seed quality is influenced by a number of factors such as environmental conditions, harvesting and processing conditions and postharvest and storage conditions (Jayas and White, 2003). The conditions that mainly affect the quality of seeds during storage include temperature, moisture, carbon dioxide (CO_2), oxygen (O_2), grain characteristics, microorganisms, insects, mites, rodents, birds, geographical location and storage facility structure (Jayas and White, 2003; Govender *et al*., 2008). Shah *et al*. (2002) reported that the fluctuations in temperature and humidity within a storing room and prolonged storage result in considerable nutrient losses. The presence of soil and seed borne pathogens, pests, weeds and other crop contaminants where crops are grown also influence the quality of seeds greatly (Msuya and Stefano, 2010). Ogutu *et al.* (2012) reported that poor availability of resources such as water, nutrients and radiation influenced not only the yield, but also the quality of seeds. De Geus *et al*. (2008) found that poor soil fertility and nutrient availability during crucial phases of seed development and maturation influenced the quality of maize seeds.

Despite significant advances in food storage methods, many African and South African communities still rely on traditional storage methods for seed to be used as food and fodder (Olakojo and Akinlosotu, 2004; Thamaga-Chitja *et al*., 2004). Setimela and Kosina (2006) reported that sometimes the seed provided through these channels may be of poor quality, i.e. low genetic purity, contaminated with pests and diseases, or poor germination. Therefore, it is always important to establish the seed quality before planting out in the field. Thus, the objective of this study was to determine the seed quality of maize (OPV) and Bambara groundnut landrace prior to establishing the field trials.

4.2 Results and Discussion

On average, germination was first observed on day 2 with an average of 36%. The time to 50% germination was achieved on day 3 (Figure 4.1). The final germination percentage obtained was 97.3% which is above the acceptable maize germination percentage of 70% according to the Plant Protection Act (1976) (Chen and Burris, 1993).

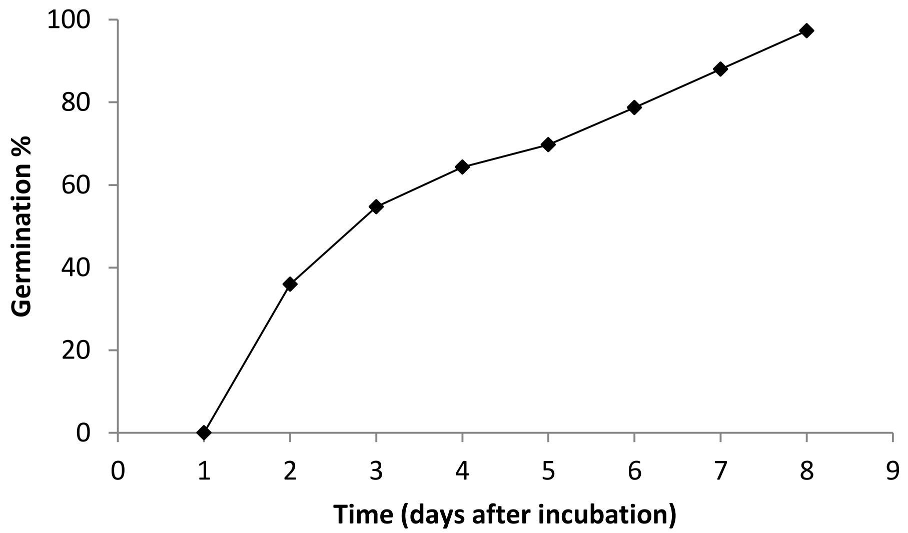

Figure 4.1: Germination percentage of maize variety ZM 305 recorded on a daily basis as observed in the standard germination test.

Table 4.1: Performance of maize under standard germination test prior to field planting.

	MGT (days)	GVI	Seedling length (cm)	Shoot length (cm)	Root length (cm)	Root: Shoot ratio	Fresh mass (g)	Dry mass (g)
Mean	3.42	3.32	36.87	14.01	24.02	1.254	2.442	0.288
LSD	0.624	0.558	2.789	1.080	2.481	0.025	0.146	0.045
%CV	10.5	9.7	3.8	3.9	5.2	1.0	3.0	7.8

* The results are performed from a comparison of replications

There were highly significant differences ($P < 0.001$) observed with respect to mean germination time (MGT) and germination velocity index (GVI) (Table 4.1). No significant differences ($P > 0.05$) were observed with respect to seedling length, shoot length, root length, root: shoot ratio, fresh mass and dry mass (Table 4.1). The seeds used in current study were of medium to large size. According to Msuya and Stefano (2010), the size of grains reflects quantity of food reserves and physiological biosynthates that can be available to support growth during germination and early seedling establishment. Yusuf *et al*. (2014) observed that larger size seeds tend to have an increase in seedling height, width, and rapid biomass accumulation more than the medium and small size seeds. The increase may be as a result of a large embryo and high food reserves for the supply of energy. Therefore, in general, larger seeds in size are best recommended in plant production, because they tend to have larger biomass and consequently produce large grain (De Gues *et al.*, 2008).

For bambara groundnut, on average, germination was first observed on day 2 with an average of 42.67%. The time to 50% germination was achieved on day 3 (Figure 4.2). The final germination percentage obtained was 93.33% which is above the acceptable germination percentage of 80% according to the industry standard.

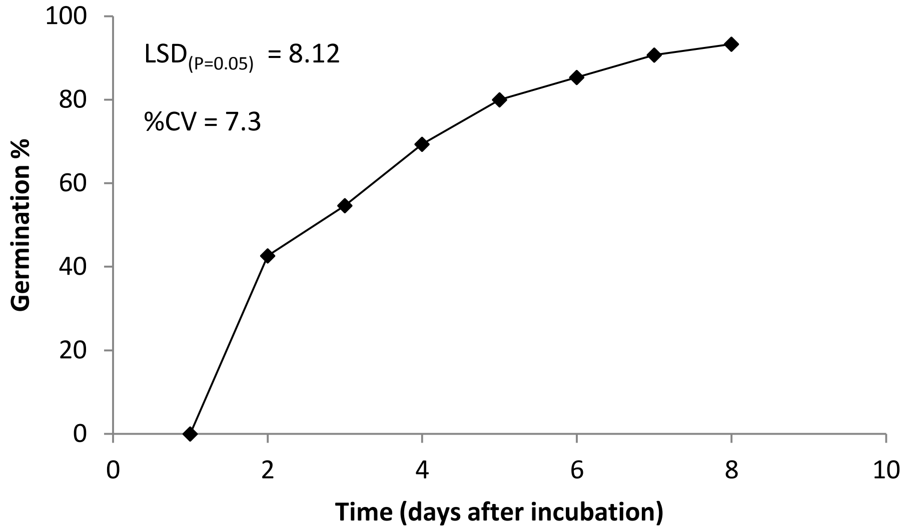

Figure 4.2: Germination percentage of Bambara groundnut recorded on a daily basis as observed in the standard germination test.

Table 4.2: Performance of Bambara groundnut under standard germination test prior to field planting.

	MGT (days)	GVI	Seedling length (cm)	Shoot length (cm)	Root length (cm)	Root: Shoot ratio	Fresh mass (g)	Dry mass (g)
Mean	3.780	3.562	13.030	5.170	7.830	1.222	1.626	0.249
LSD	0.333	0.329	0.877	0.666	0.581	0.028	0.164	0.063
%CV	5.1	5.3	3.4	6.4	3.7	1.1	5.0	12.7

* The results are performed from a comparison of replications

There were highly significant differences ($P < 0.001$) observed with respect to mean germination time (MGT), germination velocity index (GVI) and root: shoot ratio (Table 4.2). There were no significant differences ($P > 0.05$) observed with respect to seedling length, shoot length, root length, fresh mass and dry mass. The results obtained were somewhat in agreement with the results obtained by Gqaleni (2014) who found significant differences ($P<0.05$) for germination velocity index (GVI) where the plain cream seeds of bambara groundnut gave the highest GVI (4.421) and black speckled seeds gave the lowest GVI (2.529).

4.3 Conclusion

The improvement in crop productivity is dependent on the quality of seeds used in crop establishment. Crop establishment therefore serves as a requirement for successful crop production. Based on the results obtained, it can be concluded that both maize variety ZM 305 and bambara groundnut have high seed vigour and viability potential. However, these may not necessarily imply high crop yield and good quality.

CHAPTER 5

EFFECT OF INTERCROPPING ON CROP GROWTH, YIELD, SOIL WATER CONTENT AND SOIL NUTRIENTS

5.1 Introduction

In most rural communities, agricultural productivity faces constraints such as infertile soils, physical and economic water scarcity and poor access to capital for inputs (Moradi *et al.*, 2014). In addition, climate change and variability, increasing population, and land degradation have amplified these challenges. Given challenges associated with land degradation, cropping land has come under pressure to be also used for grazing (Adesogan *et al.*, 2000). There is need therefore to come up with cropping systems that can address the complexity of smallholder farming systems. Mabhaudhi and Modi (2013) reported that to improve productivity, intercropping can be used as an alternative strategy to current conventional cropping systems to also grow feed for animals and ease the pressure on grazing pastures. Intercropping is the simultaneous cultivation of more than one species in the same space at the same time and its primary purpose is to increase productivity per unit area of land (Jensen, 2005). It has been receiving more attention lately due to its potential advantages for resource utilization, decreased inputs and increased sustainability in crop production (Massawe *et al.*, 2002).

Intercropping involves different types of crop combinations (Hugar and Palled, 2008). However, cereal-legume intercrops seem to be most popular. The cereal-legume intercropping systems are old and most frequently practised, especially in developing countries with limited resources. According to Egbe (2005), cereal-legume intercropping systems have a positive impact on the future food problems in developing countries because they contribute to soil conservation, improving soil physical properties and soil fertility (Watiki *et al.*, 1993; Lemlem, 2013). Rusinamhodzi *et al.* (2006) reported that intercropping improves soil physical properties and can increase the micro-aggregation, porosity and infiltration. It also improves soil fertility as a result of biological nitrogen fixation by legumes as well as soil organic carbon although the increase varies with environmental conditions (Haynes and Beare, 1997). The improvement suggests that intercropping can contribute to the complex livelihoods of African smallholder farmers by improving their returns on minimal inputs and producing more and better food per land area (Fischler *et al.*, 1999 and Fischer *et al.*, 2000).

According to Sanchez *et al*. (1997) and Matusso *et al.* (2013), the soil is considered as productive and fertile if it enables deep rooting, provides aeration, has good water holding capacity and consists of adequate and balanced supply of plant nutrients. Sanginga and Woomer (2009) reported that a soil that fails to supply the growing plants with adequate and balanced nutrients is considered infertile. Soil infertility is caused by nutrient depletion which results from the breakdown of traditional practices and the low priority given to the rural sector (Sanchez *et al*., 1997). It is also caused by the increasing pressures on agricultural land which have resulted in much higher nutrient outflows and subsequent breakdown of many traditional soil fertility maintenance strategies, such as fallowing land, intercropping cereals with legume crops, mixed crop-livestock farming, and opening new lands (Sanchez *et al*., 1997; Smaling *et al*., 1997; Fisher *et al*., 2009). Matusso *et al.* (2013) reported that about 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} have been lost during the last 30 years from about 200 million ha of cultivated land in 37 African countries. Mugweni *et al.* (2002) reported that the decline in soil fertility poses a major threat to economic development of nations whose livelihood is dependent mostly on agriculture because it results in reduced crop productivity and subsequently food insecurity (Palm *et al*., 1997).

Gruhn *et al*. (2000) and Landers (2007) stated that it was necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and hence food security. Such technologies include the use of integrated soil fertility management practices (ISFM) such as intercropping cereals with grain legumes (Mucheru-Muna *et al*., 2010; Sanginga and Woomer, 2009). Cereal−grain legume intercropping systems have potential to address the soil nutrient depletion on smallholder farms because they are able to fix atmospheric nitrogen (Sanginga and Woomer, 2009; Nandwa *et al*., 2011). Sanginga and Woomer (2009) reported that grain legume crops such as bambara groundnut, cowpea, mung bean and soybean can help maintain and improve soil fertility because they accumulate between 80 to 350 kg nitrogen (N) ha^{-1} (Anderson, 2005).

Bambara groundnut is frequently intercropped or mixed with cowpea, maize and sorghum (Mkandawire and Sibuga, 2002). It is still among one of Africa's crops often neglected by science. Its seed makes it a good supplement to cereal-based diets and its leaves can be used for livestock feed (Massawe *et al*., 2002; Adesogan, 2011; Gqaleni, 2014). One major constraint in bambara groundnut production is inadequate information on the type and intensity of mixtures with other crop types in smallholder cropping. Ngugi (1995) indicated that bambara groundnut would do well if intercropped with maize if the maize planting density was low. The planting density of bambara groundnut is often low (<100 000 plants/ha) on farmers' fields (Egbe *et al*., 2010) resulting in low yields. Therefore, Alhassan and Egbe (2014) reported that research information on the optimal planting density, yield advantages and the profitability of bambara groundnut when intercropped with maize was still lacking in some regions of the world. It is in this regard that the study aims to determine the effectiveness of intercropping as dual purpose in terms of improving productivity and also supplying animal feed for livestock.

5.2 Results

5.2.1 Growth

There were no significant differences (P > 0.05) observed with respect to plant height of maize under sole cropping and intercropping (Fig 5.1). However, the sole crop plants were, on average, taller (135.3 cm) than plants under intercropping (120.1 cm). There were no significant differences (P > 0.05) observed with respect to plant height of bambara groundnut under sole and intercropping (Fig 5.1). The height of plants was statistically similar for both cropping systems throughout the growth period. On average, the tallest plants measured in both sole and intercrop systems were 18.9 cm and 18.43 cm, respectively.

There were no significant differences (P > 0.05) observed with respect to the number of leaves obtained for maize under sole cropping and intercropping systems (Figure 5.2). However, the plants under maize sole cropping system developed more leaves compared to plants under intercropping system. There were no significant differences (P > 0.05) observed with respect to leaf number obtained for bambara groundnut under sole cropping and intercropping systems (Figure 5.2). The results show that the plants in both systems developed more or less the same number of leaves throughout the growing period.

There were no significant differences (P > 0.05) observed with respect to chlorophyll content index measured on maize plants under sole cropping and intercropping systems (Figure 5.3). The content of chlorophyll measured in maize plants increased with an increase in the number of days after planting. There were no significant differences (P > 0.05) observed with respect to chlorophyll content index measured on bambara groundnut plants under sole cropping and intercropping systems (Figure 5.3). The results show that there were quite fluctuations on the amount of chlorophyll throughout the course of study.

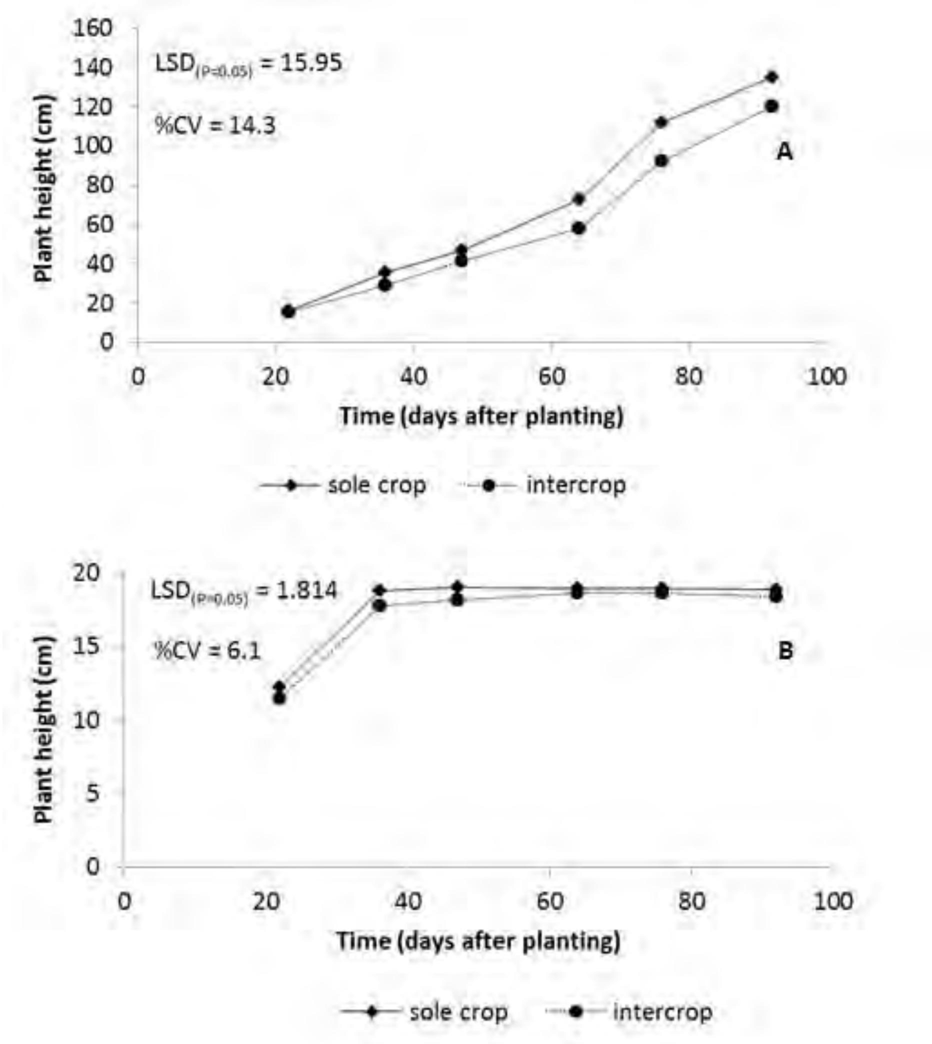

Figure 5.1: Plant height (cm) of maize variety ZM 305 and bambara groundnut (B) under sole cropping and intercropping systems.

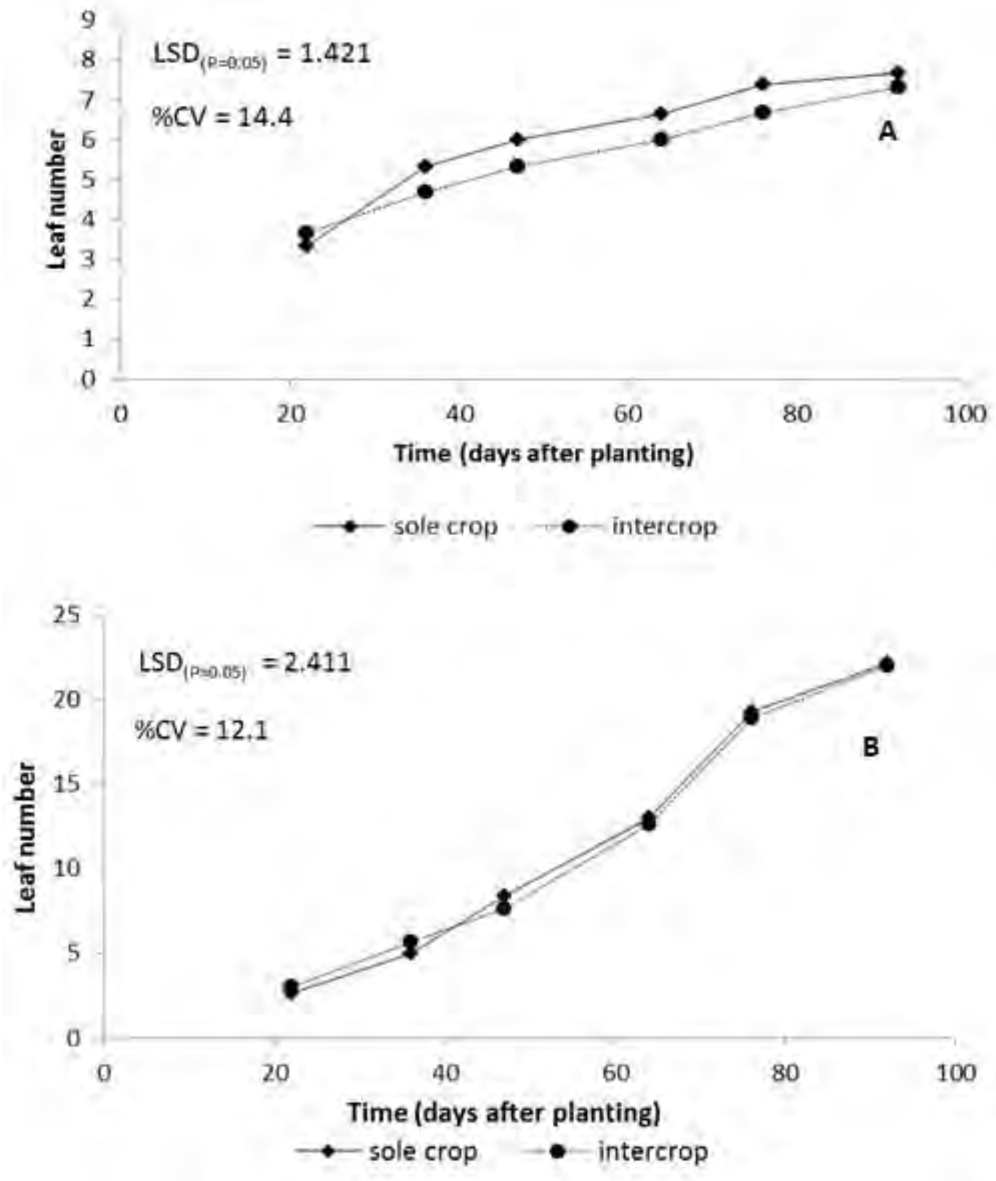

Figure 5.2: Number of leaves of maize variety (A) and bambara groundnut (B) under sole cropping and intercropping systems.

There were no significant differences (P > 0.05) observed with respect to stomatal conductance measured on maize plants under sole cropping and intercropping systems (Figure 5.4). No significant differences (P > 0.05) were observed with respect to stomatal conductance measured on bambara groundnut under sole cropping and intercropping systems (Figure 5.4). On average, the results show that the amount of stomatal conductance was highest during the middle of the growth period with 305.4 and 287.1 mmol/m^2.s for sole maize and maize-bambara intercrop systems and 296.7 and 331.6 mmol/m^2.s for sole bambara and maize-bambara intercrop systems, respectively.

There were no significant differences (P > 0.05) observed with respect to the temperature of stomatal conductance measured on maize and bambara groundnut plants under sole cropping and intercropping systems (Figure 5.5). The results show that the highest temperature recorded was at 64 and 76 (≈ 28°C) days after planting. The results also show that the average temperature decreased with an increase in number of days after planting to approximately 20°C at 92 days after planting.

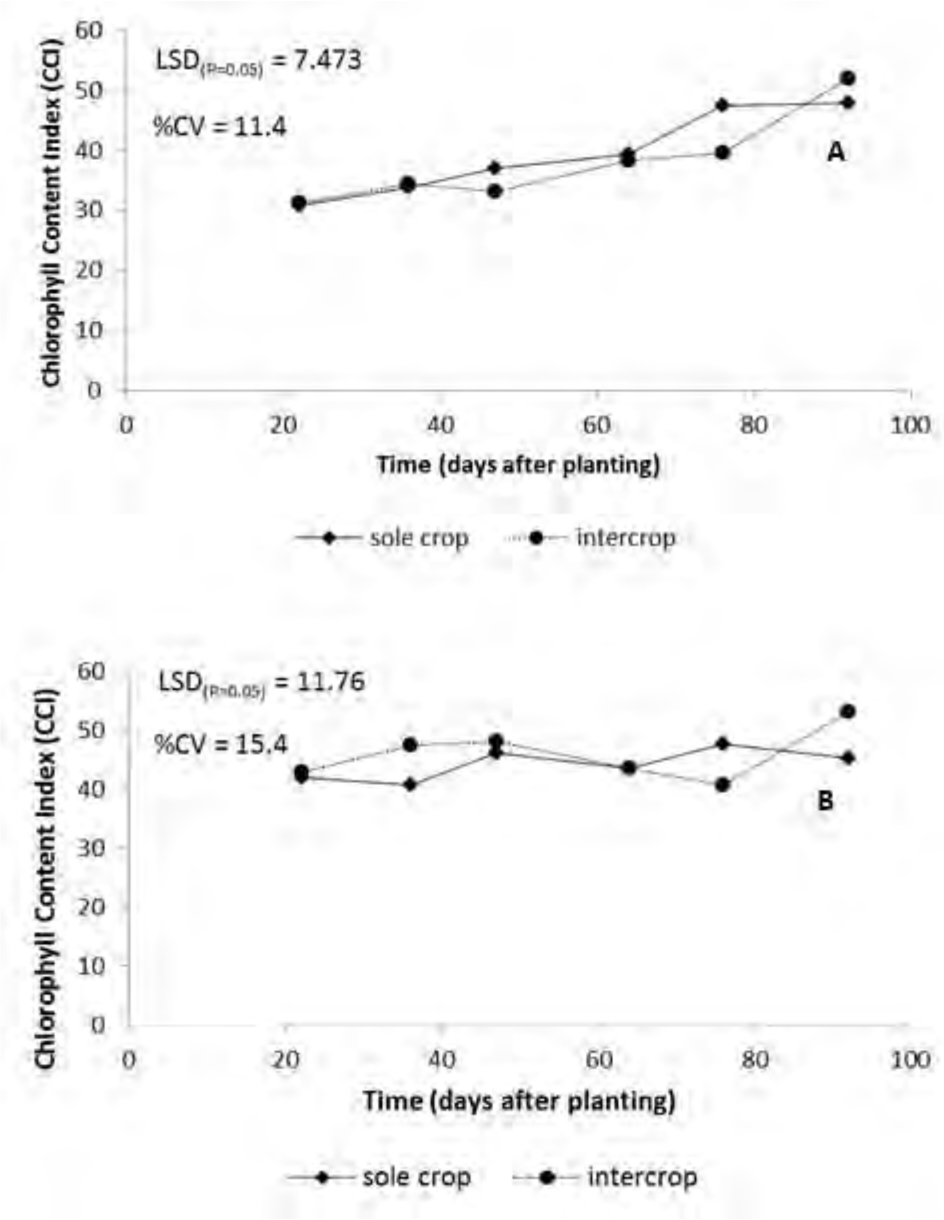

Figure 5.3: Chlorophyll content of maize variety ZM 305 (A) and bambara groundnut (B) under sole cropping and intercropping systems.

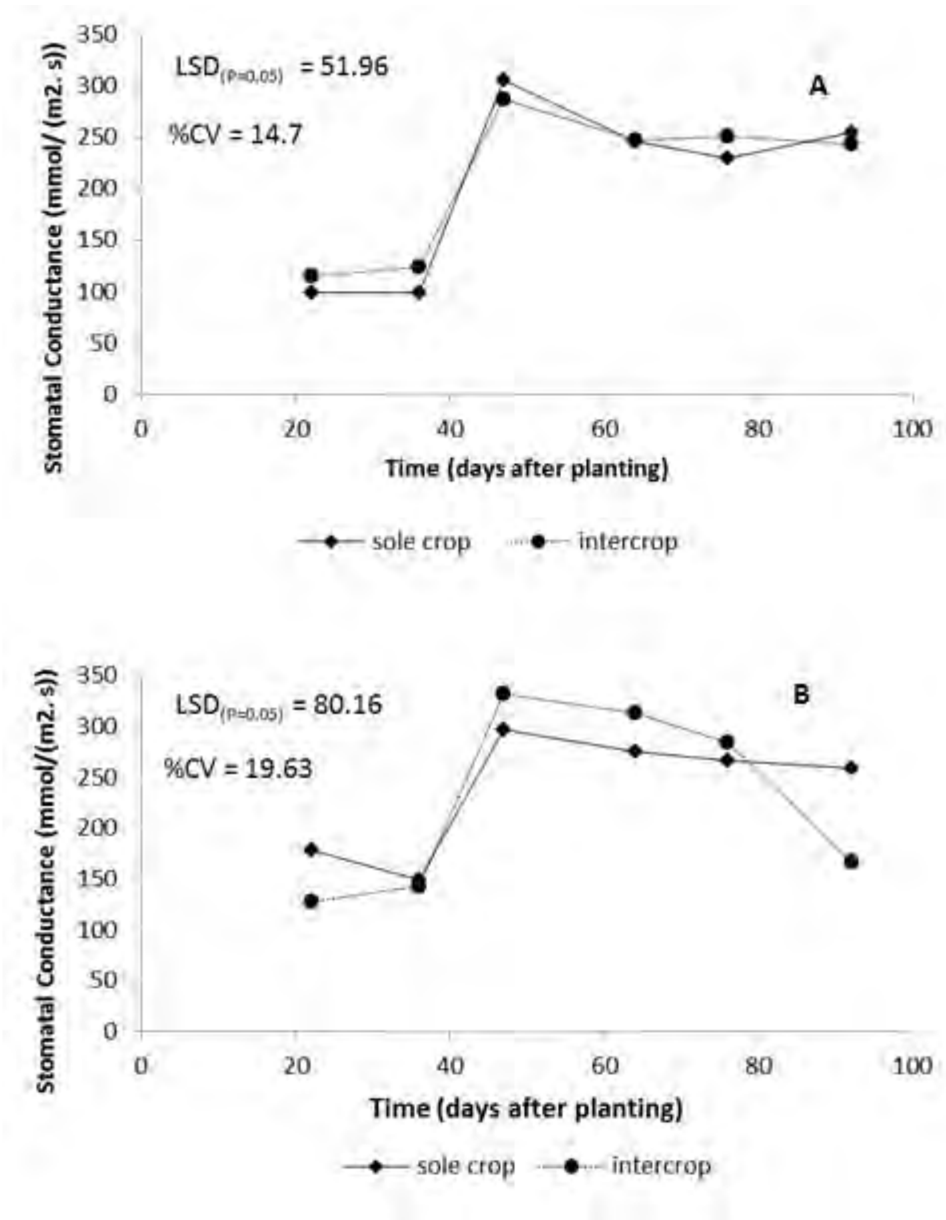

Figure 5.4: The stomatal conductance of maize variety ZM 305 (A) and bambara groundnut (B) under sole cropping and intercropping systems.

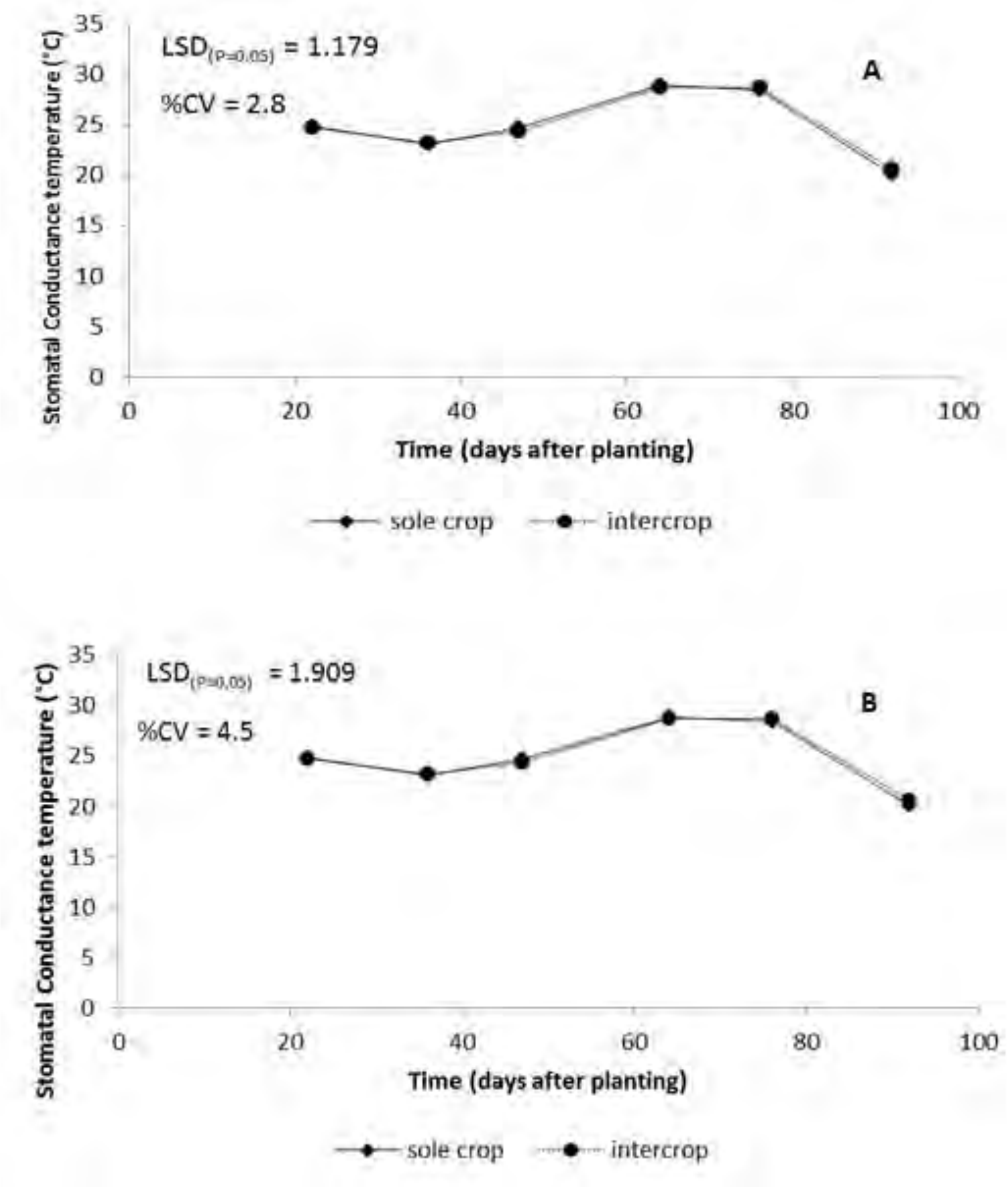

Figure 5.5: The temperature of a stomatal conductance of maize variety ZM 305 (A) and bambara groundnut (B) under sole cropping and intercropping systems.

There were no significant differences ($P > 0.05$) observed with respect to photosynthetic active radiation (PAR) and leaf area index (LAI) measured on sole maize, sole bambara groundnut and maize-bambara groundnut intercrop systems (Figure 5.6). The results show that both PAR and LAI had similar trend throughout the growth season. The sole maize had the highest amounts of PAR and LAI (765 and 1.6) while the lowest was observed in sole bambara groundnut (223 and 0.31).

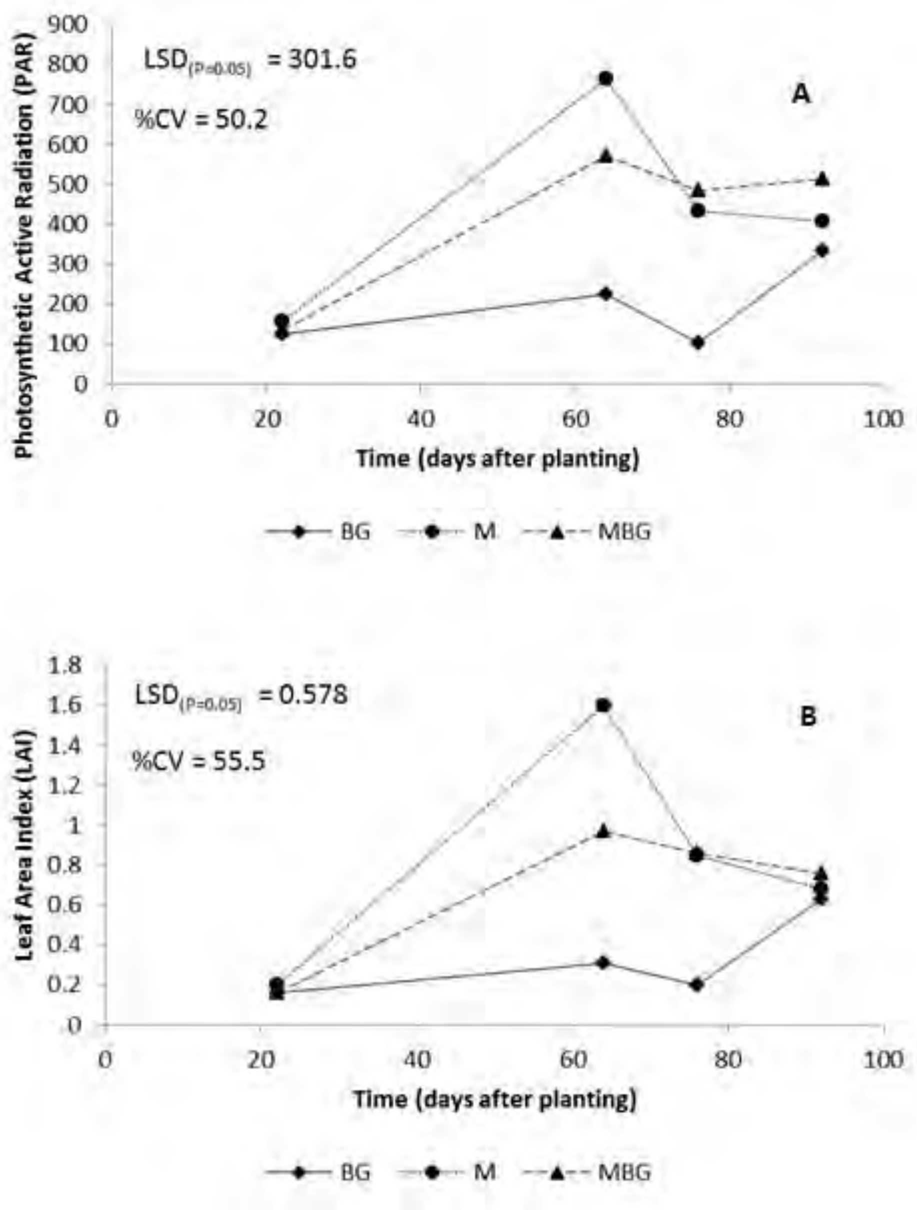

Figure 5.6: Photosynthetic active radiation (A) and leaf area index (B) of sole maize, sole bambara groundnut and maize-bambara groundnut intercrop systems.

5.2.2 Yield And Yield Components

There were no significant differences (P > 0.05) observed with respect to cob mass and cob length of maize under sole cropping and intercropping systems (Table 5.1). Significant differences (P < 0.01) were observed with respect to fresh mass, dry mass and above ground biomass of maize under sole cropping and intercropping systems (Table 5.1). The above ground biomass of sole maize was almost double the biomass of maize-bambara intercrop. The land equivalent ratio (LER) obtained for the biomass yield of maize was 1.016, which showed an advantage to intercropping indicating that the yield produced in the total intercrop would have required only 1.6% more land if planted in pure stands.

Table 5.1: Yield and yield components of maize under sole cropping and intercropping systems.

	Cob mass/ plant (g)	Cob length/ plant (cm)	Fresh mass (g)	Dry mass (g)	Biomass (g)
Maize	23.7	11.80	160.4	57.7	6.41
Maize+Bambara	23.5	12.33	118.2	35.6	3.95
Mean	23.6	12.07	139.3	46.6	5.18
LSD	19.71	5.34	28.01	26.68	2.96
CV (%)	23.7	12.7	9.3	17.1	16.3

* Comparisons made between maize sole and intercrop

Table 5.2: Yield and yield components of bambara groundnut under sole cropping and intercropping systems.

	Number of pods/plant	Number of seeds/plant	Seed yield (g)	Biomass (g)
Bambara	13.8	9.5	2.01	1.65
Bambara+Maize	3.6	2.8	0.47	0.66
Mean	8.7	6.1	1.24	1.16
LSD	11.02	10.25	1.89	1.28
CV (%)	36.1	47.4	43.3	17.6

* Comparisons made between bambara groundnut sole and intercrop

There were highly significant differences ($P < 0.001$) observed with respect to yield and yield components of bambara groundnut (Table 5.2). The results show that all yield components for sole bambara groundnut were almost three times higher than the intercrop system. Land equivalent ratio (LER) is the ratio of the area needed under sole cropping to one of intercropping at the same management level to give an equal amount of yield. The LER obtained for the seed yield of bambara groundnut was 0.234, which showed a disadvantage to intercropping indicating that the yield produced in the total intercrop was only 23.4% of that of the same amount of land that planted pure stands.

5.2.3 Environmental Conditions

The results with respect to weather data, particularly rainfall, show that Wartburg is a semi-arid environment. On average, the area receives a mean annual rainfall of about 732 mm, with most rainfall (80 % of the total annual rainfall (592 mm)) occurring mainly between November and April. The area receives the lowest rainfall of 5 mm in June and the highest rainfall of 116 mm in January. The average midday temperatures for the area range between 19.7°C in winter to 26.2°C in summer (Figure 5.7).

The results of soil water content show that there was even distribution of water throughout the field trial with the highest amount of water recorded at deeper depths of the soil profile and least at shallower depths (Figure 5.8). With regards to tube 1 and 2, the amounts of soil water content recorded at 100, 200 and 300 mm of soil depth were between 0 and 10 mm of water. The results further show that the content of soil water in tube 3 and 4 ranged between 7 and 20 mm in 100, 200, 300 and 400 mm of soil depth. On average, the minimum and maximum amount of soil water recorded from a 1 m probe ranged between 43.35 and 56.85 mm, respectively.

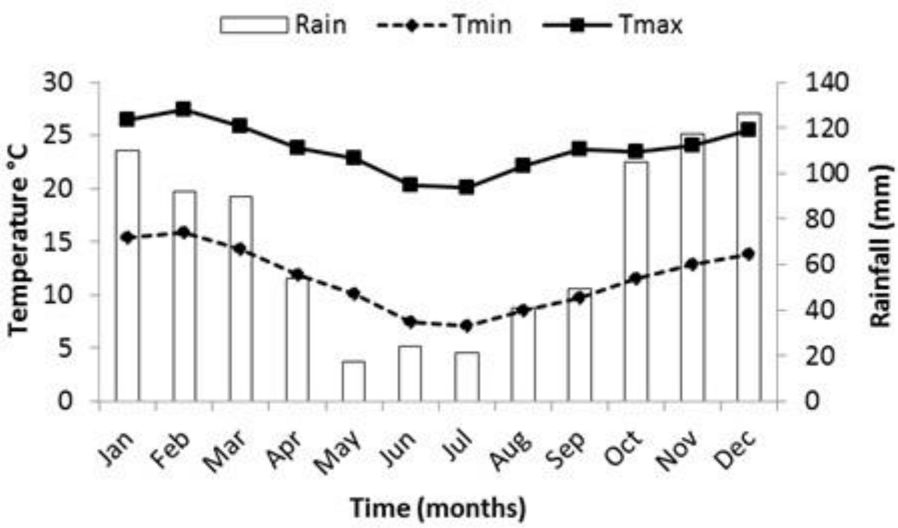

Figure 5.7: Average monthly temperatures (maximum and minimum) and rainfall distribution for Wartburg over a period of ten years (2004 to 2014).

Table 5.3: Soil nutrients obtained before planting for an intercrop system of maize and bambara groundnut.

Sample	P mg/g	K mg/g	Ca mg/g	Mg mg/g	pH (KCl)	Zn mg/g	Mn mg/g	Cu mg/g	Org.C %	N %	Clay %
Swayimane	0.0214	0.0531	0.2367	0.0214	4.28	0.0051	0.0020	0.0011	5.1	0.36	33

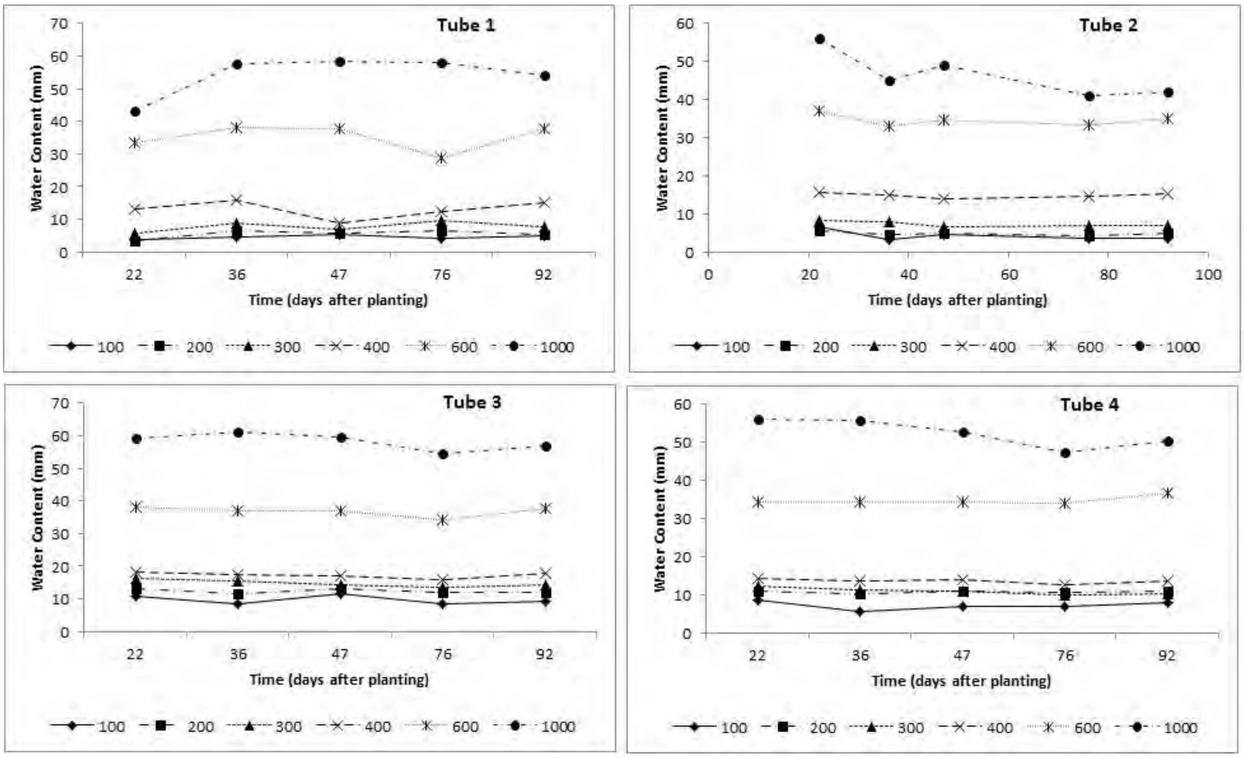

Figure 5.8: Soil water content (SWC) at six depths (100, 200, 300, 400, 600, 1000 mm) in an intercropping system of maize and bambara groundnut.

The general order of soil macronutrients obtained before planting was Ca > K > P, Mg > N and Zn > Mn > Cu for trace nutrients (Table 5.3). The soil was acidic with a pH of 4.28. The clay content of the soil was 33% which indicates a good measure for water and nutrient retention. The main source of energy for soil microorganisms, i.e. soil organic carbon was 5.1%.

On average, the concentration of nitrogen in the soil after planting decreased from 0.36% to 0.25%, 0.23% and 0.21% for sole maize (M), sole bambara groundnut (BG) and maize-bambara groundnut (MBG) intercrop systems, respectively. The results also show that nitrogen (N) was most efficiently used by the intercrop of maize and bambara groundnut compared to sole cropping systems of each crop (Figure 5.9). The concentrations of phosphorus (P) and magnesium (Mg) decrease for all cropping systems with the most decrease on the sole crop of bambara groundnut. The concentration of potassium (K) remained more or less the same for sole maize and maize-bambara groundnut intercrop while it decreased for the sole bambara groundnut. The concentration of calcium (Ca) remained the same for sole bambara groundnut while it increased for sole maize and maize-bambara groundnut intercrop systems (Figure 5.9).

The concentration of zinc (Zn) decreased on all three cropping systems from 0.0051 mg/g to 0.00127, 0.00085 and 0.00075 mg/g for sole maize, sole bambara groundnut and maize-bambara intercrop systems, respectively. The concentration of manganese (Mn) increased only for sole maize and maize-bambara groundnut intercrop while it slightly decreased for sole bambara groundnut from 0.0020 mg/g to 0.0019 mg/g. The concentration of copper increased on all cropping systems with most increase on maize sole crop (Figure 5.10).

The amount of exchangeable acidity in the soil decreased for all three cropping systems after planting with most decrease on maize sole crop system. The total cations increased for all cropping systems with most increase on maize-bambara intercrop system. The acid saturation decreased for all cropping systems with most decrease on maize sole crop system. The pH of the soil increased for sole maize while it decreased for sole bambara groundnut and maize-bambara intercrop systems. The most decrease was observed on bambara groundnut sole crop system (Figure 5.11).

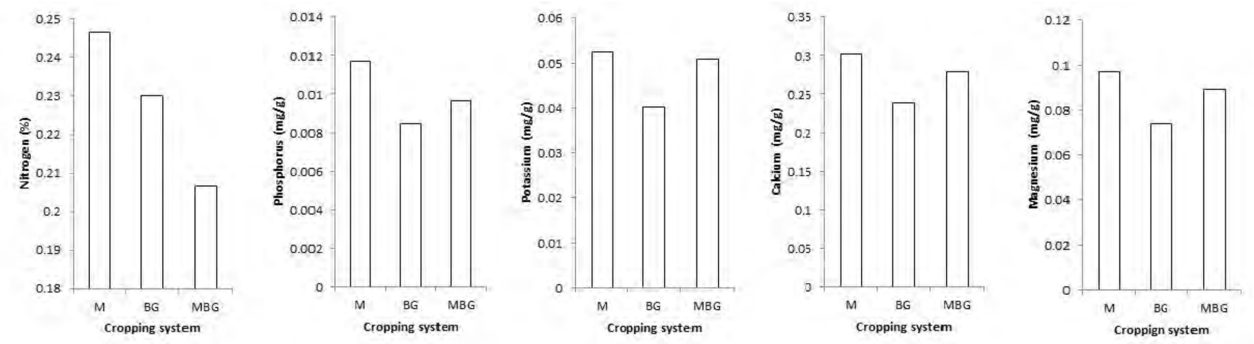

Figure 5.9: Soil macronutrients obtained after planting for three cropping systems (sole maize, sole bambara groundnut and maize-bambara intercrop).

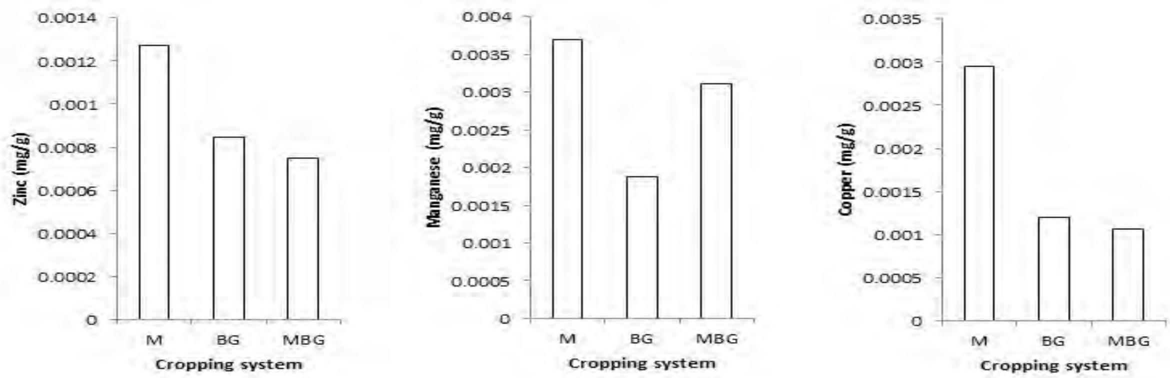

Figure 5.10: Soil micronutrients obtained after planting for three cropping systems (sole maize, sole bambara groundnut and maize-bambara intercrop).

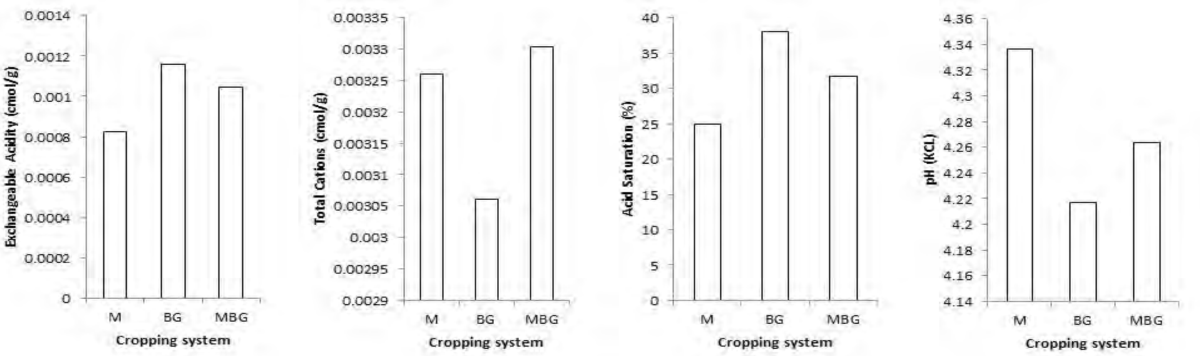

Figure 5.11: Soil chemical properties obtained after planting for three cropping systems (sole maize, sole bambara groundnut and maize-bambara intercrop).

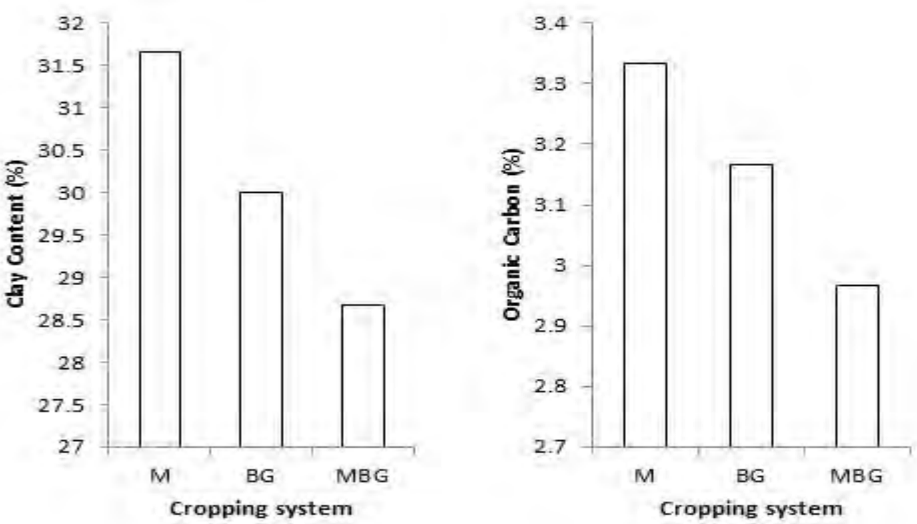

Figure 5.12: Soil physical properties obtained after planting for three cropping systems (sole maize, sole bambara groundnut and maize-bambara intercrop).

The results show that the percentage clay content in the soil decreased after planting with a slightly decrease for maize sole crop and most decrease for the intercrop of maize and bambara groundnut. The soil organic carbon decreased drastically for all three cropping systems with the most decrease in maize-bambara intercrop system (Figure 5.12).

5.3 Discussion

Plant growth and development largely depends on the availability of resources such as water, nutrients and radiation. There were no significant differences with respect to growth responses (plant height and leaf number) (Figure 5.1 and Figure 5.2) and physiological responses (chlorophyll content, stomatal conductance, PAR and LAI) (Figure 5.3, Figure 5.4 and Figure 5.6) of maize and bambara groundnut in an intercropping system. The results of the current study were in agreement with the results Watiki *et al.* (1993) that different cowpea cultivars did not have any effect on maize plant height in an intercrop system. Similarly, Thwala and Ossom (2004) did not find any significant differences between maize monocrop and intercropping with sugar beans and groundnuts. Contrary to my findings, Ahmad *et al*. (2012) who found a highly significant effect of legume species (cowpea, bush bean and soybean) on maize plant height.

The non-significant difference in the height and leaf number of both sole and intercropped bambara groundnut might have been an indication that competition at these cropping systems was not sufficient to induce a response (Figure 5.1B and Figure 5.2B). The results were in contrast to the results by Mabhaudhi and Modi (2014) who found significantly ($P < 0.001$) fewer leaves of bambara groundnut in taro-bambara intercropping system compared with sole cropping. They concluded that the difference may have been due to the fact that taro plants were advantaged over bambara groundnut because of their broad leaves that held higher in canopy structure (Ghosh *et al*., 2006).

The canopy structure is generally important for the display of leaves for light interception for photosynthesis in crop plants (Banziger and Long, 2002). Studies have shown that the larger the canopy structure, the more the light interception, thus increased rate of photosynthesis (Lemlem, 2013). The chlorophyll content index (CCI) was measured from the leaf adaxial surface of plants and there were no significance differences observed (Figure 5.3). Argenta (2004) found that regressions between SPAD readings and maize grain yield were not significant in the stages of three to four and six to seven fully expanded leaves. The non-significant differences suggested that there was no restriction of nitrogen during early stages of both species development, probably due to the high nitrogen contribution from the applied fertilizers prior to planting (Argenta, 2004). Ahmad *et al*. (2012) found a highly significant ($p < 0.01$) effect of legume species (cowpea, bush bean and soybean) on relative chlorophyll content (RCC) of sweet corn, contradicting the results of the current study.

The stomatal conductance (SC) was measured from the abaxial surface of leaves. It estimates the rate of gas exchange, i.e. carbon dioxide uptake and transpiration through the leaf stomata as determined by the degree of stomatal aperture. Hence, it is a function of the density, size and degree of opening of the stomata with more open stomata allowing greater conductance, and consequently indicating that photosynthesis and transpiration rates are potentially higher (Zhao *et al.*, 199b). Karikari *et al.* (1997) and Duc *et al.* (1999) reported that the stomatal conductance varies with a higher value in the morning and a lower value in the midday, depending on solar radiation and vapour pressure deficit. A lower stomatal conductance at midday can be explained by a limitation of photosynthesis due to the stomatal closure to prevent the water loss from the most intensive solar radiation and higher temperatures. Zhao *et al.* (1999a) found that the diurnal variation in leaf stomatal conductance of maize had higher values in the morning than in the afternoon and lower values at midday. The lower values of stomatal conductance during the midday may be attributed to higher temperatures that facilitate the rate of transpiration, inducing stomatal closure. Although there were no significant differences, the results of the current study showed that the stomatal conductance increases with an increase in leaf canopy and decreases with an increase in temperature (Figure 5.4 and Figure 5.5).

The photosynthetic active radiation is a measure used to calculate leaf area index. The leaf area index represents the whole canopy size of a plant, hence the larger the canopy size, the more photosynthesizing the plant is (Lemlem, 2013). Canopy size represents the surface area available for transpiration and plants generally cope with reduced water availability through reductions in canopy size (Mabhaudhi and Modi, 2014). The results showed that sole maize had the highest amounts of intercepted PAR and LAI (765 and 1.6) compared to maize intercrop while sole bambara groundnut had the lowest amounts (223 and 0.31) compared to bambara groundnut intercrop (Figure 5.6). This may have been due to the fact that maize has broad leaves that can reach higher in canopy structure while it is not the case with bambara groundnut.

The results obtained with regards to yield and yield components of bambara groundnut were significantly different ($P < 0.01$) for sole and intercropping systems (Table 5.2). The results were in agreement with the results by Alhassan and Egbe (2014) who observed significant differences in the number of pods per plant and grain yield of sole cropped bambara groundnut than the intercropped treatments. The reduction in the number of pods per plant and grain yield of intercropped bambara groundnut landraces as compared to sole cropping may have been associated with inter-species competition for both under- and above-ground growth resources such as water, nutrients, light and air. Muoneke *et al*. (2007) also observed similar yield reductions in soybean intercropped with maize and sorghum in Benue

State, Nigeria and associated the yield depression to interspecific competition and the depressive effect of the cereals.

The results obtained with respect to fresh mass, dry mass and biomass of maize were significantly different while cob mass and cob length were non-significant (Table 5.1). The results of the current study were in contrary with the results by Thwala and Ossum (2004) who did not find any difference with respect to yield and yield components of maize sole crop and intercropping with sugar bean and ground nuts. The results were also contrary to the results by Lemlem (2013) who observed significantly higher ($P < 0.01$) cob length for mono crop maize as compare to intercrops maize-lablab (ML) and Maize-cowpea (MC) which founded to be 23.44 cm for mono crop and 18.55 and 18.77 cm for intercrop maize-lablab and maize-cowpea respectively. The findings may have been associated with computation effects of intercropping. The results were in agreement with the results by Lemlem (2013) who found a significant difference ($P <0.01$) in above ground biomass between sole crop and intercrop systems where the highest was sole maize (SM) and lower was intercrops of maize –cowpea (MC) and maize-lablab (ML). Manna *et al*. (2003) found that intercropping maize with legumes such as pea (*Pisum sativum* L.), pigeon pea (*Cajanus cajan*) and soybean (*Glycine max* L. merril) significantly increased maize productivity.

The results obtained with respect to soil water content showed an even distribution of water throughout the soil profile with the highest amount of water at deeper depths and lowest at shallower depths (Figure 5.8). This implied an advantage to the growth of maize since it can develop a tap root that can grow up to 1.5 m while it somehow implied a disadvantage to the growth of bambara groundnut since it develops lateral roots that can only penetrate the shallower depths (du Plessis, 2008). Soil water content generally affects the mobility and availability of nutrients to plants (Eteng *et al.*, 2014). Egbe *et al.* (2013) found that the uptake of nutrients by barley per unit weight of soil and the dry matter produced in the seedlings were greater with higher water supply. In the soil, nitrogen (N) is often supplied as ammonium (NH_4) or nitrate (NO_3) in fertilizer amendments. Ahmad *et al*. (2012) reported that dissolved N has the highest concentrations in soils with pH 6 to 8. Technically, pH is defined as the negative (-) log or base 10 value of the concentration of hydrogen ions (H+). The pH of the current study was 4.28 before planting and increased after planting for maize sole crop and maize-bambara intercrop while it remained the same for sole bambara groundnut (Figure 5.11). Hence, the results of the current study showed the highest decrease of nitrogen (N) concentration in sole maize and the least in sole bambara. The macronutrient and micronutrient availability is generally affected by soil pH. Hence the results of the current study showed that.

Yakubu *et al.* (2010) reported that legumes generally need more phosphorus than grasses for root development and energy driven processes. The concentrations of magnesium (Mg) and phosphorus (P) obtained for the current study increased for all cropping systems (Figure 5.9), implying high chances of success for energy driven processes. This may have been associated with the fact that phosphorus responsible for the development of roots and is an essential ingredient for *Rhizobium* bacteria to convert atmospheric nitrogen (N_2) into an ammonium (NH_4) form useable by plants (Erkovan *et al.*, 2010). Erkovan *et al.* (2010) further mentioned that low phosphorus content in the soil may restrict rhizobia population which in turn, can affect their N_2 fixing potential. Nandwa *et al.* (2011) and Tairo and Ndakidemi (2013) reported that *Brady rhizobium* enhances the uptake of P, K, Ca, Mg, S, Mn, Fe, Cu, Zn, B and Mo in leguminous plants. In a study conducted by Zhang and Li (2003), they found that maize improved iron nutrition in intercropped peanut while faba bean enhanced nitrogen and phosphorus uptake in intercropped maize and chickpea facilitated phosphorus uptake by intercropped wheat.

The clay content and soil organic carbon both decreased for the results of the current study (Figure 5.12). The reason for such behaviour may be associated with the efficient use of resources by intercrop system as well as removal of plant debris during field preparation, respectively. The results were in contrary to the findings by Palm *et al.* (1997) who found an increase in soil organic carbon (SOC) content over time under legume-based systems. They further observed that the relative increase was the highest with the legume association and Lablab, where SOC varied from 7.5 to 8.6 $g{\cdot}kg^{-1}$ (i.e. 14.7%) and from 7.2 to 8.3 $g{\cdot}kg^{-1}$ (i.e. 15.3%) respectively, between the start and the end of the trial.

5.4 Conclusion

Research on cereal-legume intercropping systems in SSA has shown improvements in both soil fertility and crop yields, particularly for cereal crop which is the staple food crop for smallholder farmers. Intercropping maize and bambara groundnut reduced yields of bambara groundnut probably due to maize superiority over bambara. Greater nitrogen was used by maize intercropped with bambara groundnut than maize mono crop. The results were likely due to superior nodulation of bambara groundnut by native rhizobia. This suggests that selecting intercrops that are best adapted to the growing environmental conditions such as soil type, temperature and rhizobium strains would have the most positive effect on the companion crop by minimizing competition.

CHAPTER 6

NUTRITIONAL STATUS OF MAIZE AND BAMBARA GROUNDNUT

6.1 Introduction

Livestock production is the major source of livelihoods for millions of households worldwide. In many parts of the world, farmers generally rely on maize silage as a source of digestible fibre and readily fermentable energy for their cattle (Kim and Adesogan, 2006). According to Zaklouta *et al.* (2011), maize represents in all forms elementary and important feed for farm animals. This may be due to the fact that maize as forage is very cost-effective to grow and feed, with the production benefits significantly outweighing the cost of producing it (Woodfield and Clark, 2009). Also, the feed products from maize are characterized by high energetic nutrients and relatively low content of crude protein with low biological value (Summers, 2001). The starch, energy and intake characteristics of maize silage, together with its high dry matter yield potential, make it a good feed for livestock, particularly beef and dairy cattle, as well as sheep (Mlynar *et al*., 2004).

Animal nutrition is an important factor limiting livestock productivity, and feed costs are the main constraint to raising income from small scale livestock production (Nestor, 2010). Aioanei and Pop (2013) reported that there is need therefore to investigate options that will improve available feed for cattle in order to improve production and reproduction and ultimately food security and nutrition. As a result, scientists have come up with methods and technologies such as cropping systems that use the limited land and the available resources such as water, nutrients, and radiation more efficiently as means of boosting agricultural productivity and subsequently food insecurity (Auerswald *et al*., 2003; Ranum *et al*., 2014). Among such cropping systems, the most widely used is the intercrop of cereals and legumes, particularly the neglected and underutilized legume species due to their potential as sources of food, fibre, feed, oil and medicinal properties. These legume species also exhibit an agronomic advantage in terms of adaptability to low input agriculture and rain-fed agricultural systems, thus hold a significant potential for improving food security especially in rural areas (Osewa *et al*., 2013). It is therefore in this context that this study aims to evaluate the nutritional value of maize and bambara groundnut as alternative dual purpose crops with potentials to feed both humans and animals.

6.2 Results

In animal production, the quality of different feed products is determined in terms of dry matter, crude protein, crude fibre, crude fat, crude ash, minerals, tannins and other parameters (Kim and Adesogan, 2006). The dry matter (DM) is a percentage of feed that is not water. Low dry matter limits intake and high dry matter stimulates intake, e.g. the higher the dry matter, the more energy and protein the cow will receive for every kg of fresh silage that the cow eats (Salcedo *et al.*, 2010). The crude protein is a measurement of true protein and non-protein nitrogen (NPN) such as urea nitrogen and ammonia nitrogen. The fibre is, in a broad sense, defined using two feed terms, the neutral detergent fibre (NDF) and the acid detergent fibre (ADF). The neutral detergent fibre is a measurement of the total fibre content of forage and is composed of cellulose, hemicellulose, and lignin while acid detergent fibre is a measurement of the cellulose, lignin, and pectin fibre fractions of forages and is commonly used to predict energy content of maize silage as well as other forages. Mlynar *et al*. (2004) reported that acid detergent fibre and neutral detergent fibre are good indicators of fibre contents in forages. However, they do not measure how digestible the fibre is. The fat also known as ether extract (EE) comprises all substances that are soluble in ether. Although it mainly contains lipids, it also includes other fat-soluble substances such as chlorophyll and fat-soluble vitamins, and it is high in energy. The ash is the remaining residue after all organic matter present in a sample is completely burnt. It comprises all inorganic matter in the feed, as well as inorganic contaminants, such as soil or sand (Jung *et al*., 1998; Summers, 2001; Mlynar *et al*., 2004; Kim and Adesogan, 2006).

6.2.1 Nutritional Values of Maize Stalks and Leaves

The results obtained show that intercropping had no effect on the nutritional content of maize under sole cropping and intercropping (Figure 6.1). The ash, fat, acid detergent fibre (ADF) and crude protein values obtained were almost the same for both cropping systems. The content of neutral detergent fibre (NDF) of maize sole cropping system was higher (77.12%) compared to intercropping system (70.30%). The percentage of organic matter for the current study, as obtained through ash values, was 93% and 94.37% for sole cropping and intercropping, respectively.

The results show that intercropping had an effect on the amount of nitrogen accumulated on plants (Figure 6.2). More nitrogen content was found on plants under the intercrop system (1.21%) compared to sole crop system (1.16%) although the difference was not significant.

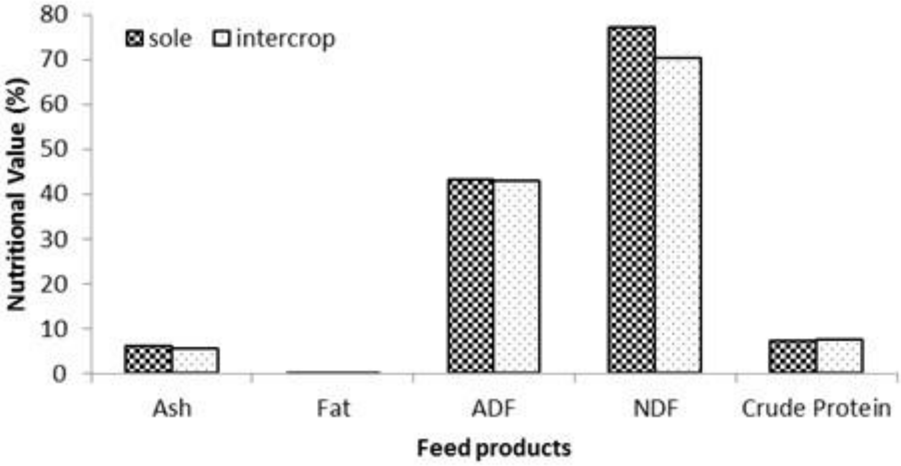

Figure 6.1: Nutritional value of maize silage in terms of crude ash, crude fat, crude fibre and crude protein on 100% dry matter basis.

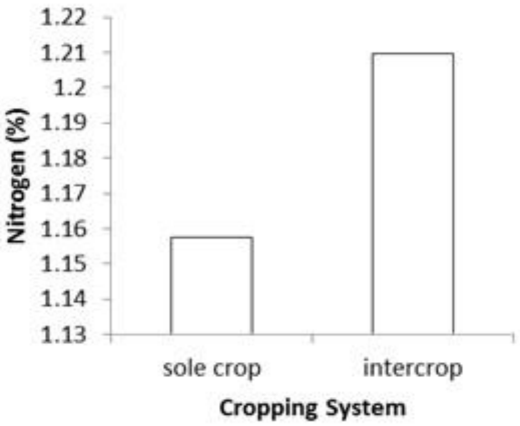

Figure 6.2: Amount of nitrogen on plant material of maize obtained through crude protein.

6.2.2 Nutritional Values of Bambara Groundnut plant

With regards to the chemical analysis of bambara groundnut, there were no significant differences with respect to the content of ash on both cropping systems (Figure 6.3). The content of fat was slightly higher for sole bambara groundnut (2.50%) compared to intercropping (2.02%). The content of detergent fibres (ADF and NDF) was both higher for the intercrop of bambara compared to the sole crop. The content of crude protein was slightly higher for the intercrop of bambara groundnut with maize compared to sole cropping (Figure 6.3). The percentage of organic matter for the current study, as obtained through ash values, was 89.48% and 89.66% for sole cropping and intercropping, respectively.

The results obtained show that the content of nitrogen on the leaves of bambara groundnut was slightly higher on the plants under an intercropping system (3.30%) compared to sole cropping system (3.14%), (Figure 6.3).

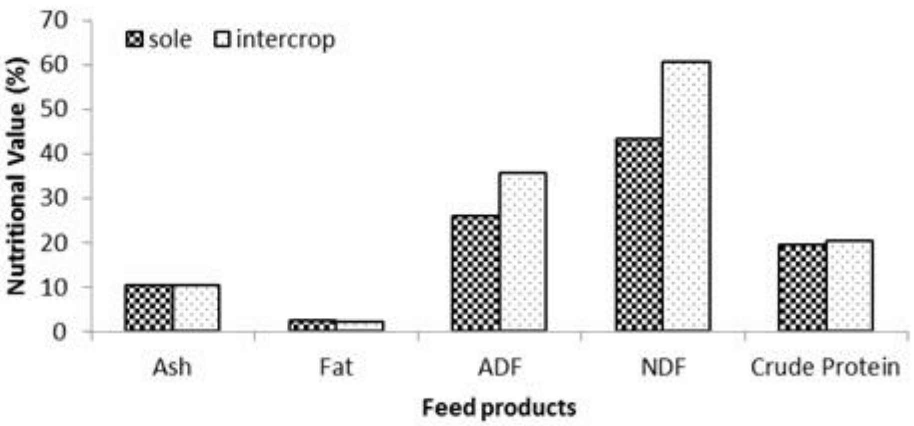

Figure 6.3: Leaf nutritional value of bambara groundnut in terms of crude ash, crude fat, crude fibre and crude protein on 100% dry matter basis.

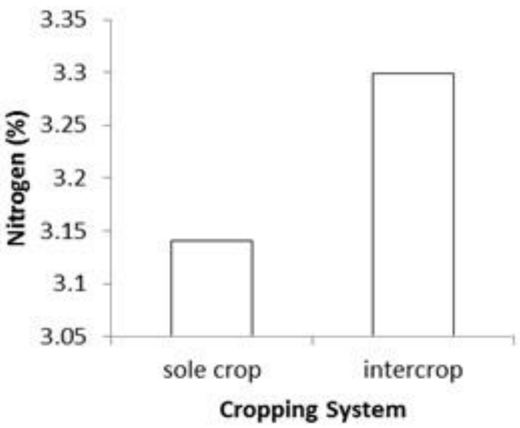

Figure 6.4: Amount of nitrogen on plant material obtained through crude protein.

6.3 Discussion

Maize silage has been recognized as excellent cattle and sheep feed for many years in South Africa due to its starch, energy and intake characteristics, together with its high dry matter yield potential (Martin *et al*., 2004). Besides the stalks and leaves, the 30% to 35% dry matter (DM) content of typical maize silage contains about 40% maize grain. According to Aioanei and Pop (2013), the dry matter content of maize found in the literature ranges from 24% to 36%. Mune *et al.* (2007) found that the higher the dry matter yield in forage production, the higher the intake was by steers when fed as silage. The dry matter content of maize silage depends greatly on the maturity of maize at time of harvest often reflecting the proportion and development of kernels in the silage. Hence, Christensen (1993) found that silage from oats cut at the early dough stage is equivalent to barley and wheat in nutritive value and digestibility. Mazahib *et al*. (2013) found up to 93.3% of dry matter content in raw flour of bambara groundnut seeds. Thus, from the literature, it was found that, in many crop species, the highest content of dry matter is found in seeds than on leaf material.

According to the results found in the literature, the normal ash content of legume-grass forages is approximately 9.0% on dry matter basis. However, researchers have observed some legume-grass forages which contain up to 18.0% ash (Ewing, 1998; Ondarza, 2008). Hoffman (2005) reported that legume-grass forages containing 10-18% ash are likely contaminated with increasing amounts of soil. According to Givens *et al*. (1995) the normal ash content of maize silage is approximately 5.0% of dry matter but silage samples which contain up to 10.0% ash have been observed. The percentage ash of maize obtained for the current study was 6.2% and 5.63% for sole cropping and intercropping, respectively (Figure 6.1). The mean results obtained for maize were within the range found in the literature of 3.7% and 7% (Adesogan, 2006). The percentage ash of bambara groundnut obtained for the current study was 10.52% and 10.34% for sole cropping and intercropping, respectively (Figure 6.3). The results obtained were above the normal ash content of legume-grass forages which is approximately 9.0% on dry matter basis, indicating soil contamination. Givens *et al.* (1995) reported that ash values over 10% usually indicate soil or organic manure contamination which can increase the risk of diseases such as listeriosis, iritis and botulism. Mazahib *et al.* (2013) found an ash content of bambara groundnut seeds to be 3.25% which was lower than the content obtained by Abdulsalami and Sheriff (2010) and Mune *et al.* (2007).

The mean values obtained for fat content of maize silage were within the range found in the literature of 2.5% and 5% (Aioanei and Pop, 2013). The values obtained for the current study were 0.44% for both maize sole cropping and intercropping (Figure 6.1). The fat content obtained for maize was too low due to the fact that silage for the current study was made only from stalks and leaves. The values obtained for the fat content of bambara groundnut were 2.50% and 2.02% for sole cropping and intercropping, respectively (Figure 6.3). The results obtained with respect to fat content of bambara groundnut was also low due to the fact that the seeds were not analysed but only the leaf material. However, from the literature, high contents of fat content of bambara groundnut seeds have been observed. Hence, Eltayeb *et al.* (2011) found a crude fat content for bambara groundnut of 6.58% in flour made out of seeds.

The mean values obtained for neutral detergent fibre content (NDF) of maize silage were 77.12% and 70.30% for sole cropping and intercropping, respectively (Figure 6.1). The content of acid detergent fibre (ADF) obtained was 43.06% and 43.02% for sole cropping and intercropping, respectively (Figure 6.1). According to Martin *et al*. (2004) and Hall (2009), the mean values for NDF content of maize silage found in the literature ranges from 36% to 57%. Martin *et al*. (2004) and Aioanei and Pop (2013) reported that the ADF content of maize silage found in the literature ranges from 21% to 33%. Hoffman (2002) reported that NDF digestibility measurements in the lab have ranged from 30% to 74.3%. The results obtained for NDF content of maize were higher than values found in the literature of 36% to 57% by Martin *et al*. (2004) and Hall (2009) and the results of the sole crop system were further higher than the laboratory findings of 74.3% by Hoffman (2002) (Figure 6.1). This may be due to the fact that the plants were harvested at ½ milk-line stage while NDF digestibility was still very high (>70 % of NDF). According to Salcedo *et al.* (2010), one unit increase of NDF digestibility is associated with 0.37 lb increase in dry matter intake and 0.51 lb increase in milk yield. The NDF content of bambara groundnut obtained was 43.21% and 60.68% for sole cropping and intercropping respectively (Figure 6.3). The content of ADF obtained for bambara groundnut was 25.99% and 35.77% for sole cropping and intercropping respectively (Figure 6.3). The mean value obtained for the content of NDF for bambara groundnut under sole cropping system was low, hence it can be improved by adding highly digestible fibre commodities such as soy hulls, beet pulp, cottonseeds, maize gluten feed, and distiller's grain. Unlike with the content of dry matter and fat, the literature shows that more fibre content is found on stems and leaves of many plants than on seeds. Mazahib *et al*. (2013) found a fibre content of bambara groundnut seeds to be 6.34% which was similar to that obtained by Abdulsalami and Sheriff (2010), and higher than that reported by Mune *et al*. (2007).

Regarding crude protein content of maize silage, the mean values obtained for sole cropping and intercropping systems were 7.18% and 7.5%, respectively (Figure 6.1). The results were within the range found in the literature which is from 7.0% to 11% (Aioanei and Pop, 2013). Adesogan (2011) found that the content of crude protein for maize silage ranged from 71.00 to 83.90 $g.kg^{-1}$ of dry matter in 2009 and from 69.90 to 97.40 $g.kg^{-1}$ of dry matter in 2010. The content of crude protein obtained for bambara groundnut was 19.47% and 20.45% for sole cropping and intercropping, respectively (Figure 6.3). The protein content of bambara groundnut can go as high as 24. 02%, which compares favourably with that reported for the more conventional legumes such as faba beans (Duc *et al*., 1999; Musalam *et al*., 2004), but higher than that reported by Nworgu (2004), (18.3%) and Aletor and Omodara (1994) (10.4%), respectively. The results obtained were higher than that reported by Eltayeb *et al.* (2011) who found a protein content of bambara seeds made flour to be 17.70% but somewhat similar to the results reported by Mazahib *et al*. (2013) who observed 20.60% of crude protein in bambara groundnut seeds.

The content of nitrogen for maize silage obtained through crude ash was 1.16% and 1.21% for sole cropping and intercropping, respectively (Figure 6.2). For bambara groundnut, the content obtained was 3.14% and 3.30% for sole cropping and intercropping, respectively (Figure 6.4). The results show that the intercropping systems had slightly higher nitrogen content than sole cropping systems of each crop. Bambara groundnut had, in general, a higher content of nitrogen for both sole cropping and intercropping systems than maize. This could be due to the fact that bambara groundnut is able to fix atmospheric nitrogen and convert it into usable forms through a process called biological nitrogen fixation.

6.4 Conclusion

With the increase in feed costs in the animal industry, the use of plant protein sources has become more necessary. The results obtained showed that bambara groundnut has high content of protein, nitrogen and neutral detergent fibre, thus is more suitable for use both as nutrient supplement in animal feeds as well as for food. Therefore, both maize, the excellent source of energy and fibre, and bambara groundnut, the subsistence-female crop rich in protein, could be used as alternative dual purpose crops with potentials to feed both humans and animals.

CHAPTER 7

GENERAL DISCUSSION

Chapter 4 evaluated the quality of maize variety ZM 305 and bambara groundnut seeds. Differences were observed in germination percentage over time and time to 50% germination was achieved on day 3 for both crop species (Figure 4.1 and Figure 4.2). High seed vigour and viability potential was shown by the laboratory results of both species. However, these did not necessarily imply high crop yield and good quality after planting.

Chapter 5 evaluated the effect of intercropping on crop growth, yield, soil water content and soil nutrients. No significant differences were observed with respect to growth and physiological responses (Figure 5.1 to 5.6). Significant differences were observed with respect to yield and yield components of bambara groundnut (Table 5.2) as a result of intra and inter specific competition for input resources as well as shading effects from adjacent maize plants. No differences were observed with respect to cob mass and cob length of maize. Significant differences were observed with respect to fresh mass, dry mass and above ground biomass of maize (Table 5.1). This behaviour may be attributed to the fact that maize plants were advantaged over the plants of bambara groundnut (Ghosh *et al*., 2006). The land equivalent ratio (LER) obtained for the seed yield of bambara groundnut was 0.234, which showed a disadvantage to intercropping indicating that the yield produced in the total intercrop was only 23.4% of that of the same amount of land that planted pure stands (Table 5.2). The land equivalent ratio (LER) obtained for the biomass yield of maize was 1.016, which showed an advantage to intercropping indicating that the yield produced in the total intercrop would have required only 1.6% more land if planted in pure stands, hence no significant differences observed (Table 5.1). The results showed an even distribution of water throughout the field trial (Figure 5.8), which implied an even mobility of nutrients. The results showed that intercropping had an effect on crop growth, yield and soil nutrients.

Chapter 6 evaluated the effect of intercropping on maize silage and bambara groundnut leaf nutrition. The good protein content and neutral detergent fibre (Figure 6.1 and Figure 6.3) of both crop species showed the potential of these crops as alternative dual purpose crops with potentials to feed both humans and animals, hence improvement of livestock productivity and alleviation of protein-malnutrition and food insecurity.

Interactions between crop varieties, climate, environment, harvesting and storage conditions needs proper planning before planting in order to maximise not only the yield of crop species but also the nutrient quality. Interactions of crop varieties are often as a result of cropping systems. Among the several types of cropping systems is intercropping of cereals and legumes which have long been found to produce stable yields of good quality due to mutual benefits that occur between the crop species. In the case of the current study, intercropping maize and bambara reduced the yield of bambara groundnut but maintained and sometimes increased the level of nutrition in both species. Thus intercropping of cereals and legumes can be more ideal for smallholder farmers who are resource poor.

Future Lessons and Research Possibilities

The following recommendations may be made, based on observations attained during the course of study;

- Seed quality tests must be done prior to planting in order to determine the vigour and viability of seeds.
- Field management practices must, at all times, be at optimum level to ensure high productivity.

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APPENDICES

Appendix 1: Analysis of Variance (ANOVA) tables for Chapter 4.

- **Maize**

Variate: GERM_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	225.33	112.67	4.24	
REP.*Units* stratum					
DAI	7	19930.00	2847.14	107.15	<.001
Residual	14	372.00	26.57		
Total	23	20527.33			

Variate: SEEDLING_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	11.327	5.663	2.91	0.131
Residual	6	11.693	1.949		
Total	8	23.020			

Variate: SHOOT_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	1.0556	0.5278	1.81	0.243
Residual	6	1.7533	0.2922		
Total	8	2.8089			

Variate: ROOT_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	3.282	1.641	1.06	0.402
Residual	6	9.253	1.542		
Total	8	12.536			

Variate: ROOT_SHOO_RATIO

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.0022896	0.0011448	7.33	0.025
Residual	6	0.0009373	0.0001562		
Total	8	0.0032269			

Variate: SEEDLING_FRESH_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.084741	0.042370	7.93	0.021
Residual	6	0.032069	0.005345		
Total	8	0.116810			

Variate: SEEDLING_DRY_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.0000887	0.0000443	0.09	0.918
Residual	6	0.0030573	0.0005096		
Total	8	0.0031460			

Variate: GI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DAI	7	152.1551	21.7364	209.41	<.001
Residual	16	1.6608	0.1038		
Total	23	153.8159			

Variate: MGT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DAI	7	160.4928	22.9275	176.71	<.001
Residual	16	2.0759	0.1297		
Total	23	162.5687			

- **Bambara groundnut**

Variate: GERM_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DAI	7	20842.00	2977.43	135.34	<.001
Residual	16	352.00	22.00		
Total	23	21194.00			

Variate: SEEDLING_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	1.3560	0.6780	3.52	0.097
Residual	6	1.1557	0.1926		
Total	8	2.5117			

Variate: SHOOT_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.3673	0.1836	1.65	0.268
Residual	6	0.6675	0.1113		
Total	8	1.0348			

Variate: ROOT_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.05420	0.02710	0.32	0.737
Residual	6	0.50680	0.08447		
Total	8	0.56100			

Variate: ROOT_SHOO_RATIO

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.0164002	0.0082001	42.98	<.001
Residual	6	0.0011447	0.0001908		
Total	8	0.0175449			

Variate: SEEDLING_FRESH_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.061071	0.030535	4.55	0.063
Residual	6	0.040250	0.006708		
Total	8	0.101321			

Variate: SEEDLING_DRY_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	0.006323	0.003161	3.15	0.116
Residual	6	0.006016	0.001003		
Total	8	0.012339			

Variate: GI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DAI	7	150.91140	21.55877	595.61	<.001
Residual	16	0.57913	0.03620		
Total	23	151.49053			

Variate: MGT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DAI	7	171.98970	24.56996	665.18	<.001
Residual	16	0.59100	0.03694		
Total	23	172.58070			

Appendix 2: List of ANOVA tables for Chapter 5.

- **Growth of bambara groundnut (BG)**

Variate: PH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	6.269	3.134	2.73	
REP.*Units* stratum					
cropping_system	1	0.694	0.694	0.61	0.445
DAP	5	249.812	49.962	43.54	<.001
cropping_system.DAP	5	4.022	0.804	0.70	0.629
Residual	22	25.244	1.147		
Total	35	286.042			

Variate: L

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	8.722	4.361	2.15	
REP.*Units* stratum					
cropping_system	1	4.694	4.694	2.32	0.142
DAP	5	1949.472	389.894	192.28	<.001
cropping_system.DAP	5	2.139	0.428	0.21	0.954
Residual	22	44.611	2.028		
Total	35	2009.639			

Variate: CCI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	157.32	78.66	1.63	
REP.*Units* stratum					
cropping_system	1	30.25	30.25	0.63	0.437
DAP	5	188.82	37.76	0.78	0.573
cropping_system.DAP	5	214.91	42.98	0.89	0.504
Residual	22	1060.53	48.21		
Total	35	1651.83			

Variate: SC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	19936.	9968.	4.45	
REP.*Units* stratum					
cropping_system	1	850.	850.	0.38	0.544
DAP	5	159381.	31876.	14.23	<.001
cropping_system.DAP	5	19858.	3972.	1.77	0.160
Residual	22	49297.	2241.		
Total	35	249322.			

Variate: SC_TEMP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	7.665	3.832	3.02	
REP.*Units* stratum					
cropping_system	1	1.174	1.174	0.92	0.347
DAP	5	281.993	56.399	44.40	<.001
cropping_system.DAP	5	4.348	0.870	0.68	0.640
Residual	22	27.948	1.270		
Total	35	323.128			

- **Postharvest data of bambara groundnut (BG)**

Variate: NUMBER_OF_PODS_PLANT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	25.480	12.740	1.29	
REP.*Units* stratum					
cropping_system	1	154.027	154.027	15.64	<.001
Residual	2	19.693	9.847		
Total	5	199.200			

Variate: NUMBER_OF_SEEDS_PLANT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	14.754	7.377	0.87	
REP.*Units* stratum					
cropping_system	1	68.546	68.546	8.06	<.001
Residual	2	17.013	8.506		
Total	5	100.313			

Variate: SEED_YIELD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.7572	0.3786	1.31	
REP.*Units* stratum					
cropping_system	1	3.5420	3.5420	12.23	<.001
Residual	2	0.5792	0.2896		
Total	5	4.8785			

Variate: BIOMASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.1659	0.0829	0.63	
REP.*Units* stratum					
cropping_system	1	1.4702	1.4702	11.08	<.001
Residual	2	0.2653	0.1326		
Total	5	1.9014			

- ## Growth for maize (M)

Variate: PH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	563.20	281.60	3.17	
REP.*Units* stratum					
cropping_system	1	1573.44	1573.44	17.74	<.001
DAP	5	59927.22	11985.44	135.11	<.001
cropping_system.DAP	5	1315.30	263.06	2.97	0.034
Residual	22	1951.63	88.71		
Total	35	65330.80			

Variate: L

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5.1667	2.5833	3.67	
REP.*Units* stratum					
cropping_system	1	1.7778	1.7778	2.52	0.126
DAP	5	65.0000	13.0000	18.45	<.001
cropping_system.DAP	5	1.5556	0.3111	0.44	0.815
Residual	22	15.5000	0.7045		
Total	35	89.0000			

Variate: CCI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	13.91	6.96	0.36	
REP.*Units* stratum					
cropping_system	1	15.34	15.34	0.79	0.384
DAP	5	1470.17	294.03	15.10	<.001
cropping_system.DAP	5	131.60	26.32	1.35	0.280
Residual	22	428.50	19.48		
Total	35	2059.52			

Variate: SC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	334.6	167.3	0.18	
REP.*Units* stratum					
cropping_system	1	250.7	250.7	0.27	0.611
DAP	5	189315.6	37863.1	40.21	<.001
cropping_system.DAP	5	2353.5	470.7	0.50	0.773
Residual	22	20714.6	941.6		
Total	35	212969.1			

Variate: SC_TEMP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.7489	0.3744	0.77	
REP.*Units* stratum					
cropping_system	1	0.0069	0.0069	0.01	0.906
DAP	5	315.9447	63.1889	130.35	<.001
cropping_system.DAP	5	0.8114	0.1623	0.33	0.886
Residual	22	10.6644	0.4847		
Total	35	328.1764			

Variate: PAR

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1397.	698.	0.02	
REP.*Units* stratum					
TRT	2	451585.	225792.	7.12	0.004
DAP	3	701931.	233977.	7.38	0.001
TRT.DAP	6	308115.	51352.	1.62	0.189
Residual	22	697825.	31719.		
Total	35	2160853			

Variate: LAI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0425	0.0213	0.18	
REP.*Units* stratum					
TRT	2	1.6559	0.8280	7.11	0.004
DAP	3	2.8960	0.9653	8.29	<.001
TRT.DAP	6	1.7403	0.2901	2.49	0.054
Residual	22	2.5605	0.1164		
Total	35	8.8953			

- **Postharvest data for maize (M)**

Variate: COB_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	123.59	61.80	1.96	
REP.*Units* stratum					
cropping_system	1	0.08	0.08	0.00	0.965
Residual	2	62.94	31.47		
Total	5	186.61			

Variate: COB_LENGTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.542	2.271	0.97	
REP.*Units* stratum					
cropping_system	1	0.421	0.421	0.18	0.713
Residual	2	4.681	2.341		
Total	5	9.645			

Variate: FRESH_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	674.61	337.30	5.31	
REP.*Units* stratum					
cropping_system	1	2669.57	2669.57	41.99	0.023
Residual	2	127.15	63.57		
Total	5	3471.33			

Variate: DRY_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	253.25	126.63	2.20	
REP.*Units* stratum					
cropping_system	1	736.16	736.16	12.77	0.070
Residual	2	115.31	57.66		
Total	5	1104.72			