INFLUENCE OF LABLAB (*LABLAB PURPUREUS*) AND DRY BEAN (*PHASEOLUS VULGARIS*) INTERCROPS WITH MAIZE *(ZEA MAYS L.)* ON MAIZE GRAIN YIELD AND SOIL FERTILITY STATUS

MAHUBANE WILLIAM MAKGOGA

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SOUTH AFRICA

SUPERVISOR: PROFESSOR I. K. MARIGA

CO-SUPERVISOR: MS M. P. MABAPA

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DECLARATION

I Mahubane William Makgoga, hereby declare that the mini-dissertation for Master of Science (M.Sc.) degree in agriculture (Agronomy) has never been submitted before for any degree.

Student’s signature	Date
Supervisor’s signature	Date
Co-supervisor’s signature	Date

DEDICATION

I dedicate this mini-dissertation to my beloved parents Mr S.T and Mrs. E.M. Makgoga, and secondly to my beloved Son Phuti Matthews Makgoga.

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ABSTRACT

Maize (*Zea mays L.*) is the third most important cereal crop after wheat and rice in the world. Maize/legume intercropping system has become one of the solutions for food security among small scale maize producers due to unaffordability of chemical nitrogenous fertilizers and limited access to arable land. A study was conducted to determine the effect of maize/dry bean and maize/lablab intercropping on maize grain yield and soil fertility status. A field experiment was conducted during 2010/2011 and 2011/2012 growing seasons at the University of Limpopo experimental farm. Treatments included sole maize (ZM 521, an improved open pollinated variety, ex-CIMMYT), sole lablab (Rongai, indeterminate cultivar), sole dry bean (DBS 360, indeterminate Type II cultivar), maize/dry bean and maize/lablab intercrops arranged in randomized complete block design with five replications. Phosphorus (P) was applied on sole and intercropped maize at the rate of 30 kg P/ha in the form of superphosphate (10.5%P) at planting and 40 kg N/ha of nitrogen (N) was applied in the form of Limestone Ammonium Nitrate (LAN) (28%N) on both sole and intercropped maize four weeks after plant emergence. For maize and dry bean, grain yield, yield components and biomass were determined. Only biomass yield was measured for lablab. Soil samples were collected for soil analysis at the beginning and the end of the experiment The results showed that maize/lablab intercropping yielded significantly ($P<0.05$) lowered maize grain (1259.3 kg/ha) than sole maize and maize/dry bean intercropping which yielded maize grain of 2093.7 kg/ha and 2156.3 kg/ha, respectively. Sole dry bean yielded significantly ($P <0.05$) higher dry bean grain (1778.5 kg/ha) than intercropped dry bean (691.8 kg/ha). Rongai was only flowering by the time maize and dry bean matured hence only maize yield is reported for the Maize/lablab intercrop. Maize/dry bean intercropping was advantageous to sole cropping with a Land Equivalent Ratio (LER) of 1.42. The partial Land Equivalent Ratio (PLER) for maize in maize/lablab intercropping was 0.60. Dry bean was outcompeted by maize as calculated aggressivity value was positive at +0.64.The highest monetary value was achieved in sole dry bean and the lowest monetary value was found in intercrop dry bean. Soil TN, P, K, Ca, Mg and Na were reduced by both sole cropping and intercropping systems. Intercropping with lablab is likely to significantly lower maize yield under dryland conditions.

Key words: dry bean, grain yield, Intercropping, lablab, maize, smallholder, soil fertility

CHAPTER 1

1. GENERAL INTRODUCTION

1.1 Background

Maize (*Zea mays L.*), which is the third most important cereal crop after wheat and rice in the world, is used as food for human beings, feed for livestock and poultry and for mulching. Maize has the potential to supply large amounts of energy-rich forage for animal diets, and its fodder can safely be fed at all stages of growth without any danger of oxalic acid and prussic acid, as is the case for sorghum (Dahmardeh *et al.,* 2009). Maize is a member of Gramineae (grass family) which requires much nitrogen to achieve optimum yield. The nitrogen (N) requirements of maize can be met through application of inorganic fertilizer. However, chemical nitrogenous fertilizes tend to be unaffordable to small scale farmers producing maize for their food security (Javanmard *et al.,* 2009).

Maize/legume intercropping has become one of the solutions for food security among small scale maize producers (Thobatsi, 2009). Sullivan (2003) defines intercropping system as the system where two or more crops are grown on a piece of land within the same year to promote the interaction of component crops and maximize land productivity, as well as avoid the dependence on only one crop. As a result, intercropping of cereal/legumes is being practiced in many areas of South Africa, including Limpopo Province, due to land scarcity and need to enhance food production.

Systems that intercrop maize with a legume are able to reduce the amount of nutrients taken from the soil as compared to a maize monocrop. When nitrogen fertilizer is added to the field, intercropped legumes use the inorganic nitrogen instead of fixing atmospheric nitrogen and thus compete with maize for nitrogen. However, when nitrogen fertilizer is not applied, intercropped legumes will fix most of their nitrogen requirements from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi *et al.,* 2007).

Improving performance of maize/legume intercrops can significantly benefit the smallholder (SH) farmers by increasing yield on a limited amount of land, reducing risk of total crop failure, and maximizing the efficiency of labour utilization. In addition, some of intercropping systems help to stabilize soil nutrient levels, which will keep yields sustainable into the future. Pests and weeds may also be controlled, which leads to higher yields.

Lablab purpureus tolerates drought conditions in marginal rainfall areas especially Rongai cultivar. Lablab is a forage legume which has wide range of uses in agriculture such as animal feed, soil fertility improvement through biological nitrogen fixation and green manuring, cover crop for management of weeds, water and pests and also as human food and its large above ground biomass mulches the soil and conserves moisture for maize (Chigariro, 2004). Ayisi and Poswall (1997), cited by Maluleke *et al.* (2004) reported that the planting date and density of *L. purpureus* affect maize yield when they are simultaneously intercropped due to its prolific growth characteristics. However, *L. purpureus*/maize relay intercropping results in increased yield of both component crops.

Dry bean (*Phaseolus vulgaris*) is a grain legume which has wide range of uses such as human and animal feed, soil improvement through biological nitrogen fixation and green manuring. National Department of Agriculture and ARC-Grain Crop Institute (2002) reported that dry bean is at present regarded as one of the most important field crops in South Africa on account of its high protein content and dietary benefits for humans. Maize/dry bean intercropping in Limpopo Province plays an important role in food security for SH farmers, particularly in Vhembe District. According to Hudgens (1996), although intercropping of maize/dry bean is efficient for food security, dry bean is believed to fix too little atmospheric nitrogen, thus intercropping still requires large amount of nitrogenous fertilizers for maize to thrive well. It is known that indeterminate dry bean cultivar fix more nitrogen than determinate types.

1.2 Problem statement

Maize production by small scale and emerging farmers in South Africa is very low due to low soil fertility, especially N, and most SH farmers cannot afford inorganic fertilizers. Comparative performance of lablab and dry bean in intercrops with maize for N management is not documented for Limpopo dryland conditions.

1.3 Motivation of the study

Maize is an important agronomic crop in South Africa and the globe at large. In many countries, especially Africa, maize grain is processed to produce maize flour which is the staple food.

Almost all of the SH and emerging farmers face the constraints of low soil fertility which makes them produce low yield of low quality maize due to the unaffordability of chemical fertilizers, especially nitrogenous fertilizers. Intercropping has potential to sustain nitrogen requirements of maize in the SH farming sector. Maize normally requires 140-160 kg N/ha. Intercropping of leguminous crops with maize might result in reduction of amount of chemical nitrogen fertilizer required for maize growth.

1.4 Aim and objectives of the study

1.4.1 Aim: The aim of this study was to improve maize productivity and soil fertility through intercropping with grain legumes.

1.4.2 Objectives of the study were to:

i) To determine the effects of *L. purpureus* and *P. vulgaris* intercrops with *Z. mays* on intercrop performance.

ii) To determine the effects of *L. purpureus* and *P. vulgaris* intercrops with *Z. mays* on soil fertility status.

1.5 Hypotheses of the study

i) Intercropping maize with lablab or dry bean does not influence maize grain yield.

ii) Intercropping lablab or dry bean with maize has no effect on soil fertility.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Introduction

Intercropping is the practice of growing two or more crops in the same field at the same time (Sullivan 2003). There are different types of intercropping spatial arrangements which need to be practiced to produce at optimal levels for both crops and to benefit the environment, especially with regards to soil fertility. The types of spatial arrangements are,

(i) Row intercropping which is growing two or more crops at the same time in well-defined rows. Variations of row intercropping are inter-row intercropping (when the component crops are grown in separate rows between each other) and intra-row intercropping (when the component crops are grown within each row),

(ii) Strip intercropping, when growing two or more crops together in strips wide enough to permit separate management of crops, including use of machinery, but close enough for the crops to interact agronomically,

(iii) Mixed intercropping, when growing two or more crops together in no distinct row arrangement and,

(iv) Relay intercropping, when planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting (Sullivan, 2003 and Carlson, 2008).

Intercropping systems increase yield per unit area, and thus improve food security (Asmat *et al.,* 2004). This is critical for SH farmers, such as those in Limpopo province, who have limited arable land (Ayisi and Mpangane, 2004). Willey (1979) was of the opinion that intercropping also increases N level in the soil for non-legume crops such as cereals. Dahmardeh *et al.* (2010) reported the increase in nitrogen, phosphorus and potassium contribution during maize/cowpea intercropping.

2.2 Intercropping as a practice

2.2.1 Plant Density

Plant population is the important factor in intercropping of legume-maize as it can determine the extent of competition between intercrops (Fisher, 1977; Kgasago, 2006). Factors such as moisture availability, soil fertility status and cultivars to be planted determine the plant population to be planted in the specific area (Molatudi and Mariga, 2012). In low rainfall areas, such as Limpopo province, too low plant population reduces yields whereas too high plant population in intercropping leads to competition of the intercrops especially for light, soil nutrients and moisture (Molatudi and Mariga, 2012; Moriri *et al.,* 2010). To optimize plant density, the seeding rate of each crop in the mixture is adjusted below its full rate. Optimum seeding rate results in high solar radiation interception (Jensen, 1996), and increases the rate of photosynthesis and biological nitrogen fixation in the cereal/legume intercropping system (Thobatsi, 2009).

2.2.2 Effect of planting and maturity dates on intercropping

In areas which receive low rainfall for short period; small-scale farmers who depend on rainfall for production must plant short season cultivars in intercropping. Planting early maturing component crops in early part of the rainy season becomes an important aspect for small scale farmers to increase productivity (Egbe, 2010). Proper planting date of intercrop species leads to high production due to reduced competition between them. Aggressive climbing legumes such as *L. purpureus* and indeterminate dry bean climb on, pull down and lodge the intercrop cereal species, such as maize, and this lowers the cereal yield (Sullivan, 2003; Kgasago, 2006).The release of biological nitrogen fixed by the legume for utilization by the cereal depends on the sowing and maturity date of the legume species. In sorghum-pigeon pea intercropping where sorghum dominates the early stages of growth and matures earlier than legume, the slow-growing pigeon pea has no effect on the sorghum yield (Sullivan, 2003).

2.2.3 Plant morphology

Plant architecture is a commonly used strategy for maximum solar radiation interception by both crop species. Morphological growth characteristics are very important factors for both crops when designing intercropping systems. According to

Eskandari and Ghanbari (2009), optimal plant morphology of both crop species in the intercropping system plays an important role for photosynthetic active radiation (PAR) interception, which is critical factor determining intercrop productivity. Eskandari *et al.* (2009) reported that intercropping of corn and cowpea, where corn was growing more vigorously than cowpea, resulted in over-shadowing of cowpea which subsequently led to poor BNF due to lower solar radiation interception. Eskandari and Ghanbari (2009) further reported that appropriate plant architecture of intercrops provides large ground cover on the surface area and this lowers the temperature of intercrops microclimate thus reducing the water evaporation from soil surface.

2.2.4 Choice of crop species

In designing intercropping systems, ideal choice of crop species becomes an important factor. Suitable combination of cereal/legume species in intercropping increases yields in intercrops and minimizes intercrop competition. In choosing crop species, several factors such as difference in crop architecture, rooting patterns, competitive and yield advantages, and the potential of nitrogen fixing capacity must be considered (Thobatsi, 2009) and also the preference of cultivars by the communities in the country (Mariga, 1990). Legumes such as *L. purpureus* play an important role in SH farming in Southern Africa, including Zimbabwe and South Africa, especially in crop-livestock farming systems. *L. Purpureus* is intercropped with maize to fix N for maize, supply large quantity of good quality fodder for animals, and grains and leafy vegetables for human food, thus this increases food security (Chigariro, 2004).

2.3. Benefits of intercropping

2.3.1 Soil nutrients replenishment

Productivity of maize and other crops is mainly limited by low soil fertility, especially nitrogen. Nitrogenous fertilizers are unaffordable to SH maize producers and this results in poor soil nutrition management and decline in soil fertility. However, in cereal/legume intercropping systems, legumes are the primarily source of nitrogen. Thobatsi (2009) reported that BNF by legumes is the primary source of N in Low External Input Agriculture (LEIA) technologies. Brady (1990) and Peoples *et al*. (1995) postulated that the amounts of nitrogen fixed by different legumes differ between 5 and 300 kg N/ha/year, with an average of about 100 kg N/ha/year. Fixed nitrogen released by the leguminous nodules or residues after they have been decomposed improve soil N for the next season's crop. Deep rooting legumes, such as pigeon pea, also take up nutrients from deeper soil layers and reduce the competition for nutrients uptake with cereals, thus enhancing absorption of nutrients by cereals in the top layers (Nzabi *et al*., 1998).

2.3.2 Nutrient Use Efficiency (NUE)

Maize production in Southern Africa is limited by high costs and sub-optimal use of chemical fertilizers under continuous cultivation. Declining soil fertility resulting from shortened fallow periods and continuous cultivation, with few or no inputs, is the most important constraint threatening food production by SH farmers in South Africa (Thobatsi, 2009). Cereal/legume intercropping systems reduce the amount of nutrients taken from the soil as compared to sole crops (Akinnifesi *et al.,* 2006). Dahmardeh *et al*. (2010) reported the amount of N: P: K produced in maize/cowpea intercropping, which was 40, 30 and 30 kg N/ha respectively. Valenzuela and Smith (2002) reported that soybean produces 60 kg N/ha during intercropping with maize and 120 kg N/ha when used as green manure

Nutrient use efficiency is one of the most important aspects of cereal/legume intercropping. Crop choice has been reported to be important in increasing NUE in cereal/legume intercropping (Thobatsi, 2009). Intercrops which differ in rooting and nutrient uptake patterns result in efficient use of nutrients, especially N-uptake, in intercropping system compared to monoculture. A pulse crop, such as pigeon pea, with deeper rooting system takes up nutrients from deeper soil layers, thus recycling leached nutrients and reducing competition (Dalal, 1974; Masson *et al.,* 1986).

2.3.3 Water Use Efficiency (WUE)

Water use efficiency is defined as yield per unit area divided by the water consumed to produce the yield. Soil moisture is reported as one of the main constraints threatening the production of maize by SH farmers. In low rainfall regions, such as Limpopo Province, there is a need to increase WUE of crops especially in joint cultivation such as intercropping (Thobatsi, 2009; Lange *et al.,* 2004). Maize is a C4 plant which uses more water during many growth stages (Huang *et al.,* 2006). Cereal/legume intercropping uses water more efficiently than in monoculture, this results in less water competition under unfavourable water conditions. Ideal management of the intercropping system will reduce the competition between the component crops (Lange *et al.,* 2004).

Cereal/legume intercrops with deep rooting systems reduce water loss, increase water uptake and transpiration. In addition, increase in transpiration makes the intercrops microclimate to be cooler; thus reducing water evaporation from the soil surface (Carlson, 2008). Increasing canopy of intercrops by applying fertilizers can also decrease water loss by shading the soil surface (Cooper *et al.,* 1987). Gaiser *et al.* (2004) reported the efficient use of water during maize/cowpea intercropping, which was ranging from 60 to 80% increment of WUE in intercropping as compared to sole crops. Wheat/maize intercropping increased WUE by 30 to 60% as compared to sole wheat and maize (Yang *et al*., 2009). High WUE of 50.2 kg/ha/mm in maize/dry bean intercropping as compared to sole maize and dry bean value of 44.7 and 24.1 kg/ha/mm respectively, was reported by Tsubo *et al*. (2003).

2.3.4 Radiation Use Efficiency (RUE)

Radiation use efficiency (RUE) under optimal conditions refers to the relationship between dry matter and radiation intercepted (Monteith, 1977). Photosynthetic Active Radiation (PAR) is important radiation which is intercepted and utilized by green leaves and other green organs for the process of photosynthesis to produce photosynthetic products which are important for the process of BNF in cereal/legume intercropping (Tsubo *et al.,* 2001; Thobatsi, 2009). Cereal/legume intercropping intercepts and efficiently utilizes solar radiation better than the monocrop system as the component crops form complete cover on the soil surface. Light interception depends on the Leaf Area Index (LAI) and Leaf Area Duration (LAD) thus earlier loss of leaves on the crops reduces RUE and also lowers PAR interception. Maintenance of LAI or attainment of longer LAD is influenced by many factors such as component crop density, soil fertility and plant arrangement (Tsubo *et al.,* 2001). Tsubo *et al*. (2003) reported high RUE of 3.18 g/MJPAR in maize/dry bean intercropping as compared to sole dry bean and maize, RUE of 1.00 and 2.82 g/MJPAR, respectively.

2.3.5 Weed control and intercropping

Weeds such as large thorn apple and striga are the common weeds which are major constraints for maize production in SH farming. Cereal/legume intercropping is an important way to control weeds and increase maize yield, and also reduce the use of herbicides. Weeds cause severe yield reduction in maize production and losses of 40-60% have been reported (Ayeni *et al.,* 1984). However, Zuofa *et al.* (1992) reported that cereal/legume intercropping reduces weed occurrence and increases maize production. Weeds compete for the nutrients more effectively than maize, temporarily immobilizing them. In addition, weeds dry out the plough layer thus reducing root penetration of maize and water infiltration.

Maize/legume intercropping controls weeds when the legume component of the intercrop is established one month after planting maize. The tillage required to establish the interplanted legume acts as the weed control measure (Joubert, 2000). Interplanted legume provides high LAI and provides cover, thus competing with weeds for light. To increase legume competition with weeds, fertilizer application through placement can rapidly enhance growth of legumes to increase canopy cover and provide rapid, early ground cover and result in effective light interception for the legumes than weeds and this improves weed suppression (Mashingaidze, 2004; Thobatsi, 2009). Oswald *et al.* (2002) reported 40 to 80% decreases of striga when maize/lablab was planted as relay intercropping. Thobatsi (2009) reported 52 % reduction of weeds in intercropping.

2.3.6 Intercropping effect on pests and diseases

Pests and diseases are common maize production constraints which decrease yield (Flett *et al.,* 1996; Drinkwater *et al.,* 2002). Intercropping of two or more crop species with or without distinct row arrangement is a common method used to control pests and diseases by SH farmers due to unaffordability of pesticides. Maluleke *et al.* (2005) reported reduced stem borer infestation by 70% in intercropped maize as compared to sole maize. Pests or diseases have specific hosts and they do not spread easily in intercropping as they do in monoculture. They are misled by the canopy of the intercrops as it is not easy to recognize specific hosts (Ramert *et al*., 2002). Root (1973) cited by Thobatsi (2009) reported that pests are visually disturbed by the canopy of the intercrops and thus tend to stay for shorter period because of the disruptive effects of lending on non-hosts and this results in their slow survival. Ayisi and Mphosi (2001) reported that intercropping cowpea reduced stalk borer infestation in sorghum compared to the sole crop and Maluleke *et al.* (2005) showed that intercropping of maize and lablab reduced maize stalk borer when compared to sole maize.

2.4 Potential problems of intercropping

2.4.1 Labour

Labour requirements of an intercropping system are higher than in the sole cropping, as multiple crops are planted at the same time or shortly after one another and harvested at different times. Also cultural practices such as weeding and harvesting are slower in intercrops, however, components crops can suppress weeds thus reduce labour for weeding operation (Sullivan, 2003). In intercropping, it is difficult to use machines in some field operations such as harvesting and weeding, however, strip intercropping is a useful alternative as compared to other intercropping arrangements in this regard (Van Wolfswinkel, 2005).

2.4.2 Competition

Intercropping different crop species results in interspecific competition between the crops. This competition usually decreases survival, growth or reproduction of at least one species (Zhang and Li, 2003). According to Corre-Hellou and Crozat (2007), the competition between plant species occurs both above-ground for light and below-ground for water and soil nutrients. Sobkowicz (2006) showed that crop competition in intercropping depends on choice of the appropriate ratio of component species, proper choice of total density of plants per unit area for the intercrops and planting time of the intercrops.

2.5 Lablab and dry bean as intercrop species

2.5.1 Botanical description and adaptation of lablab

Hyacinth bean, field bean, Egyptian bean and Indian bean are some of the common names of lablab bean. *Lablab purpureus* L. or *Dolichos purpureus* L. is the scientific name of lablab bean which falls under the family of Fabaceae (Murphy and Colucci, 1999). Lablab is a climbing perennial herbaceous legume grown as an annual and it grows up to 1 m tall, with long stems in climbing types extending as much as 6 m from the base of the plant. The leaves are trifoliate, and the flowers are purple or white. It has a strong taproot which grows deeper with many lateral and adventitious roots (Valenzuela and Smith, 2002).

Lablab is a summer-growing season legume which is adapted to wide range of well-drained soils. It grows well in deep soils, clay loam and it is tolerant to drought, acidic and low fertility soils when it is well established. Lablab is intolerant to flooded conditions and it is unable to grow well in wet soils (Murphy and Colucci, 1999; Valenzuela and Smith, 2002).

2.5.2 Uses of lablab

Lablab is the forage legume which has wide range of uses in agricultural practices such as animal feed, soil fertility improvement, management of weeds and pests and also as human feed. It is among the most palatable legumes for animals, the foliage contains high protein content estimated to be 15-30%, with high levels of lysine and about 55% digestibility. It can be grazed as stand over feed late in the wet season or early in the dry season or can be cut while still green, dried and stored (hay) and fed to animals during the dry season (Pengelly and Maass, 2001). Murphy and Colucci (1999) reported that lablab is used to improve soil fertility through green manuring, cover crops or planted in mixture with cereal species for BNF. Lablab bean produces 60 kg N/ha and 120 kg N/ha as intercrop and green manure, respectively. In some countries, such as India, China, Southeast Asia, West Africa, Japan, and the Caribbean, it is used as a vegetable (Valenzuela and Smith, 2002). Maluleke *et al.* (2005) reported that simultaneous planting of maize and lablab bean with high lablab plant densities reduced stem borer by 70% as compared to sole maize. According to Creamer and Baldwin (2000), lablab bean suppressed weeds by 40% with its vine morphology when intercropped with sorghum-sudangrass as compared to weedy sole sorghum-sudangrass. Oswald *et al.* (2002) reported 40 to 80% decreases of striga when maize/lablab was planted as relay intercropping.

2.5.3 Biological Nitrogen Fixation (BNF) and biomass production of lablab

Biological nitrogen fixation (BNF) is the process whereby atmospheric nitrogen (N=N) is reduced to ammonia by living microorganisms e.g. rhizobia in the presence of nitrogenase enzyme (Lindemann and Glover, 2003). According to Valenzuela and Smith (2002) and Lindemann and Glover (2003) lablab bean can fix atmospheric nitrogen up to 120 to 200 kg N/ha when it is planted either as an intercrop or as a sole crop depending on the climatic and soil conditions. Creamer and Baldwin (2000) reported BNF of 40 to 80 kg N/ha when lablab is planted in sole cropping. Biomass production of lablab bean is reported to be high in sole or intercropping. Mpangane *et al*. (2004) and Gbaraneh *et al*. (2004) reported high lablab biomass 2215 to 3125 kg/ha in intercropping which was higher than total biomass of 1985 to 2018 kg/ha in sole cropping.

2.5.4 Botanical description and adaptation of dry bean

Small White Beans, Speckled Sugar Beans, Brown and Yellow Haricot Beans and Green Beans are common names of common dry bean. *Phaseolus vulgaris* is the scientific name of common dry bean which falls under the Fabaceae family. It is a grain legume which has determinate (bush type) and indeterminate (vining or trailing type) growth habit (National Department of Agriculture and ARC-Grain Crop Institute, 2010). Common or dry bean is a warm-season, annual legume that must be planted at the soil temperature of at least up to 10 ºC. Dry bean is generally considered a short-season crop with most varieties maturing in a range from 85 to 110 days from emergence to harvest. Dry bean is not tolerant to frost or to long periods of exposure to near-freezing temperatures at any stage of growth. It is not affected by high temperatures if adequate soil water is present. Optimum average growing temperature is 18 to 25 ºC. Dry bean prefers an optimum soil pH of 5.8 to 6.5, and are highly sensitive to acidic, alkaline and poorly drained soils. Dry beans are shallow rooted, in deep soils; roots grow laterally 20 to 30 cm and downward to a depth of 90 cm or more. Root distribution is concentrated near the soil surface which is considered as the effective rooting depth for irrigation purposes (National Department of Agriculture and ARC-Grain Crop Institute, 2002).

2.5.5 Uses of dry bean

Dry bean is a grain legume which has wide range of uses such as human and animal feed, soil improvement through biological nitrogen fixation and green manure. In many countries, including South Africa, tender leaves of dry beans are consumed as a vegetable and dried bean seeds as a supplement. In addition, secondary industries process dry bean seeds i.e. canned and used as secondary products. Livestock feed is made from beans which do not meet human food quality standards (National Department of Agriculture and ARC-Grain Crop Institute, 2010). It can be used for soil improvement because of its nitrogen fixation ability and also as green manure, increasing organic matter in the soil.

2.5.6 Biological Nitrogen Fixation (BNF) and biomass production of dry bean

According to Werner (2005) indeterminate dry bean plants fix more atmospheric nitrogen than determinate ones. Dakora and Keyaz (1997) reported 60 kgN/ha biologically fixed by common dry bean when intercropped with maize. Manrique *et al.* (1993) reported the contribution of biological nitrogen fixed by different common dry bean cultivars which was ranging from 30 to 60 kgN/ha. Common dry bean has ability in BNF, it can fix atmospheric nitrogen to about 60 to 100 kg N/ha in sole cropping (Lindemann and Glover, 2003).Indeterminate common bean fixes large amount of biological nitrogen to be utilized by intercrop species, leave some small amount of fixed nitrogen in the soil which improves soil fertility. The amount of biological nitrogen found in maize/dry bean intercropping was 18 to 30 kg N/ha and in sole dry bean was 30 to 50 kg N/ha (Werner, 2005). Dry bean produces high biomass in sole cropping as compared to intercropping. Cereal/dry bean intercropping reduces dry bean biomass due to competition for resources by cereal crops and these results in suppression of dry bean growth. Dry bean in mixture with maize produced a reduced biomass of 509 kg/ha as compared to 810 kg/ha produced by sole dry bean (Saleem *et al.,* 2011).

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Study site

The study was conducted during 2010/2011 and 2011/2012 seasons at the University of Limpopo Experimental Farm (Syferkuil) (latitude of 23° 51' 0S, longitude of 29° 41' 60 E), altitude of 1324 masl. The farm has sandy loam soil, of the Hutton form, Glenrosa family, with pH ranging from 6.0-6.2 (Moshia, 2005). The area usually receives mean annual rainfall of 500 mm and daily temperature ranges from 18 to 35°C from October to March and 25ºC or lower from April to September (Shiringani, 2007; Mpangane *et al*., 2004).

3.2 Research design and treatments

The trial had five treatments:

1. Sole ZM 521, an improved open pollinated variety (ex-CIMMYT),

2. Sole Rongai, an indeterminate lablab cultivar,

3. Sole DBS 360, an indeterminate (Type II) dry bean cultivar,

4. ZM 521-lablab (Rongai) intercrop and

5. ZM 521-dry bean (DBS 360) intercrop.

The treatments were laid out in randomized complete block design (RCBD) with five replications. Each plot comprised of five plant rows and the legume row was put between the maize rows in the intercrops. All crops (maize, lablab and dry bean) were sown using the same inter row spacing of 90 cm, with intra row spacings of 30, 50 and 10 cm for maize, lablab and dry bean, respectively. Phosphorus (P) was applied on sole and intercropped maize at the rate of 30 kg P/ha in the form of superphosphate (10.5%P) at planting and 40 kg N/ha of nitrogen (N) was applied in the form of Limestone Ammonium Nitrate (LAN) (28%N) on both sole and intercropped maize four weeks after plant emergence.

3.3 Data collection

3.3.1 Soil sampling

Soil samples were collected randomly from three different places using a soil auger at two depths of 0-15 cm and 15-30 cm prior to planting to determine soil chemical properties. The three soil samples at each depth were mixed to form a representative composite soil sample. Soil samples from each treatment in all replications at the depths of 0-15 cm and 15-30 cm were collected at maize physiological maturity stage using a soil auger. Soil samples from each treatment at mentioned depths were mixed to form a representative composite soil sample.

3.3.2 Maize data

Number of days to 50% tasseling and number of days to physiological maturity of maize were monitored and recorded as days after planting (DAP). Physiological maturity of maize was recorded when a black layer appeared at the tip of the maize kernel (detachment of kernel from the cob).

Biomass and grain yield were determined from the net plot of 7.2 m^2 (1.8 x 4 m) at harvest maturity. Hundred (100) seed mass was determined by weighing two samples of 100 seed per plot. Number of cobs per plant, number of seeds per cob, cob length and plant height were determined from five consecutive plants from each plot. Biomass, hundreds (100) seeds mass, shelled and unshelled weight were determined using an electronic weighing balance.

Harvest index (HI) was calculated using the formula, HI = Grain yield/total above-ground biomass. Shelling percentage was calculated using the formula, shelling % = (shelled grain weight/ unshelled cob weight) × 100.

3.3.3 Dry bean data

Number of days to 50% flowering and number of days to physiological maturity of dry bean were monitored and recorded as days after planting (DAP). Days to physiological maturity for dry bean were recorded when pods turned brown and seeds shook loose.

Biomass and grain yield were collected and determined from the net plot of 7.2 m² (1.8 x 4 m) at harvest maturity. Hundred (100) seed mass was determined from two samples of 100 seeds per plot. Number of pods per plant and number of seeds per pod were determined on five consecutive plants randomly taken from the net plot. Biomass yield, hundreds (100) seed mass, shelled and unshelled weight were determined using an electronic weighing balance.

Harvest index (HI) was calculated using the formula, HI = Grain yield/total above-ground biomass. Shelling percentage was calculated using the formula, shelling % = (shelled grain weight/ unshelled pod weight) ×100.

3.3.4 Lablab data

Only total above ground biomass (dry matter) was recorded at maize harvest maturity stage because lablab had just started flowering. Biomass was collected from an area 7.2 m² (1.8 x 4 m). Lablab was dried in the oven at the temperature of 60 ºC for 72 hours and weighed using an electronic weighing balance.

3.4 Data analysis

Data obtained from the trial were subjected to Analysis of Variance using Statistix version 9.0. Differences amongst treatment means were separated using the least significant difference (LSD) method at 5% level of probability.

3.5 Biological productivity (LER)

Land Equivalent Ratio (LER) value was calculated to compare advantages between intercropping and sole cropping systems as described by Mead and Willey (1980). LER is the sum of partial LER values of the intercrops. LER for grain yield was calculated in maize/dry bean intercropping

$$LER=Ym+Yd \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \ (1)$$

where Ym is the partial LER of maize and Yd is partial LER of the dry bean.

$$Ym = \frac{Ymi}{Ysm} \text{ and } Yd = \frac{Ydi}{Yds} \cdots\cdots\cdots\cdots\cdots\cdots \ (2)$$

where Ymi is maize grain yield in intercropping, Ysm is maize grain yield in sole maize, Ydi is dry bean grain yield in intercropping and Yds is dry bean grain yield in sole dry bean.

An LER value of less than 1.0 indicates lower productivity of intercropping relative to sole crops; LER with the value of 1.0 shows no yield difference between intercropping and sole crops, and an LER value of greater than 1.0 shows yield advantage of intercropping as compared to sole crops.

3.6 Aggressivity (A)

Aggressivity is a competition implication to determine the competitive ability of a crop when grown in association with another crop (intercropping). An aggressivity value of zero indicates that component crops are equally competitive. The same aggressivity value in both component crops but different signs (positive or negative signs) the sign of the dominant species is positive and that of dominated species is negative. The greater the numerical value, the higher is the difference in competitive abilities and the higher the differences between actual and expected yields (Willey, 1979). Aggressivity was calculated using this formula:

$$Aab=\frac{Yab}{Yaa \times Zab}-\frac{Yba}{Ybb \times Zba}\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

where Yab is intercrop yield of crop ‘a’, Yaa is pure stand yield of crop ‘a’, Zba and Zab are sown proportions of crop ‘a’ and ‘b’ in an intercropping system, Yba is intercrop yield of crop ‘b’, Ybb is pure stand yield of crop ‘b’.

3.7 Monetary value (MV)

Monetary value was calculated using the price of R1907/t for maze and for dry bean R4082/t which were released by SAFEX in 2012.

CHAPTER 4

4. RESULTS

Results for the trial of 2010/2011 season are not presented as the trial was destroyed by wild pigs (warthogs) at the post-tasseling growth stage. Only results for the trial of 2011/2012 season are presented.

4.1 Pre-plant soil analysis

Pre-plant soil analysis and at harvest maturity of maize are presented in Table 4.1. At pre-plant, soil analysis showed that the soil at the trial site had high nitrogen (N), phosphorus (P) and potassium (K). The soil contained soil nutrients N, P, and K of 469, 32 and 123 mg/kg at the depth of 0-15cm, respectively (Table 4.1). At the depth of 15-30cm soil N, P and K was 455, 37 and 130 mg/kg, respectively. Soil N, P and K was approximately 34, 28 and 30%, respectively.. At the depth of 15-30 cm, N, P and K were 40, 24 and 20% more than the amount of N, P and K required by maize. With dry bean and lablab, N, P and K were approximately 28, 34 and 45% respectively at the depth of 0-15cm and 48, 32 and 41% at the depth of 15-30cm more than the required amount. Soil pH was at optimal level at both depths 0-15 cm and 15-30 cm with the values of 6.4 and 7.3, respectively, for both components crops (Table 4.1).

4.2 Soil analysis at harvest

Soil analysis showed that there was no difference in soil pH at pre-plant and at harvest of the trial under the different treatments (Table 4.1). Soil pH (H_2O) measured in soil at the depth of 0-15 cm ranged from 6.0-6.4, indicating moderate acidity and at the depth of 15-30 cm soil pH (H_2O) was in the range of 7.2-7.8, indicating moderate alkalinity of the soil.

Sole maize affected soil TN which was reduced by 24.9% and 23.5% at the depths of 0-15 and 15-30 cm, respectively (Table 4.1). Sole dry bean reduced soil TN by 30.7% and 25.7% at 0-15 and 15-30, respectively. Pre-plant and harvest time soil analyses showed that sole lablab reduced TN and by 33.5% and 40% at 0-15 and 15-30 cm depths, respectively (Table 4.1). Pre-plant and harvest time soil analyses showed that maize/dry bean intercropping highly reduced TN by 36.5% and 29.9% at 0-15 and 15-

30 cm depths, respectively (Table 4.1). Maize/lablab intercropping reduced soil TN by 24.1% and 21.5% at the depths of 0-15 and 15-30 cm, respectively (Table 4.1).

Sole maize did not affect soil P (mg/kg) at the depths of 0-15 cm but reduced it by 24.3% at the depth of 15-30 cm by the end of the trial as compared to pre-plant soil analysis. Sole dry bean did not affect soil P at 0-15 cm but considerably reduced it by 32.4% at the 15-30 cm depth. The sole lablab treatment reduced soil P by 12.5% and 48.6% at the 0-15 and 15-30 cm, depths respectively. The maize/dry bean intercrop reduced soil P by 9.4% and 27.0% at the respective depths. Maize/lablab intercropping reduced soil P by 6.3% and 13.5% at the 0-15 and 15-30 cm respective depths.

Soil K increased by 16.3% and decreased by 23.1% at the 0-15 cm and 15-30 cm depths, respectively, under sole maize. Sole dry bean reduced soil K by 10.6% and 34.6% at the 0-15 cm and 15-30 cm depths, respectively. Sole lablab reduced soil K by24.4% and 47.7% at the 0-15 cm and 15-30 cm depths. Soil K was reduced by 24.4% and 23.1% under maize/dry bean intercropping at the 0-15 cm and 15-30 cm depths, respectively. Maize/lablab intercropping slightly affected soil K at 0-15 cm depths and reduced it by 24.6% at 15-30 cm depth. These results show that most nutrient elements were saturated in the 15-30 cm depth.

Sole maize only reduced soil Ca by 2.96% at the 15-30 cm depth. Sole dry bean reduced soil Ca by 14.7% at both 0-15 and 15-30 cm depths. Sole lablab decreased soil Ca by 15.0% and 19.7% at the 0-15 and 15-30 cm depths, respectively. Under maize/dry bean intercropping, soil Ca was reduced by 9.5% and 2.5% at the respective depths. Maize/lablab intercropping only reduced soil Ca by 6.8 and 7.9% at 0-15 and 15-30 cm depths, respectively.

Soil magnesium slightly increased under sole maize (Table 4.1). Sole dry bean reduced soil Mg by 10.8% and 9.8% at 0-15 and 15-30 cm depths. Soil Mg declined by 14.2 and 13.8% at 0-15 and 15-30 cm depths under sole lablab. Maize/dry bean intercropping reduced soil Mg by 7.9% at 0-15 cm depth while increased it by 3.1% at 15-30 cm depth. Maize/lablab had very little effect on soil Mg (Table 4.1).

Soil Na was reduced by 28.3 and 44.1% at 0-15 and 15-30 cm depths, respectively, under sole maize, and it increased by 13.2% at 0-15 cm but declined by 11.8% under sole dry bean at the respective depths. Sole lablab caused a minor reduction of soil Na of 5.7% at 0-15 cm and a reduction of 11.8% at 15-30 cm depth. Maize/bean intercropping had very little influence on soil Na causing an increase of 13.2% and a decrease of 7.4% at the respective depths. Soil declines of 18.9 and 4.4% in Na at the 0-15 and 15-30 cm depths, respectively, were obtained under maize/lablab intercropping.

Table 4.1. Soil chemical analyses before planting and at the end of the experiment

Pre-planting soil analysis			Soil analysis at harvest maturity of maize								
	Depths (cm)					milligram/kilogram ($mg\ kg^{-1}$)					
	0-15	15-30	Treatments	Depths (cm)	pH(H_2O)	TN	P	K	Ca	Na	Mg
pH(H_2O)	6.4	7.3	SOLE MAIZE	0-15	6.3	352	35	143	550	38	363
$mg\ kg^{-1}$				15-30	7.3	348	28	100	523	38	333
TN	469	455	SOLE DRYBEAN	0-15	6.2	325	34	110	465	60	315
P	32	37		15-30	7.2	338	25	85	428	60	293
K	123	130	SOLE LABLAB	0-15	6.0	312	28	93	463	50	303
Ca	545	508		15-30	7.8	273	19	68	408	60	280
Na	53	68	MAIZE/DRYBEAN INTERCROPPING	0-15	6.4	298	29	93	493	60	325
Mg	353	325		15-30	7.2	319	27	90	495	63	335
			MAIZE/LABLAB INTERCROPPING	0-15	6.3	356	30	118	508	43	348
				15-30	7.6	357	32	98	468	65	318

TN=total nitrogen, P=phosphorus, K=potassium, Ca=calcium, Na=sodium, Mg=magnesium

4.3 Number of days to 50 % flowering and physiological maturity

Dry bean reached 50% flowering 55 days after planting (DAP) and physiological maturity at 125 DAP. Maize reached 50% tasseling at 65 DAP and physiological maturity at 129 DAP.

4.4 Dry bean grain yield, yield components and biomass

Dry bean grain yield and yield components are presented in Table 4.2. Dry bean biomass is presented in Table 4.3. Number of pods per plant was significantly ($P \leq 0.01$) reduced by intercropping (Table 4.2). Dry bean grain yield and 100 seed mass were significantly ($P \leq 0.05$) lower in the intercrop compared to sole cropping. Grain yield of sole dry bean obtained was 1778.5 kg/ha and was significantly ($P<0.05$) higher compared to the grain yield of dry bean in intercropping which was only 691.8kg/ha (Table 4.2). Grain yield and hundred (100) seed mass obtained in intercropping were approximately 38.9% and 86.5%, respectively, of the values for sole cropping. Harvest index was significantly ($P<0.05$) reduced in sole dry bean as compared to intercropped dry bean. Number of pods per plant was high in sole dry bean which was approximately 32.5% higher than in intercropping. Number of seeds per pod and shelling percentage were not affected by cropping system (Table 4.2).

Intercropping significantly ($P \leq 0.05$) affected dry bean total aboveground biomass (Table 4.3). Dry bean total aboveground biomass at physiological maturity was higher in sole dry bean (509.4 kg/ha) compared to maize/dry bean intercropping (386.4 kg/ha) (Table 4.3). Total aboveground biomass obtained in sole dry bean was 27% higher than that obtained in maize/dry bean intercropping.

Table 4.2. Effect of maize/dry bean intercropping on yield and yield components of dry bean

Treatments	Number of pods /plant	Number of seeds/pod	100 seed mass (g)	Grain yield (kg/ha)	Shelling %	Harvest index (%)
SOLE BEAN	22.0a	4.0a	41.6a	1778.5a	75.8a	28.0b
MAIZE/BEAN INTERCROPPING	16.6b	3.6a	36.0b	691.8b	76.1a	56.2a
SIGNIFICANCE	**	ns	*	*	ns	*
$LSD_{0.05}$	1.41	–	3.50	756.76	–	27.51
CV (%)	4.18	10.19	5.14	34.89	2.70	37.21

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** significant at $P \leq 0.01$,* significant at $P \leq 0.05$.

4.5 Lablab total aboveground biomass

There were significant differences at $P \leq 0.05$ level of probability for lablab biomass between sole lablab and lablab in intercropping (Table 4.3). Sole lablab produced higher biomass of 1359.8 kg/ha than lablab in intercropping which obtained 1126.9 kg/ha (Table 4.3). Thus, biomass accumulation in sole lablab was 20.7% higher than biomass obtained in maize/lablab intercropping.

Table 4.3.Effect of maize/dry bean and maize/lablab intercropping on biomass yield of dry bean and lablab

	Biomass (kg/ha)	
Cropping systems	Dry bean	Lablab
SOLE CROPPING	509.4a	1359.8a
INTERCROPPING	386.4b	1126.9b
SIGNIFICANCE	*	*
$LSD_{0.05}$	83.62	181.09
CV (%)	10.63	8.29

LSD= Least Significant Difference, CV= coefficient of variation, * significant at P≤0.05. Lablab was evaluated at the time of dry bean maturity and was still in vegetative phase.

4.6 Maize grain yield, yield components and biomass

Maize grain yield, yield components and biomass are presented in Table 4.4. Number of rows per cob, shelling percentage and harvest index were not affected by cropping system for both sole maize, maize/dry bean and maize/lablab intercropping. Number of cobs per plant was significantly (P≤0.01) affected by cropping system for both dry bean and lablab treatments. Maize obtained highest number of cobs per plant (1.6) when maize was intercropped with dry bean followed by sole maize (1.3) with the lowest mean value being 1.0 cob per plant in maize/lablab intercropping (Table 4.4). Number of seeds per cob, 100 seed mass, plant height and grain yield were not significantly different between sole maize and maize/dry bean intercropping but were significantly (P≤0.01) lowered by intercropping maize with lablab (Table 4.4). Highest number of cobs per plant was obtained in maize/dry bean intercropping followed by sole maize and with lowest number of cobs per plant obtained in maize/lablab intercropping. Number of seeds per cob in maize/dry bean intercropping and sole maize was 22% and 18% higher than in maize/lablab intercropping.

Cob length obtained in maize/dry bean intercropping and sole maize was not significantly different (15.1 cm) but was significantly (P≤0.05) higher than in maize/lablab intercropping (Table 4.4). Plant height and 100 seeds mass in maize/dry bean intercropping were higher, 2.0 m and 30.8 g respectively, followed by sole maize 1.9 m and 30.4 g, and lowest mean values were obtained in maize/lablab intercropping at 1.7 m and 13.2 g. Maize/dry bean intercropping and sole maize produced high grain yield of 2156.3 kg/ha and 2093.7 kg/ha, respectively, while a significantly lower grain yield of 1259.3 kg/ha was obtained in maize/lablab intercropping. Maize yield in maize/dry bean intercropping and sole maize grain were higher than in maize/lablab intercropping by approximately 48% and 45%, respectively.

Statistical analysis showed no significant difference for total aboveground biomass at maize physiological maturity between maize/dry bean intercropping and sole maize but total aboveground biomass of maize in maize/lablab intercropping was significantly (P≤0.01) lower (Table 4.4). Maize/dry bean intercropping and sole maize obtained high total aboveground biomass mean values of 1509.2 kg/ha and 1377.7 kg/ha for maize/dry bean intercropping and sole maize, which were higher than that of maize/lablab intercropping by 44% and 34%, respectively.

Table 4.4. Effects of intercropping lablab and dry bean with maize on yield and yield components of maize

Treatments	Number of cobs/ plant	Number of seeds /cob	Cob length (cm)	100 seed mass (g)	Plant height (m)	Grain yield (kg/ha)	Shelling %	Harvest index	Total aboveground biomass (kg/ha)
SOLE MAIZE	1.3a	470.0a	15.1a	30.4a	1.9a	2093.7a	77.7a	66.0a	1377.7a
MAIZE/BEAN INTERCROPPING	1.6b	489.6a	15.1a	30.8a	2.0a	2156.3a	76.3a	70.0a	1509.2a
MAIZE/LABLAB INTERCROPPING	1.0c	388.6b	13.2b	21.7b	1.7b	1259.3b	79.8a	70.0a	941.6b
SIGNIFICANCE	**	**	*	**	**	**	ns	ns	**
$LSD_{0.05}$	0.19	38.95	1.58	5.92	0.16	502.73	–	–	248.79
CV (%)	10.15	5.94	7.49	14.67	6.11	18.77	3.81	15.04	13.37

LSD= Least Significant Difference, CV= coefficient of variation, ns=non significant, ** significant at P≤0.01, * significant at P≤0.05.

4.7 Intercrop productivity

LER was calculated for maize/dry bean intercropping only. Partial LER values for maize and dry bean were 1.03 and 0.39, respectively The LER for maize/lablab intercropping was not calculated as the lablab was still in the vegetative stage at the time of maize maturity. The PLER for maize in maize/lablab intercropping was 0.60.

4.8 Aggressivity (A)

Aggressivity value for maize/dry bean intercropping was calculated. Aggressivity value obtained in maize/dry bean intercropping grain yield was positive (+), with the value of +0.64.

4.9 Monetary value

Monetary value for sole dry bean was statistically ($P \leq 0.05$) similar to that of maize/dry bean intercropping, R7259/ha and R6951/ha, respectively. Monetary value of sole maize (R3992/ha) was significantly lower ($P \leq 0.01$) than that of sole dry bean and maize/dry bean intercropping (Table 4.5). Monetary value of sole dry bean and maize/dry bean intercropping were 58% and 54% higher than monetary value of sole maize respectively.

Table 4.5.Monetary value of the different treatments

Treatments	Monetary value (R/ha)
SOLE MAIZE	3992b
SOLE DRY BEAN	7259a
MAIZE/DRY BEAN INTERCROPPING	6951a
SIGNIFICANCE	**
$LSD_{0.05}$	2446.9
CV (%)	27.65

LSD= Least Significant Difference, CV= coefficient of variation, ** significant at $P \leq 0.01$.

CHAPTER 5

5. DISCUSSION

5.1 Biological yield

5.1.1. Maize

Maize/dry bean intercropping and sole maize achieved similar levels of maize above-ground biomass but maize/lablab significantly reduced maize above-ground biomass This clearly shows that lablab gave much higher competition to maize for growth factors than did dry bean. This competitiveness of lablab was reported by Maluleke *et al.* (2004) who showed that simultaneous maize/lablab intercropping reduced maize total aboveground biomass as compared to sole maize cropping system. Maize total aboveground biomass increased when lablab was planted 45 days after planting (DAP) maize. Similarly, Gbaraneh *et al*. (2004) reported that planting lablab four (4) weeks after planting (WAP) maize resulted in high biological yield of maize. In this study, maize aboveground biomass was 62% only of that in maize/bean intercropping and sole maize had 8.7% less biomass than in maize/bean intercropping, implying that intercropping enhanced maize growth. Marer (2005) also found higher total aboveground biomass in maize/pigeon pea intercropping as compared to sole maize. Maize biomass is important for livestock feed in winter in southern Africa (Syomiti *et al.,* 2011). The drastic reduction in maize biomass is unlikely to be looked at favourably by farmers. However, lablab biomass in the intercrop of 1127 kg/ha more than compensates for the reduced maize biomass given the higher nutritional value of lablab and that it fixes more atmospheric nitrogen than dry bean.

5.1.2. Dry bean

Statistical analysis showed significant difference in total aboveground biomass between maize/dry bean intercropping and sole dry bean. Sole dry bean obtained higher total aboveground biomass mean value of 509.4 kg/ha compared to 386.5 kg/ha obtained in maize/dry bean intercropping. This was expected as the taller cereal crop sheds the grain legume. Marer (2005), Thobatsi (2009) and Saleem *et al.* (2011) reported similar results on reduced total aboveground biomass of the grain legumes possibly due to the suppression of maize canopy on the legumes.

5.1.3. Lablab bean

Total aboveground biomass of lablab was significantly ($P<0.05$) reduced by intercropping with maize, a reduction of 17.1%. Sole lablab obtained higher total aboveground biomass of 1359.8 kg/ha. Mpangane *et al.* (2004) reported similar results of higher lablab biomass accumulation in sole cropping system than in maize intercropped with lablab at different days after planting maize. They reported 5562 and 3539 kg/ha in sole lablab and maize/lablab intercropping, respectively. Gbaraneh *et al.* (2004) also reported similar findings of high lablab biomass of 4370 kg/ha in sole cropping and low biomass of 2850 kg/ha in simultaneous maize/lablab intercropping. The lablab biomass yields obtained in this study were considerably lower than those reported by Gbaraneh *et al*. (2004) and Mpangane *et al*. (2004). This was because the lablab biomass was determined at maize maturity when the lablab had just begun flowering. Future studies should include shorter duration lablab cultivars so that they can seed by the time the maize is removed from the field. These are also likely to compete less with the maize crop.

5.2 Yield components and grain yield

There was no lablab grain produced during this trial so only the grain yield of maize and dry bean is presented here.

5.2.1 Maize

There was significant difference for number of cobs per plant in maize/dry bean, maize/lablab intercropping and sole maize cropping system. Maize/dry bean intercropping showed higher number of cobs per plant (1.6 cobs per plant), followed by sole maize with mean value of 1.3 cobs per plant and maize/lablab intercropping with lower mean value of 1.0 cobs per plant. This result also suggests that intercropping maize with dry bean benefitted the maize plants and that lablab offered more competition to maize than dry bean. Gbaraneh *et al*. (2004) and Maluleke *et al.* (2004) reported that intercropping maize and lablab at the same time reduced number of cobs per plant as compared to sole maize. Number of seeds per cob, cob length, 100 seeds mass, plant height and grain yield were not affected by intercropping maize with dry bean. These results agree with those of Saleem *et al.* (2011) on mash and mung bean, and Thobatsi (2009) on cowpea that intercropping maize with grain legumes resulted in no significant differences in number of seeds per cob, cob length, 100 seeds mass, plant height and grain yield.

There were no significant differences found for number of rows per cob, shelling percentage and harvest index between maize/dry bean, maize/lablab intercropping and sole maize. Undie *et al.* (2011), Saleem *et al.* (2011), Tunku *et al.* (2010) and Marer (2005) reported similar findings of obtaining no significant difference ($P \leq 0.05$) between sole maize and when maize was intercropped with soybean, pigeon pea, and mung bean and mash bean, respectively.

Highly significant differences were found in number of cobs per plant, number of seeds per cob, 100 seeds mass, plant height and grain yield under maize/dry bean intercropping and sole maize as compared to maize/lablab intercropping($P<0.01$). Cobs from maize/dry bean intercropping and sole maize plots were significantly ($P<0.05$) longer as compared to those from maize/lablab intercropping. Maluleke *et al.* (2004) reported similar results that simultaneous maize/lablab intercropping reduces maize plant height and grain yield. This result is also supported by the findings of Ngwira *et al.* (2011) that intercropping maize with lablab three weeks after planting (WAP) maize results in higher number of cobs per plant, number of seeds per cob, 100 seeds mass, plant height and grain yield than simultaneous maize/lablab intercropping.

5.2.2 Dry bean

Intercropping had no significant effect on shelling percentage and number of seeds per pod. Saleem *et al.* (2011) and Marer (2005) also found no significant difference in shelling percentage when maize was intercropped with pigeon pea and soybean, respectively. Gandebe *et al*. (2010) found no significant difference in seeds per pod of cowpea when it was intercropped with maize.

Sole dry bean had significantly ($P<0.05$) higher 100 seeds mass and grain yield than in intercrop. It had mean values of 41.6 g for 100 seeds mass and 1778.5 kg/ha for grain yield as compared to maize/dry bean intercropping with low mean values of 36.0 g and 691.8 kg/ha for 100 seed mass and grain yield, respectively. Maize/dry bean intercropping had significantly ($P<0.05$) higher harvest index as compared to sole dry bean. Undie *et al*. (2011), Thobatsi (2009) and Saleem *et al.* (2011) found similar results that intercropping maize with soy bean, mash bean and cowpea reduced legumes grain yield and 100 seeds mass as compared to the sole legumes. Ndung'u *et al*. (2005a) and Ndung'u *et al*. (2005b) also reported that maize/dry bean intercropping reduced dry bean yield due to competition. The results in this study showed that highly significant difference was found in number of pods per plant ($P<0.01$). Sole dry bean produced higher number of pods per plant with mean value of 22.00 pods per plant as compared to maize/dry bean intercropping with a lower mean value of 16.60 pods per plant. Similar results were found by Ndung'u *et al*. (2005a) and Ndung'u *et al*. (2005b) who reported that intercropping of maize with dry bean reduced dry bean yield as compared to sole dry bean due to reduced light penetration and increased competition. Thobatsi (2009) and Undie *et al*. (2011) also found similar results that intercropping maize with cowpea and soybean, respectively, resulted in reduction of number of pods per plant as compared to sole legumes.

5.3 Intercrop productivity

Maize/dry bean intercropping showed the advantage of efficient utilization of resources as compared to maize and dry bean planted as sole crops. Dry bean obtained lower partial LER of 0.39 where maize obtained partial LER of 1.03 for grain yield. In this study, intercropping did not reduce but raised maize yield. This is hard to explain for marginal rainfall environments. These results with total LER value of 1.42 indicate that intercropping had 42% yield advantage over sole cropping. Kutu and Asiwe (2010), Tsubo *et al*. (2004) and Silwana and Lucas (2002) found similar results that maize/dry bean intercropping increased LER in different intercrop systems and weeding levels. These results suggest that maize/dry bean intercropping is a viable option even in seemingly marginal rainfall environments. The lower PLER value of 0.60 for maize in maize/lablab intercropping relative to that of maize in maize/dry bean intercropping clearly suggested that in order to maintain maize productivity, one has to use shorter duration lablab varieties, plant lablab after maize or plant lablab at reduced density.

5.4 Aggressivity (A)

Aggressivity calculated was a positive value of +0.64 which indicates that maize was competitive on dry bean in maize/dry bean intercropping during growing season. Yilmaz *et al.* (2008) and Mahapatra (2011) reported similar results of maize obtaining positive aggressivity value when intercropped with legumes. Khan and Khaliq (2004) also found similar results of positive aggressivity value in maize/cotton intercropping. This implies that to enhance maize/bean intercrop productivity, there is a need to try to minimize the direct competition of maize on the lower legume. For example, effort should be made to use spatial separation to minimize root contact and shedding, or use of shorter statured maize cultivars.

5.5 Monetary value (MV)

Monetary values calculated showed sole dry bean and maize dry bean intercropping as the most profitable treatments as compared to sole maize. Sole maize monetary value was lower and could reduce income by approximately 58% and 54% as compared to sole dry bean and maize/dry bean intercropping, respectively. Tsubo *et al*. (2005) who found similar results reported that yield of sole maize was lower as compared to intercropping. Molatudi and Mariga (2012) also reported similar results of higher income generated by sole dry bean relative to sole maize and maize/dry bean intercropping. Sole dry bean and maize/dry bean intercropping were not significantly different in income level. Molatudi and Mariga (2012) also reported similar findings where monetary values were not significant different in both high and low maize densities intercropped with small white haricot and red speckled dry beans.

5.6 Soil fertility status

For most nutrients were reduced at the end of the trial and many had slightly higher levels in the 0-15 cm than in the lower 15-30 cm depth. Soil total nitrogen (TN) was highly reduced in all cropping systems. Reduced TN was higher in sole lablab and maize/dry bean intercropping, in sole legumes was highly reduced due to non-application of fertilizers during the growing season. Rao and Mathuva (2000) and Beedy *et al*. (2010) reported similar results where intercropping and sole cropping of maize, pigeon pea, cowpea and gliricidia reduced soil TN in the soil at the end of the trial.

Soil phosphorus (P) was slightly reduced in all cropping systems at all depths. Similar results were reported by Olasantan *et al* (1996) and Moshia (2005) but Mei *et al*. (2012) reported different results where maize/Faba bean intercropping increased soil P accumulation. Potassium (K) was highly reduced in sole lablab and maize/dry bean intercropping at both depths and was moderately increased in sole maize at the depths of 0-15 cm. Different results were reported by Makumba *et al*. (2006) where maize/gliricidia intercropping increased soil K as compared to sole maize cropping system. Soil calcium (Ca) was increased in sole maize and was highly reduced in sole dry bean and sole lablab. Makumba *et al*. (2006) reported different results where sole legume (*Gliricidia sepium*) increase soil Ca as compared to sole maize.

Soil Na slightly increased at the depth of 0-15 cm and slightly decreased at the depth of 15-30 cm under sole dry bean. Sole lablab slightly reduced soil Na at both respective depths. Similar results reported by Beedy *et al.* (2010) when maize intercropped with *Gliricidia sepium.* Maize/lablab intercropping slightly declined soil Na at both 0-15 and 15-30 cm, respectively. Soil Na decreased at the depth of 0-15 cm and increased at the depth of 15-30 cm under maize/dry bean intercropping. These results agree with the results found by Akinnifesi *et al.* (2006); Dakora and Keyaz (1997) when maize intercropped with *Gliricidia sepium* and cowpea. Soil Mg slightly increased under sole maize at both respective depths. Soil dry bean reduced soil Mg at both depths 0-15 and 15-30 cm, respectively. Maize/dry bean intercropping reduced soil Mg at 0-15 cm depth and slightly increased it at 15-30 cm. Maize/lablab intercropping had little effect on soil Mg at both respective depths. Makumba *et al*. (2006) reported similar findings where Olasantan *et al* (1996) reported different results where maize/soybean intercropping increased soil Mg.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATION

Maize/dry bean intercropping did not affect maize grain yield, maize lablab intercropping decreased grain yield of maize. Intercropping dry bean with maize reduced yield of dry bean. Land equivalent ratio (LER) provided evidence of efficient utilization of resources by maize/dry bean intercropping. Aggressivity showed that maize was dominating on dry bean. Dry bean obtained high monetary value in sole cropping than in intercropping with maize. Both sole cropping and intercropping systems decreased soil fertility status, suggesting that short term cereal/legume intercropping should not preclude fertilizer or manure application.

Further field studies to compare simultaneous intercropping of dry bean and shorter duration lablab with maize are necessary. Inoculation of legume seeds with specific bacteria and fertilization of beans to enhance biological nitrogen fixation and plant growth in simultaneous intercropping with maize also needs to be incorporated in future research.

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APPENDICES

Summary of Analysis of Variance (ANOVA) tables for dry bean

Appendix 1. Number of pods per plant

Source of variation	DF	SS	MS	F	P
Treatment	1	72.900	72.9000	112.15	0.0004
Replication	4	284.600	71.1500		
Error	4	2.600	0.6500		
Total	9	360.100			

Appendix 2. Number of seeds per pod

Source of variation	DF	SS	MS	F	P
Treatment	1	0.40000	0.15000	2.67	0.1778
Replication	4	0.60000	0.15000		
Error	4	0.60000	0.15000		
Total	9	1.60000			

Appendix 3. 100 seeds mass

Source of variation	DF	SS	MS	F	P
Treatment	1	78.400	78.4000	19.62	0.0114
Replication	4	68.336	17.0840		
Error	4	15.980	3.9950		
Total	9	162.716			

Appendix 4. Grain yield

Source of variation	DF	SS	MS	F	P
Treatment	1	2952292	2952292	15.90	0.0163
Replication	4	519655	129914		
Error	4	742912	185728		
Total	9	4214860			

Appendix 5. Shelling percentage

Source of variation	DF	SS	MS	F	P
Treatment	1	0.3610	0.36100	0.09	0.7842
Replication	4	25.0240	6.25600		
Error	4	16.8440	4.21100		
Total	9	42.2290			

Appendix 6. Harvest index

Source of variation	DF	SS	MS	F	P
Treatment	1	0.19881	0.19881	8.10	0.0466
Replication	4	0.11174	0.02793		
Error	4	0.09814	0.02453		
Total	9	0.40869			

Appendix 7. Biomass

Source of variation	DF	SS	MS	F	P
Treatment	1	37810	37810.2	16.67	0.0151
Replication	4	139780	34944.9		
Error	4	9072	2268.1		
Total	9	86662			

Summary of Analysis of Variance (ANOVA) tables for lablab

Appendix 8. Biomass

Source of variation	DF	SS	MS	F	P
Treatment	1	135606	135606	12.75	0.0234
Replication	4	136902	34225		
Error	4	42539	10635		
Total	9	315047			

Summary of Analysis of Variance (ANOVA) tables for maize

Appendix 9. Number of cobs per plant

Source of variation	DF	SS	MS	F	P
Treatment	2	1.15733	0.57867	31.00	0.0002
Replication	4	0.09067	0.02267		
Error	8	0.14933	0.01867		
Total	14	1.39733			

Appendix 10. Number of seeds per cob

Source of variation	DF	SS	MS	F	P
Treatment	2	28677.0	14338.5	20.10	0.0008
Replication	4	39221.2	9805.3		
Error	8	5705.9	713.2		
Total	14	73604.1			

Appendix 11. Cob length

Source of variation	DF	SS	MS	F	P
Treatment	2	12.0333	6.01667	5.07	0.0378
Replication	4	11.1507	2.78767		
Error	8	9.4933	1.18667		
Total	14	32.6773			

Appendix 12. 100 seeds mass

Source of variation	DF	SS	MS	F	P
Treatment	2	263.969	131.985	8.00	0.0123
Replication	4	49.357	12.339		
Error	8	131.971	16.496		
Total	14	445.297			

Appendix 13. Grain yield

Source of variation	DF	SS	MS	F	P
Treatment	2	2508162	1254081	10.55	0.0057
Replication	4	610634	152659		
Error	8	950565	118821		
Total	14	4069361			

Appendix 14. Plant height

Source of variation	DF	SS	MS	F	P
Treatment	2	0.29857	0.14929	11.09	0.0049
Replication	4	0.07483	0.01871		
Error	8	0.10769	0.01346		
Total	14	0.48109			

Appendix 15.Shelling %

Source of variation	DF	SS	MS	F	P
Treatment	2	31.132	15.5660	1.76	0.2324
Replication	4	84.943	21.2357		
Error	8	70.721	8.8402		
Total	14	186.796			

Appendix 16. Harvest index

Source of variation	DF	SS	MS	F	P
Treatment	2	0.00649	0.00325	0.30	0.7473
Replication	4	0.04243	0.01061		
Error	8	0.08597	0.01075		
Total	14	0.13489			

Appendix 17.Biomass

Source of variation	DF	SS	MS	F	P
Treatment	2	882809	441404	15.17	0.0019
Replication	4	291694	72924		
Error	8	232793	29099		
Total	14	1407296			

Appendix 18. Analysis of Variance for monetary value maize/dry bean intercropping

Source of variation	DF	SS	MS	F	P
Treatment	1	3.254E+07	1.627E+07	5.78	0.0280
Replication	4	4795839	1198960		
Error	8	2.252E+07	2814903		
Total	14	5.986E+07			

Appendix 19.Partial ANOVA table for maize, dry bean and lablab

	Maize	Dry bean	Lablab
Source of variation	DF	DF	DF
Treatment	2	1	1
Replication	4	4	4
Error	8	4	4
Total	14	9	9

Appendix 20.Partial monetary value table for maize/dry bean intercropping

Source of variation	DF
Treatment	2
Replication	4
Error	8
Total	14