EVALUATING WATER USE EFFICIENCY OF MAIZE IN DIFFERENT INTERCROPPING SYSTEMS WITH LEGUMES

Nonjabulo Lynne Bambalele

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DECLARATION

I, Nonjabulo Lynne Bambalele, certify that the material reported in this thesis represents my original work, except where acknowledged. I further declare that these results have not otherwise been submitted in any form for any degree or diploma to any university. The work does not contain any other people's information or data such as graphs, tables and pictures unless acknowledged to be found or sourced from other researchers.

Signature …………………………………. Date………………………………………….

Nonjabulo Lynne Bambalele

As research supervisors we agree to submission of this dissertation for examination:

Signature …………………………………… Date………………………………………….

Prof. Paramu Mafongoya (Main Supervisor)

Signature …………………………………… Date………………………………………….

Dr Lembe Samkelo Magwaza (CO-Supervisor)

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GENERAL ABSTRACT

Water scarcity remains one of the key constraint in crop production. Projections indicate that drought will increase throughout the world. Consequently, as water resources decrease crop production will be negatively affected. Furthermore, the population in the Sub-Saharan Africa is continuously increasing. This poses major concerns as the land size available for crop production is declining. A study with the following two objectives: i) to evaluate water use efficiency of maize (*Zea mays*) and various legumes in an intercropping system ii) to gain understanding of different legumes response when intercropped with maize; was conducted at Ukulinga Research Farm of the University of KwaZulu-Natal, Pietermaritzburg, South Africa. The experiment was arranged in a randomised complete block design, with three replicates. The experiment consists of three blocks with 9 experimental units replicated three times results into 27 experimental units. The treatments were maize intercropped with bambara groundnut, cowpea, pigeon pea and tepary beans as well as monocrops of each crop. Data was collected at a 14-day interval on all parameters measured (water use efficiency, transpiration, photosynthesis, stomatal conductance and soil moisture). Data collection commenced at 35 days after planting. Seedling emergence days to 50% flowering, pod mass and grain yield at harvest was collected on maize and legumes. Water use efficiency, stomatal conductance, transpiration and photosynthesis were measured on the second new fully expanded leaf.

The results of leaf gas exchange in chapter three showed a significance difference ($P < 0.05$) between intercropping treatment means. Stomatal conductance of pigeon pea (0.42 mol H_2O m^{-2} S^{-1}) was greater than pigeon pea intercrop (0.18 mol H_2O m^{-2} S^{-1}). This was greater than that of cowpea (0.23 mol H_2O m^{-2} S^{-1}), tepary beans (0.19 mol H_2O m^{-2} S^{-1}) and bambara groundnut (0.11 mol H_2O m^{-2} S^{-1}) planted in a monocrop. Monocrops of pigeon pea (18.32 mol H_2O m^{-2} S^{-1}), cowpea (9.24 mol H_2O m^{-2} S^{-1}) and tepary beans (7.94 mol H_2O m^{-2} S^{-1}) had a high transpiration rate compared to their intercrops. Cropping systems significantly ($P < 0.05$) affected WUE. In legumes, pigeon pea (1.06 µmol CO2 mol^{-1} H_2O) monocrop had the highest WUE.A significance difference ($P < 0.05$) was observed between intercrops treatment means with regards to grain yield. Results in chapter four revealed that highest percent of seedling emergence was observed in cowpea monocrop (96.3 %). There was a significance difference ($P < 0.05$) between cropping systems with regards to percentage seedling emergence. There was a significance difference ($P < 0.05$) in the number of days to 50 % flowering of crops. Tepary beans reached 50 % flowering in 45 days. The intercrops of maize-cowpea had the highest grain yield of 2094.6 kg/ha followed by maize-tepary beans, maize-bambara groundnut and maize monocrop which, respectively, had yields of 2003.0, 1917.1 and 1847.3 kg ha^{-1}.

In monocrops the best cropping systems were cowpea and pigeon pea as they had the highest WUE. In the intercrops the best cropping system was maize-cowpea pea and maize-tepary beans. This was concluded based on high WUE. Cropping systems of maize-cowpea and maize-tepary beans had high grain yield, and competition indices. The legumes were more competitive than maize. This implies that they were able to efficiently utilise resources such as nutrients, light and water. The reasons for their good performance needs further research.

Key words: Bambara groundnut, cowpea, pigeon pea and tepary beans

CHAPTER ONE
General introduction

1 Introduction

Climate change is significantly and continuously changing. It is predicted to cause rise in temperature and decline available water which leads drylands (Small, 2014). This poses a major threat to food security and water resources for agricultural use (Ziervogel et al., 2014). South Africa is classified as a semi-arid country. According to the department of water affairs (DWA, 2013), the total average precipitation received by the country (450 mm) is lower than the world (860 mm). In South African context, agriculture is regarded as the largest consumer of water (DWA, 2013). However, only 1.5 % of this water is used for irrigating land under crop production (DWA, 2013). The area under irrigation is small, the rest of the agricultural land is under dryland production.

Water is known as one of the most important factor limiting crop growth and production. Crop growth and final yield are negatively affected by water scarcity. Legumes such as bambara groundnut, cowpea, pigeon pea and tepary beans are known to have drought adaptation traits (Jørgensen et al., 2010; Belko et al., 2012; Wilson et al., 2012; Rao et al., 2013; Small, 2014). Researchers have advocated the importance of these traits for good crop growth under water scarcity. Jørgensen et al. (2010) reported that bambara groundnut have dehydration escape and avoidance traits. This was concluded based on the sensitivity of stomatal closure. Other drought survival trait such as dehydration avoidance and drought resistance are reported in cowpea (Abdou et al., 2013) and tepary beans (Mohamed &Tawfik, 2007), respectively. The legumes had diverse root traits which are essential for absorption of soil in large volumes. These traits play a vital role in the crop water use efficiency (WUE).

Water use efficiency is a physiological mechanism that enables plants to withstand water scarcity). In agronomy WUE is defined by Tomás et al. (2012) as the overall biomass produced in relation to water transpired. Singh et al. (2012), on the other hand, defined WUE as total carbon dioxide (CO_2) assimilate relative to the amount of water evapo-transpired per unit area. In this study the definition described by Singh et al. (2012) will be used as WUE was measured on the leaf. In plants stomatal conductance is highly correlated with WUE (Efeoğlu et al., 2009). The first response of plants towards drought is closing the stomata (Efeoğlu et al., 2009). This process ensures that there is minimal water loss within the plant through the leaves. Hence, plants that undergo such process are known to be drought tolerant (Belko et al., 2012).

Correlation exist between crop grain yield and water use efficiency. Moroke et al. (2011) observed a linearly increase in grain yield and water use efficiency of cowpeas. Abdou et al. (2013) also perceived an affirmative correlation between WUE and crop biomass in cowpea. Asare et al. (2011) observed a positive correlation between WUE and grain yield. This advocates that increasing WUE in crops, increases yield under water stress conditions. However, genetic variation exists between plant species and within each species. Abdou et al. (2013) showed that only two cowpea varieties were able to use water efficiently. This variation can be accountable for the crops diverse response to WUE.

Populations in the sub-Saharan is continuously increasing (OECD/FAO). This has translated to the decline in the land available to small scale farmers (Fuglie & Rada, 2013; Jayne et al., 2014). There is an increase in the cultivation of arid land due to the increase in the world population (Singh et al., 2011; Small, 2014). Statistics South Africa (Stats SA, 2015) reported an increase of 22 million in the population of the country in the past four years. Cereal crops such as maize are part of the daily diet consumed by humans in the African continent. Annual maize production has been stable in South Africa (DAFF, 2013). However, there are no assurance that current productions will be able to sustain the increasing population. Therefore, there is a need to increase crop production by small scale farmers. Cropping systems such as intercropping could provide a better solution.

Cropping systems practiced throughout the world vary significant. One of the most common cropping system practiced by small scale farmers in Africa is cereal-legume intercropping (Rusinamhodzi et al., 2012). Cereal-legume intercropping is advantageous as it improves soil structure and nutrient availability (Beedy etal. 2010; Zhang et al., 2015). Increased soil nutrients can positively affect crop quality and crop yields.

The advantage in an intercropping system is assessed through competition indices. These include land equivalent ratio (LER), competition ratio (CR), aggressivity (A), relative crowding and actual yield loss (AYL) (Yilmaz et al., 2008; Hirpa, 2014). The effectiveness of an intercropping system is assessed by an LER, which compares the yields of monocrops against the intercrops (Dhima et al., 2007). The intercrop is regarded as effective if the LER is greater than one. However, if it is less than one it is a disadvantage to the cropping system. The competition ratio assesses the LER of each crop in the intercropping system (Dhima et al., 2007). Relative crowding evaluates the dominance of one species over the other in the cropping system (Yilmaz et al., 2008).

Though crop WUE and adaptation to harsh environmental conditions is important for optimum yields. There is still limited data in South Africa about bambara groundnut, cowpea, pigeon pea and tepary beans WUE. The other issue facing the country is limited land that farmers possess. To ensure good crop yields, intercropping is recommended as a solution. This cropping system would ensure optimum use of a small area. The study will evaluate the cropping system of maize with various legumes with regards to WUE and adaptation to climate change.

Overall aim and objective

The overall aim was to assess the agronomic performance of maize in an intercropping system with various legumes with regards to WUE and grain yield.

Specific objectives:

1. To evaluate water use efficiency of maize (*Zea mays*) and various legumes in an intercropping system
2. To gain understanding of different legumes response when intercropped with maize

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CHAPTER TWO
LITERATURE REVIEW

1 Introduction

The unceasing changes in climate due to global warming, constitute high threats to agriculture. Drivers of the climate change include greenhouse gases (GHG) and carbon dioxide emissions (Zargar et al., 2011; Peters et al., 2013). CO_2 emissions is the chief contributor to global warming, and human being's actions are to be held accountable. According to National Aeronautics and Space Administration (NASA, 2015) atmospheric CO_2 concentrations have increased enormously in the past decades. Recent extremes in climatic factors such as drought and floods can be attributed to global warming. Several predictions and scenarios have been made on climate change. These predictions indicate that variations in precipitation, temperature, drought and water availability will affect crop production (Alexandratos & Bruinsma, 2012; Small, 2014).

Lack of resources in small scale farmers, particularly in rural areas makes them more vulnerable. Projections are mainly done based on current climate situations and future scenarios, however, they are not certain. Although projections have been made about climate change for the future, it evident that some negative effects are currently occurring. World annual mean temperature has increased by 0.68 °C (NASA/GISS, 2014). In South Africa temperature has increased by 0.5 °C in the last decade (Blignaut et al., 2009).

South African livelihoods are at risk of food insecurity and water resources through climate change. Consequently, negative impacts are mostly going to be experienced in agricultural sector because South Africa is categorised as semi-arid (DWA, 2013; Ziervogel et al., 2014). Crop growing season length and crop growth is dependent upon factors such as soil water availability and temperature (Calzadilla et al., 2014). Any changes in these factors below or beyond plants optimum will affect growth and development, especially in rain fed agriculture. Adverse effects of climate change are expected to continue and affect agriculture. This has led to adaptation being the priority in climate change (Calzadilla et al., 2014).

Genetic variation may exist in crops response and adaptation to climate change and drought. Researchers have recognized drought adaptation characteristics of bambara groundnuts (*Vigna subterranea* (L.) Verdc), pigeon pea (*Cajanus cajan (*L.) Millsp), tepary beans (*Phaseolus acutifolius*) and cowpea (*Vigna unguiculata* (L.) Walp) at different developmental periods (Jørgensen et al., 2010; Belko et al., 2012; Wilson et al., 2012; Rao et al., 2013; Small, 2014).

Water use efficiency (WUE) is one of the crops drought adaptation mechanism which enables them to produce optimum yields under low soil moisture. WUE in plants is influenced by cropping systems, water availability and evapotranspiration rate (Djaman & Irmak, 2012). A robust connection exists between stomatal conductance and relative water content (RWC) in crops (Anyia & Herzog, 2004). Plants have established explicit physiological mechanism during water scarcity, such as closing stomata to prevent dehydration (Efeoğlu et al., 2009). Primary response in plants during droughts is stomatal closure regulated by intricate hormones which include abscisic acid (ABA), methyl jesmonate (MJ), cytokinins and auxins (Zhang et al., 2001; Belko et al., 2012). These hormones are linked to WUE and transpiration which act as secondary traits (Lu et al., 2011). WUE in plants is a vital under drought conditions. However, cultivation practices also play an important role in increasing yields of subsistent farmers under harsh environmental conditions.

Cultivating many crops concurrently in the same field, known as intercropping has been practiced by many smallholder farmers in different parts of the world. Cereal-legume intercropping is the most common intercropping system which has been practiced by small scale farmers for decades. Intercropping systems has been shown to have optimum use of resources such as nutrients, moisture while producing good crop yields (Dania et al., 2014). Yield advantage in intercropping is attained through improved land equivalent ratio (LER), radiation use efficiency (RUE) and competition ratio (CR) (Rusinamhodzi et al., 2012; Zhong et al., 2015). LER is one of the key component in evaluating the effectiveness of the intercropping system. An LER greater than 1.0 is regarded as an advantage, which indicates that yields attained under mixtures are superior to those achieved in monocrops using equivalent land size. Other advantage of intercropping involves weed suppression. Silva et al. (2009) showed a reduction in weed infestation in maize-cowpea intercrop compared to monocrop. This review critically evaluates and synthesise mechanisms of climate change, its impact on agriculture and crops adaptation to drought and water use efficiency.

2 Climate change and crop production

Climate in the world is continuously and significantly changing, and is expected to continue in this manner in the next decades. Drylands are predicted to expand worldwide due to climate change which causes extreme rise in temperatures as well as decrease in water availability (Small, 2014). Decrease in groundwater resources and renewable surface water is projected in the 21st century as a result of climate change (IPCC, 2014). According to the projections made by Alexandratos & Bruinsma (2012), the global agricultural production is expected to decrease by 1.3 and 0.8 % in 2030 and 2050, respectively. Crop production on the other hand is projected to decrease by 1.3-3.3 % in 2050, owing to climate change (Calzadilla et al., 2014).

Projections made by Christensen et al. (2007) indicate an escalation in mean temperatures of 1.8-4.8 °C annually by 2100 in the Sub-Saharan Africa. Authors further projected variations of -12 and + 25 % in mean annual regional rainfall. These projections are alarming as agriculture in the Sub-Saharan Africa is mostly dependent on rain water availability rather than irrigation resources (Müller, 2009). Rainfed agriculture accounts for 97 % of total crop productions in the region (Calzadilla et al., 2013). Poor crop yields exist in the Sub-Saharan Africa, which is characterised by poor soils, lack of irrigation and absence of market access. Currently in South Africa, 12 % of land is arable land and 3 % is considered fertile (DWA, 2013). In the African continent climate change will effect agriculture, mainly through crop yields, crop production area. Ringler et al. (2010) projected a decrease of 3.2 and 4.6 % in cereal productions and yields, respectively by 2050. Crops with yields that are projected to be severely affected by climate change comprise of wheat and sweet-potato. However, other crops may be effected as well, with the variations in climate change.

Climate change constitute foremost constraints to South African livelihoods, especially through food security and water resources (Ziervogel et al., 2014). According to the Department of Water Affairs (DWA, 2013), South Africa is classified as a semi-arid country, as it receives an average annual rainfall of 450 mm, a value lower than the world's average of 860 mm per annum (DWA, 2013). The country is characterised by a diverse climate recurrent droughts, few tropical cyclones and mid-latitude cut-off low pressure systems (Bezuidenhout & Singels, 2007). The main water source in South Africa is surface water, of which 60 % is used for agricultural irrigation (DWA, 2013).

Although more than half of available water is used for agriculture, merely 1.5 % of total crop production land is irrigated (DWA, 2013). This poses major concerns as only a small portion of the land is under irrigation and the rest of the agricultural production land is facing irrigation and water constrains. Climate change poses major threats to all economic sectors in South Africa, the most sensitive is agriculture, due to water scarcity.

Adverse effects caused by climate change on agriculture have made adaptation of agronomic practices one the of key factors in reducing its impacts (Calzadilla et al., 2014). Adaptation is practices done by people and ecosystem to decrease actual and unforeseen negative impacts of climate change (IPCC, 2007). Adaptation involves actions to reinforce current management practices and the ability to continuously adapt and respond to the effects. Adaptation can be anticipatory, reactive, autonomous or planned. Reactive adaptation is defined by Fankhauser et al. (1999) as actions taken by organizations, government, plants and animals in response to the occurrence of climate change effects. Whereas anticipatory adaptive refers to actions taken by organizations and individuals in advance prior to the impacts of climate change. Anticipatory adaptation involves planning as well as research (Fankhauser et al., 1999). Research is a crucial tool in adaptation. New data provided by research can offer knowledge on adaptation practices that can be vital in combating negative effects of climate change.

Planned adaptive is intentional actions done based on current climatic conditions and future projections (IPCC, 2007). It encompasses creating policies, decisions and programs with the objectives of benefiting from new opportunities as well as decreasing current climate change impacts. Adaptation that occurs due to human organisations and environmental variations in natural systems is defined as autonomous adaptation (IPCC, 2007). This adaptation is not premeditated and involves short duration alterations. There may be variation in crops response and adaptation to climate change. However, with variation in rainfall distribution as well as increases in temperatures and carbon dioxide concentrations, certain plants may be well adapted to these conditions (Saha et al., 2012). These plants may be growing vigorously while use water efficiently.

2.1 Water use efficiency

Water use efficiency is the physiological mechanism that enables plants to withstand low soil moisture content and perform well under water stress. This is an essential characteristic and is defined as total biomass produced per unit area in relation to water evapo-transpired (Singh et al., 2012). Developing effective and ideal agricultural practices for water management and preservation, has become the most unique important strategy in dealing with water scarcity (Djaman & Irmak, 2012). Due to diverse South African weather and climate change, it is essential that selected crops under water scarcity can utilise water efficiently, without profoundly decreasing crop production and yield (Asare et al., 2011). This is particularly important under rain fed agriculture, which most smallholder farmers are practising.

Improving WUE in agriculture has become significantly imperative as water resources are deteriorating and irrigation is becoming more expensive due to energy costs (Singh et al., 2012). WUE is regarded as the key factor into successful crop production under drought conditions in small scale farming communities.

Research on WUE has been conducted by different researchers throughout the world. These experiments were mostly done on cereals and legumes involving monocrop as well as intercrop. They have provided significant data with regards to the crops WUE and identification of drought adaptation traits. These traits are critical for breeding improved WUE crops under drought conditions.

Drought is regarded as one of the major factor that present threats to food security in the world (Farooq et al., 2009). Crops production and yields, differs due to variations in water accessibility. Therefore, WUE of the same crop varies, and is influenced by the amount of irrigation applied, rate of evapotranspiration, rainfall and crops growth stage (Djaman & Irmak, 2012). WUE in certain genotypes is increased by water stress, this is achieved as a result of reduced respiration in plants (De Costa & Ariyawansha, 1996). Irrigation system can enhance WUE in plants. Li et al. (2010) reported that an alternate fractional root irrigation had optimistic effects on WUE and leaf relative water content in maize plants.

Anyia & Herzog (2004) observed a strong correlation between RWC and stomatal conductance in cowpea. Mohamed et al. (2002) reported that stomatal conductance was associated with RWC in tepary beans. These characteristics allowed the crops to withstand drought conditions, while producing optimum yields. When planted under drought conditions, crops with high RWC are able to utilize water efficiently. Mohamed et al. (2002) reported that the variation in RWC was beneficial in tepary bean lines under water stress. This was achieved through decrease in transpiration rate as a result of reduced leaf area. WUE is one of the fundamental plant traits that provide an indication of the crops adaptation to water scarcity.

2.2 Crops adaptation to drought

High increase in the amount of required water above existing available water resources in a specific area, is referred to as water scarcity (FAO, 2012). Water scarcity is predisposed by lack of access and distribution, capacity of organizations to supply adequate water and deficiency in water available to meet current demands (FAO, 2012). Fresh water available in the world is 2.5%, of which more than half is in the form of ice, snow and underground water (Hoekstra & Mekonnen, 2011). A slight portion is available and accessible for human use. With projected changes in climate the amount of water available might decline, signifying a small percentage which will be available in the future.

Agriculture uses more water than any other sector, as 70 % of fresh water is used for agriculture globally (FAO, 2012). South Africa has average runoff of 49 billion m^3 per annum and only 10.24 billion m^3 is available (DWA, 2013). Water usage presently is projected to be at 15-16 billion m^3 and total registered water usage has increased and reaching year 2050 requirement of 17.3 billion m^3 (DWA, 2013). This suggest that the country's current water usage maybe approaching or be beyond available surface limit.

Optimum yields, superior crop growth, emergence and establishment are depended on water availability and photosynthesis (Osakabe et al., 2014; Calzadilla et al., 2014). Water stress leads to stomatal closure, which reduces CO_2 uptake and affects photosynthesis (Osakabe et al., 2014). This can affect crop growth and final yield at harvest. Stomatal closure is considered as one of the early response by crops to drought stress (Efeoğlu et al., 2009). Thus, prevention of high dehydration in plants is through stomatal closure. The mechanism of stomatal closure incorporates intricate hormonal processes, biotic and abiotic stimuli.

Abscisic acid (ABA) and methyl jasmonate (MJ) are among the factors that triggers stomatal closure (Belko et al., 2012). ABA and MJ are hormones produced throughout the plants lifecycle, they stimulate growth and wound healing. These hormones are also produced during water stress as the plants defense mechanism against drought. Cytokinins and auxin regulate stomatal opening through biosynthesis of ethylene (Tanaka et al., 2006). Hydrogen peroxide (H_2O_2) plays an important role in stimulating ABA, which triggers closing of stomata (Zhang et al., 2001). Increased ABA in plant leaves oppose the function of ethylene and prevent stomata opening. Numerous signaling pathways are regulated by sensor and receptor proteins in the membrane (Osakabe et al., 2014). These proteins through catalytic process transfer information to cytoplasmic protein as they serve as secondary messengers in signaling pathway of stomatal closure.

Sustaining turgor is the plants physiological mechanism that is intricate in maintaining its hydration status. During water deficit, stomatal conductance, decrease in leaf area index and osmotic adjustment collectively maintain turgor (Daszkowska-Golec & Szarejko 2013). This leads to a reduction of water loss in plant during water stress. The amount of water transpired in plants is regulated by transpiration rate. Belko et al. (2012) observed that drought tolerant cowpea had low transpiration rate, which decreased water transpiration within the plant. The findings reported by these authors were similar to those observed by Mohamed & Tawfik (2007) in tepary beans lines. Hence, reducing transpiration rate is a vital characteristic of plants under drought conditions. Research conducted on bambara groundnuts, pigeon pea, tepary beans and cowpea indicated that theses legumes have drought tolerance l traits at different developmental phases (Jørgensen et al., 2010; Belko et al., 2012; Wilson et al., 2012; Rao et al., 2013; Small, 2014). Therefore, these crops have been recognised as possible substitute that can be grown under drought prone areas. These crop species have diverse characteristics which enables them to be adapted to drought such as dehydration avoidance, escape and tolerance (Abdou et al., 2013).

Dehydration avoidance is defined by Blum (2005) as the plants physiological mechanism to maintain high tissue moisture potential during water stress; whereas dehydration tolerance is the plants ability to withstand drought with low water tissue potential. Dehydration escape, on the other hand is defined as the plants mechanism that allows it to grow and complete the life cycle during the period of water availability before drought occurs (Courtois et al., 2000). Cowpea is known to undergo dehydration avoidance as drought mechanism trait (Abdou et al., 2013). According to these authors, dehydration avoidance is attained by stomatal closure and deep root system. Comparable findings were observed by Mohamed & Tawfik (2007), as tepary beans attributed drought resistant traits. These traits were shown through intense and high root mass, which improved soil water absorption.

Bambara groundnut landraces on the other hand have both dehydration avoidance and dehydration escape mechanism traits (Jørgensen et al., 2010). They attributed traits such as early stomatal closure, compressed phenology; which define dehydration escape and avoidance (Jørgensen et al., 2010).

Diverse genotypic variation exists between crops and within species in response to water scarcity (Mwale et al., 2007; Ahmed & Suliman, 2010; Abdou et al., 2013). A study on cowpea attributed that one genotype was more adapted to drought than the others (Ahmed & Suliman, 2010). This was due to certain adaptive traits that were observed such as short stem, few leaves and less number of branches, nodes and leaves per plant. According to Jørgensen et al. (2010), bambara groundnut landraces had similar attribute responses to drought and WUE, and genotype variation is influenced by climatic conditions and origin of landraces. This response is not unique to legumes since similar findings were observed in maize lines, where environmental conditions effected disparity in genotypes (Lu et al., 2011). Results confirms the ability of these crops performance at different climatic conditions, an important characteristic to be used by plant breeders.

Patanè & Cosentino (2013) reported that kenaf plants also produced good yields under moderate water stress. Yield at final harvest is regarded as the primary trait in plants. However, other secondary attractive traits exist in plants such as drought tolerance, WUE and transpiration regulation (Lu et al., 2011). Numerous drought adaptation traits exist in plants. These traits enable plants to produce optimum yields under harsh environmental condition, and advocate for these-plants to be used under such conditions.

3 Intercropping

Intercropping is a cropping system that involves simultaneous cultivation of two or multiple crops with different growth habits in the same field (Hirpa, 2014). Different types of intercropping systems exist worldwide and are influenced by diverse climatic conditions (Seran & Brintha, 2010). Intercropping systems are either categorised into row, strip, mixed or relay intercropping. In mixed intercropping systems, two or more crops are cultivated concurrently without any different row arrangements in the same field (Ouma & Jeruto, 2010). Row intercropping is defined by Ouma & Jeruto (2010) as cultivating two or more crops in rows, whereas strip intercropping is cultivation of crops in strips with spatial arrangement wide enough to permit separation yet narrow enough to allow interactions amongst plants. Relay intercropping is defined as the cropping system where crops lifespan intersects each other (Sandler et al., 2015). Thus, the second crop is sown prior to harvesting of the first crop, allowing complete utilisation of the land.

Diverse intercropping systems exist and are practiced in different countries throughout the world. Cereal-legume intercropping is a common cropping system practiced mostly by small-scale farmers in the African continent (Marer et al., 2007; Rusinamhodzi et al., 2012). In Mozambique, small-scale farmers usually intercrop maize with cowpea or pigeon pea (Rusinamhodzi et al., 2012). Similarly, small-scale farmers generally intercropped maize with cowpea, bambara groundnut and dry beans in countries such as Nigeria, Kenya and South Africa (Miriti et al., 2012; Dania et al., 2014). In general, small-scale farmers prefer maize-cereal intercropping. This could be due to the benefits provided by legumes to the soil.

Intercropping’s main concept is achieving optimum yields under a small unit area, with reduced inputs such as fertilizer, labour and water. Intercropping is known to increase crop production under a small unit area (Hirpa, 2014). Nutrient use efficiency is likely to increase when crops of different root architecture are cultivated in the same field (Stoltz & Nadeau, 2014). Pigeon pea has an extensive root system (Upadhyaya et al. 2012), which enables it to be more compatible when intercropped with cereals or any other crops. Root architecture ensures sufficient water absorption and decrease competition between crops.

Cereal-legume intercropping is beneficial as legumes supplies most of the nitrogen in the soil. Thus, atmospheric nitrogen (N) fixation is achieved through symbiotic relationship between legume and specific *Rhizobium,* thereby increasing soil nitrogen available for the companion crop (Mohale et al., 2014). Soil nitrogen availability is also increased for subsequent crops after planting legumes (Dania et al., 2014). Intercropping cereal crops such as maize with leguminous crops is advantageous as it increases water use efficiency, soil nutrients status and yields; expressed as land equivalent ratio (Rusinamhodzi et al., 2012).

Hirpa (2014) reported that yields in the intercropping system are influenced by the crop spacing, indicating that population density used should limit competition between plants. High plant densities in intercropping leads to competition between crops, which results in poor yields (Takim, 2012).

3.1 Resources use in cropping systems

Soil structure is influenced by several factors including soil organic matter, nutrients and moisture. Cereal-legume intercropping is resourceful as it maintains soil organic matter (SOM) stability (Beedy et al., 2010) increase crop N as well as soil N budget and nutrient uptake (Zhang et al., 2015). An example includes results by Wang et al. (2015) who reported variations in biological properties and soil chemicals where there was an increase in SOM (18.9 g kg^{-1}) and total N (1.30 g kg^{-1}) in cereal-legume intercropping. However, these changes were observed after a decade, indicating that benefits of cereal-legume intercropping are observed in a long-term.

An earlier study evaluating maize-*Gliricidia* intercropping, conducted over a period of 14 years by Beedy et al. (2010) revealed an increase in SOM as well as cation exchange capacity (CEC) consequently improved soil quality. This study also showed that N and P pools were augmented at the end of experiment. CEC is regarded as an important soil chemical characteristic, as it decreases leaching of cautions including K^+ and $NH4^+$. Through improved soil quality, crop yields also increased over the years. Rusinamhodzi et al. (2012) reported an improved rainfall soil infiltration in cereal-legume intercropping. This also indicated that long term advantageous results of enriched soil quality and stability.

3.1.1 Yield advantage

The concept of yield advantage is assessed using a complex and collective marginal factors. Researchers have attributed factors such as LER, CR and RUE as concepts of assessing the yield advantage in intercropping systems. Crop yield is influenced by a combination of aspects which comprises of grain yield, harvest index, RUE, crops intercepted fraction of incident radiation and lifespans entire incident photosynthetically active radiation (Saha et al., 2012). Numerous factors are involved in assessing yield advantage of an intercrop and are vital in indicating the benefit of mixtures.

3.1.2 Radiation use efficiency

Radiation use efficiency is defined by Saha et al. (2012) as the radiation light fixed by plants to the ratio of biomass generated. Plants transform solar radiation into biomass through the process of photosynthesis. Incoming solar radiation in plants is absorbed through leaf area index, which in turn influences crop canopy development (Saha, 2012). Hence, this characteristic is vital for achieving optimum yields. Leaf area index (LAI) can be affected by environmental conditions. Saha at al. (2012) observed an intensification in LAI at increased CO_2 conditions. High LAI enhances canopy development. Accordingly, Patanè & Cosentino (2013) observed that kenaf plants had RUE of 1.76 g DM MJ^{-1} in moderate water stress, which was 0.19 g DM MJ^{-1} below that of plants without water stress. Similar findings were observed by Zhong et al. (2015) in maize-soybean intercropping, where mixtures attained high RUE under no irrigation. These results indicated that these plants can utilize resources efficiently under water stress conditions and produce optimum yields.

Sowing time may be highly correlated to RUE. Early planting in mustard plants resulted in high RUE (Pradhan et al., 2014). RUE can be affiliated to plant genotype disparity (Du et al., 2015). This latter study revealed disparity in cotton genotypes RUE, which is important for breeding purposes and improving resource utilization.

3.1.3 Land equivalent ratio

Land equivalent ratio is a concept of assessing the effectiveness of an intercropping system. This concept measures and compare yield of monocrop versus intercrop. It is defined as the total area in monocrop required to produce yields that are equivalent to those of intercropping (Yilma et al., 2008). LER of a maize-legume intercropping system is computed using Eq. 1 defined by Hirpa (2014).

$$LER = \frac{M_{ym}}{M_{ys}} + \frac{L_{ym}}{L_{ys}} \quad (1)$$

Where:
M_{ym} = maize yield in mixture
M_{ys} = maize yield in sole
L_{ym} = legume yield in mixture and
L_{ys} = legume yield in sole.

The supremacy of one crop over the other in an intercropping system is measured through relative crowding coefficient (K) (Takim, 2012). LER of 1.0 suggests that there is no yield advantage in the intercropping system. However, LER above 1.0 suggests that there is interaction between the crops in the mixture, and is regarded as an advantage. This designate that under the same area, yields produced in an intercrop are more than those of monocrop.

Various resource inputs such as fertilizer application and water availability in a cropping system; are interrelated to the LER. Temesgen et al. (2015) observed that in a maize-navy bean intercrop high LER was attained with minor resource input. The results are similar to those experienced by Zhang et al. (2015) in maize-soybean and maize-red bean intercropping where the highest LER was attained in mixtures and maize-soybean intercrop. These findings collectively show that these intercropping system can be resourceful in producing optimum yields and play a vital role for subsistent farmers under rain fed agriculture and fertilizer constrains.

3.1.4 Competition ratio (CR)

Crops competitiveness capability is obtained through competition ratio, which measures the ratio of the individuals LERs in the cropping system. CR is computed using Eqs. 2 and 3, recently described by Yilmaz et al. (2008).

$$CR_a = \frac{LER_a}{LER_b} \ x \ \frac{Z_{lb}}{Z_{la}} \quad (2)$$

$$CR_b = \frac{LER_b}{LER_a} \ x \ \frac{Z_{la}}{Z_{lb}} \quad (3)$$

Where:

CR_a and CR_b is the competition ratio for both crops

LER_a = the LER for sole crop a

LER_b = the LER for sole crop b

ZI_a = yields of intercrop a

ZI_b = yields of intercrop b

Interspecific nutrient competition exists between crops cultivated in an intercropping system. Reduced competition between plants can be achieved by its characteristics such as deep rooting, growing efficiently during off-season, short life cycle and sluggish early development rate. Pigeon pea is known to have a deep root system (Upadhyaya et al. 2012), this trait is vital and could enable the competitiveness of the crop in intercropping systems. Makumba et al (2009) reported that *Gliricidia* and pigeon pea root lengths were 200 cm, longer than maize 130 cm. Deep root system enabled legume crops to extract intensely leached soil nutrients. As a result, these crops were more competitive then the companion crop and produced better yields. According to Kimaro et al. (2009) low interspecific competition between maize and pigeon pea was achieved by the legumes sluggish early development. Competition amongst crops can be moderately reduced by fertilizer application.

3.2 Weed control

One of the most vital component of plant protection is increasing crop potential through weed management. Commercial crops compete with weeds for resources such as nutrients, light and water. The competition imposed by weeds on commercial crops leads to 10 % loses globally every year (Yadollahi et al., 2014). Weed control is crucial in agricultural production. The ability of the crop to with stand competition, suppress weeds and reduce weeds infestation is an important trait; which can ensure good yields and reduce agricultural loses.

Cultural practises such as intercropping have been used in weed control, with good effects. Several researchers have recognised the effect of intercropping legumes with maize in reducing the number of weeds (Silva et al., 2009; Jamshidi et al., 2013). Intercropping maize with cowpea in Brazil was observed to be effective in suppressing weeds (Silva et al., 2009). These weeds were mostly from the Poaceae family and typically annuals. Jamshidi et al. (2013) observed similar results in a study of maize-cowpea intercropping, where intercropping decreased weeds mostly belonging to the Poaceae, Amarantheae and Chenopodiaceae families. Results observed in these studies, indicate that cowpea can be used in intercropping systems to decrease the occurrence of a wide range of weed species. Variation of cowpea in decreasing different weed species could be attributed to the cultivar and genotype of cowpea as well as the planting space used in the study.

Altering planting time and plant density can be effective in reducing weed infestation (Asiwe & Kutu, 2007; Jamshidi et al., 2013). In a study of bambara groundnut, Asiwe & Kutu (2007) observed a decline in weed biomass at narrow spacing than at wide spacing. Gharineh & Moosavi (2010) perceived similar results in canola and bean mixed cropping, conducted under tapered spacing. These results revealed the crops capability to compete well at narrow spacing, thus suppressing weeds. However, reducing spacing between plants in an intercrop can negatively create high competition not only with weeds but to the crops as well. This statement was sustained by findings of Takim (2012) on cowpea-maize intercropping, which showed a decline in maize yield due to competition. Thus, plant density used should aim at decreasing competition between crops, whilst suppressing weeds manifestation.

Apart from efficient resource utilisation maize-legume intercropping can be effective in controlling Striga weeds. Suppression of Striga weeds infestation was observed in mixtures of maize with bambara groundnut, cowpea and soybean (Oswald et al 2002). The intercrop decrease Striga densities, whereas crop yields were not affected. Maize-bean intercropping decreased Striga weed emergence (Midega et al., 2014). These studies revealed that these legumes could have some allelochemical exudation on Striga weeds. Although weeds remain one of the key issues facing farmers, cereal legume intercropping could provide a solution in suppressing certain weeds.

4 Major research gaps identified in literature

As climate change impacts continues to affect agricultural production, adaptations and mitigations are the key features in reducing these effects. Objectives of adaptation and mitigation events should be to lessen vulnerability of agriculture to drought and climate change. Climate change research is required to assist government and organizations in policy making and adaptation processes. Currently the world is dependent on a small number of crop for food security. However, research will provide data on new crop species that could be cultivated successfully under climate change, hence improving world food security.

Although cultivation and production of pigeon pea is done successfully in countries such as India, which leads the world production (Kumar et al., 2011), constrains still exist in South Africa. Bambara groundnut, pigeon pea and tepary beans are legumes with potential of food security and yet little research has been invested in them in the past decades. Recently these legumes have gained some popularity, and more researchers are working on these crops. Currently these crops are cultivated on local landraces; breeding of varieties for agro-ecological purposes is required.

Multiple cropping could be the key technique under climate change, as projections indicate reduction in production area. Research is required about compatibility of different cereal crops intercropped with legumes.

Drought stress is one of the most important crop production constraint. Therefore, further research is required, to gain understanding legumes water use efficiency in intercropping systems. This is essential as the country is facing water scarcity issues.

5 Conclusion

It has been well recognized by several researchers that current trends in CO_2 emissions will continue to cause climate change (NASA, 2015). Projections on climate change also reveal variations in annual precipitation and temperature as well as change in growing season and crop production. Predictions holds many uncertainties, actions need to be taken to enhance mitigation and adaptation processes. Although water availability affects all crop growth, development and influences crop yields, crops adaptation traits are important for optimum production. Plants have complex diverse traits which enable them to be adapted and perform well under low soil moisture. These characteristics include the plants ability to respond quickly under drought through traits such as WUE, RUE and stomatal closure.

With arable land production decreasing, intercropping could play an important role in achieving food security. Multi cropping also has an advantage of suppressing weeds (Jamshidi et al. (2013), enhancing soil fertility and water infiltration (Rusinamhodzia et al., 2012). This is essential for small scale farmers, as they can achieve high yields with little inputs. Though numerous research has been done on these crops, there is still room for further research

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CHAPTER THREE:
WATER USE EFFICIENCY OF DIFFERENT LEGUMES AND MAIZE IN AN INTERCROPPING SYSTEM

Abstract

Water scarcity is one the key constraints in agriculture due to climate change. Drought spells are expected to increase throughout the world. Crop growth and final yield are negatively affected by the decline in water availability. An experiment was conducted at Ukulinga Research Farm to evaluate water use efficiency (WUE) of maize and various legumes in an intercropping system. The experiment was arranged in a randomised complete block design, with three replicates. The treatments were maize intercropped with bambara groundnut, cowpea, pigeon pea and tepary beans. Data was collected at a 14-day interval on all parameters measured (water use efficiency, transpiration, photosynthesis, stomatal conductance and soil moisture). Water use efficiency, stomatal conductance, transpiration and photosynthesis were measured on the second new fully expanded leaf. A significance difference ($P < 0.05$) was observed between intercropping treatment means with regard to stomatal conductance and transpiration. Stomatal conductance of pigeon pea (0.42 mol H_2O m^{-2} S^{-1}) was greater than pigeon pea intercrop (0.18 mol H_2O m^{-2} S^{-1}). Monocrops of pigeon pea (18.32 mol H_2O m^{-2} S^{-1}), cowpea (9.24 mol H_2O m^{-2} S^{-1}) and tepary beans (7.94 mol H_2O m^{-2} S^{-1}) had a high transpiration rate compared to their intercrops. There was a significance difference ($P < 0.05$) between cropping systems treatment means with regards to WUE. Water use efficiency of maize-tepary beans (1.24 µmol CO_2 mol^{-1} H_2O) intercrop was the highest across all cropping system. In pigeon pea and cowpea cropping systems, the stomatal conductance was accompanied by a decline in transpiration rate and an increase in photosynthesis. This translated to an increased WUE of these legumes. Crop agronomic variation observed in the current study is important for plant breeding purposes and requires further research.

Keywords: Bambara groundnut, cowpea, pigeon pea, stomatal conductance, tepary beans

1 Introduction

The decreased water availability negatively affects crop growth and yields. Water is one of the crucial factors affecting plant growth, which reduce crop production and yield. At different growth stages, crops may be exposed to water stress. Thus, it is crucial that plants have adaptive traits. These traits must enable crops to produce optimum yields under stressful conditions. One of such essential characteristic is water use efficiency (WUE).

A significant amount of research has been conducted on WUE of different crops such as maize (Asare et al., 2011), sorghum and sunflower (Moroke et al., 2011) and cowpea (Abdou et al. 2013). Specific plant traits have been attributed to WUE of these crops, which are an essential tool for breeding drought resistant varieties. Thus, such traits could play a crucial role in water management in rainfed agriculture, especially by small-scale farmers. Singh et al. (2012) define WUE as the equilibrium between water loss and CO_2 assimilate in each precise unit area. In agronomy WUE is defined by Tomás et al. (2012) as the overall biomass produced for every component area in relation to used water.

WUE is influenced by various factors such as transpiration rate, soil textural class, irrigation and precipitation (Li et al., 2010; Tolk et al., 2016). At different plant growth stages, WUE varies. Li et al. (2010) attributed that partial root irrigation of maize at tasselling had a positive effect on WUE. The study conducted in cucumber (*Cucumis sativus* L.) revealed a variation in WUE at different plant growth stages (Ikkonen et al., 2015). This suggests that while plants may be exposed to water stress at various growth stages, certain stages are more crucial than others. Hence, if plants experience water stress at these stages, they may be able to utilize water efficiently and produce optimum yields. Tolk et al. (2016) reported that soil textural class effects WUE in crops. These authors also reported higher WUE in fine-textured soils than coarser soils.

There is a close relationship between WUE and stomatal conductance in plants (Efeoğlu et al., 2009). When plants are exposed to water stress, one of the primary responses is stomatal closure (Efeoğlu et al., 2009). This mechanism inhibits further dehydration within the plant. Transpiration rate regulates the amount of water transpired through stomata. Plants that decrease their transpiration rate during water stress are regarded as drought tolerant (Belko et al. (2012).

In South Africa, there is insufficient data reporting water use efficiency of certain legumes such as bambara groundnut, tepary beans and pigeon pea. These legumes have a potential to alleviate food security. Thus, such data could be vital in gaining an understanding of the crops adaptation to climate change and water stress. The objective of this study was to evaluate water use efficiency of maize (*Zea mays*) and various legumes in an intercropping system.

2 Materials and methods

2.1 Site location and experimental design

The study was conducted at Ukulinga Research Farm of the University of KwaZulu-Natal; Pietermaritzburg (29˚37'S; 30˚16'E). A randomized complete block design was used in the experiment, replicated three times. The experiment consists of three blocks with 9 experimental units replicated three times results into 27 experimental units. Each plot measured 15.75 m^2, resulting in a total area of 621 m^2 of land used. The spacing used for maize monocrop was 75 cm between rows and 50 cm within the row. For legumes monocrops, it was 60 cm between rows and 40cm within the row. The spacing of intercropped maize and the legumes was similar to that of the monocrop

2.1.1 Climatic data

The mean rainfall and temperature received during the experimental period (January-June 2016) was not greater than 21 mm per month with an average daily temperature between 15 and 20 °C (Figure 3.1)

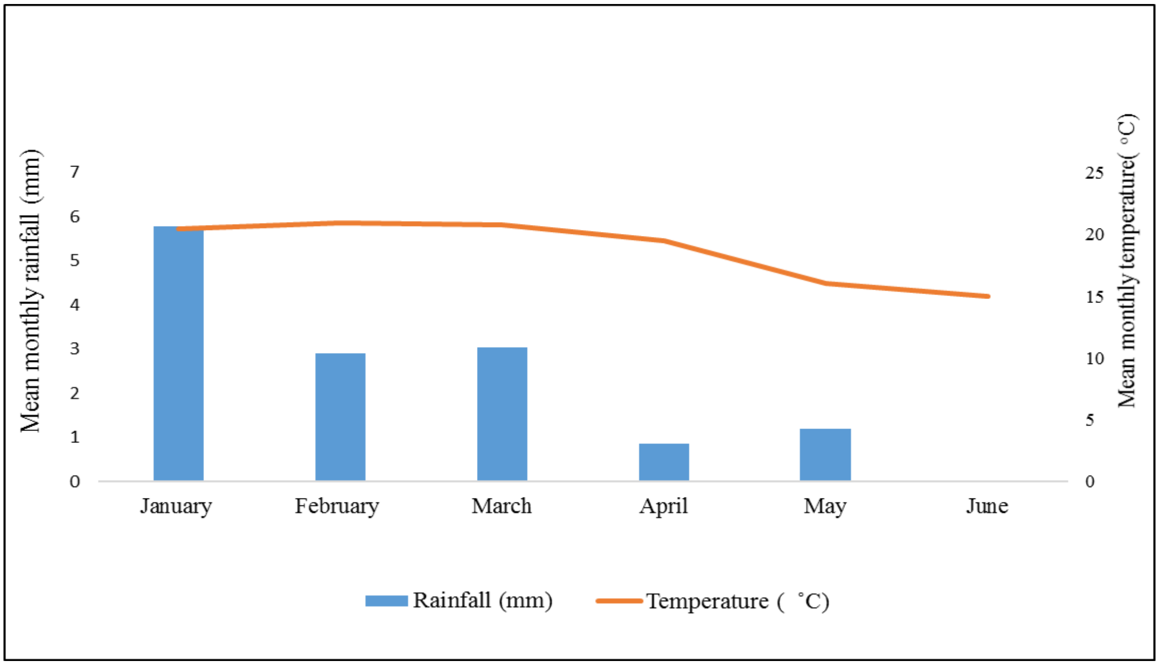

Figure 3.1: Mean monthly temperature and rainfall for the experimental period

There was poor rainfall distribution during the experimental period. Highest precipitation was observed in January and March only. In the remaining months, precipitation peaks didn't exceed 20 mm.

2.2 Field preparation and plant material

Maize hybrid (SC701) was intercropped with cowpea, bambara groundnut, tepary beans and pigeon pea. Maize and cowpea seeds were purchased from Agricol and Pannar seeds, respectively. Seeds of bambara groundnut were obtained McDonald Seeds They were then classified according to seed colour. A red landrace was selected to be used in the study. Seeds of tepary beans and pigeon pea were sourced from the University of Zimbabwe.

A tractor was used to plough the field in preparation for planting. Planting of maize and legume seeds in the field occurred on 25 January 2015. Prior to planting, samples were collected from the top 20 cm of the soil using an auger. The samples were collected randomly in all three blocks. They were mixed thoroughly; a single representative sample was taken for analysis at Cedara laboratory (Cedara, South Africa). Table 3. 1 shows the results of the soil analysis. Fertilizer application was based on soil analysis results. LAN 20 kg/ha was applied at planting and 20 kg/ha was side dressed at five weeks after sowing. Side dressing was applied to maize only. Superphosphate 20 kg/ha was applied at sowing.

Table 3. 1: Soil characteristics of Ukulinga site

Soil properties	**Values**
Bulk density (g/m^3)	1.1
Clay (%)	26
Org. C (%)	2.7
Acid sat. (%)	1.0
pH (KCl)	4.57
N (%)	0.19
P (mg/L)	19.0
K (mg/L)	217

2.3 Data collection and Measurements

Volumetric water content was measured using the HydroSence II (Sensor model CS659 and CS658, Campbell Scientific Inc., Somerset West, South Africa) with 12 and 20 cm rods. Soil moisture measurements were done between and within the row in each plot, then averaged to one data set. In monocrops, measurements were made between and within in each crop rows. In the intercrops, measurements were made between and within maize rows as well as within and between legume rows.

Water use efficiency (expressed in photosynthesis divided by transpiration rates), stomatal conductance, transpiration, photosynthesis, were measured using LI 6400XT portable photosynthesis system (Li-Cor Inc., Lincoln, NE, USA). Measurements in each crop were done on the second new fully expanded leaf (between 10:00 am and 14:00 pm) (SU et al., 2014). In each crop, three leaves were measured, then averaged. For all parameters measured (WUE, transpiration, photosynthesis, stomatal conductance and soil moisture), data was collected at 14-day interval monthly.

2.4 Statistical analysis

Data was subjected to the analysis of variance (ANOVA) using Genstat® statistical software (version 17, VSN International, Hemel Hempstead UK). Fischer's least significance difference (LSD) was used to separate means and significance difference between means was done at $P \leq 0.05$.

3 Results

3.1 Leaf gas exchange

A significant difference ($P < 0.05$) was observed between cropping systems with regards to stomatal conductance. Stomatal conductance of pigeon pea (0.42 mol H_2O m^{-2} S^{-1}) was greater than pigeon pea intercrop (0.18 mol H_2O m^{-2} S^{-1}) (Figure 3.3: There was no significant difference between intercropped and monocrop stomatal conductance of bambara groundnut, cowpea and tepary beans. However, stomatal conductance of pigeon pea (0.42 mol H_2O m^{-2} S^{-1}) was greater than that of cowpea (0.23 mol H_2O m^{-2} S^{-1}), tepary beans (0.19 mol H_2O m^{-2} S^{-1}) and bambara groundnut (0.11 mol H_2O m^{-2} S^{-1}) planted in a monocrop. In the intercropping system, cowpea had the highest stomatal conductance which was greater than that of pigeon pea, tepary beans and bambara groundnut. Intercrops of maize with bambara groundnut had the highest stomatal conductance which was greater than maize in intercrops of pigeon pea, tepary beans and maize monocrops.

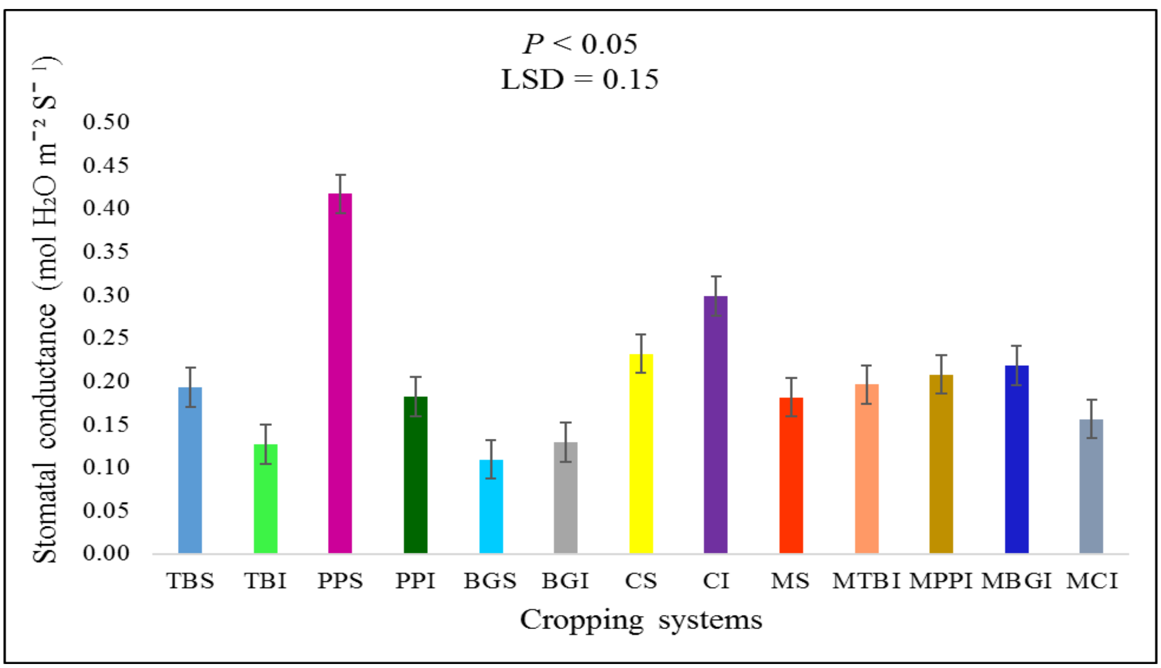

Figure 3.3: Effect of intercropping system on different crops stomatal conductance. LSD: least significance difference.

Key:

TBS: Tepary beans monocrop

PPS: Pigeon pea monocrop

BGS: Bambara groundnut monocrop

CS: Cowpea monocrop

MS: Maize monocrop

TBI: Tepary beans intercrop

MTBI: Maize in tepary beans intercrop

PPI: Pigeon pea intercrop

MPPI: Maize in pigeon pea intercrop

BGI: Bambara groundnut intercrop

MBGI: Maize in bambara groundnut intercrop

CI: Cowpea intercrop

MCI: Maize in cowpea intercrop.

Transpiration rate was significantly (P < 0.05) affected by cropping system. The results of cropping systems are shown in Figure 3.4. Monocrops of pigeon pea (18.32 mol H_2O m^{-2} S^{-1}), cowpea (9.24 mol H_2O m^{-2} S^{-1}) and tepary beans (7.94 mol H_2O m^{-2} S^{-1}) had a high transpiration rate compared to their intercrops. With regards to bambara groundnut there was no significance difference between monocrop and intercrop transpiration rate. With regards to maize transpiration rate, there was no distinct difference (P > 0.05) between maize monocrop and maize in the intercrops of pigeon pea, tepary beans and bambara groundnut. Lowest transpiration rate was observed in intercrops of maize with cowpea (7.23 mol H_2O m^{-2} S^{-1}).

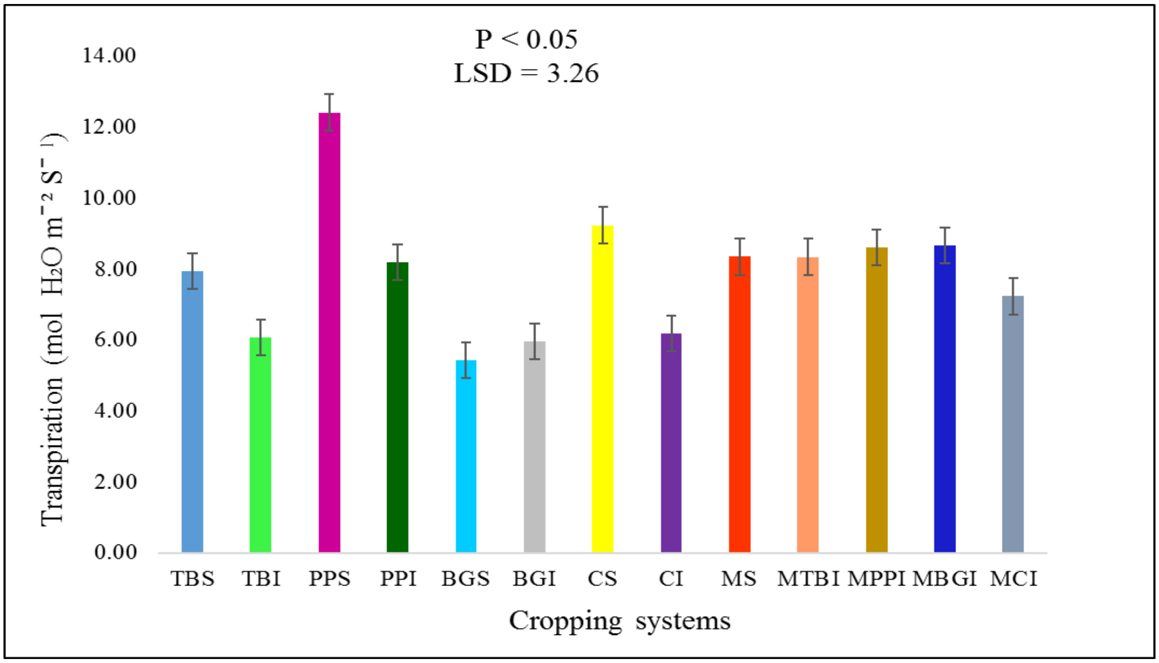

Figure 3.4: Effect of the intercropping system on different crops transpiration. LSD: least significance difference.

The highest rate of photosynthesis was observed in maize (Figure 3.5). The photosynthesis of cropping system was significantly different ($P < 0.05$). With regards to legumes, pigeon pea (12.41 µmol CO_2 m^{-2} S^{-1}) monocrop was observed to have the highest rate of photosynthesis compared to the intercrop. Tepary bean monocrop (6.09 µmol CO_2 m^{-2} S^{-1}) photosynthesis was higher than the intercrop (4.05 µmol CO_2 m^{-2} S^{-1}). There was no significance difference between monocrop and intercrop with regards to cowpea photosynthetic rate. Intercrops of maize with tepary beans photosynthesis (18.88 µmol CO_2 m^{-2} S^{-1}) was greater than maize in intercrops of bambara groundnut, pigeon pea and maize monocrop. Pigeon pea monocrop had the highest photosynthesis rate across all cropping systems. Bambara groundnut monocrop had the least photosynthetic rate.

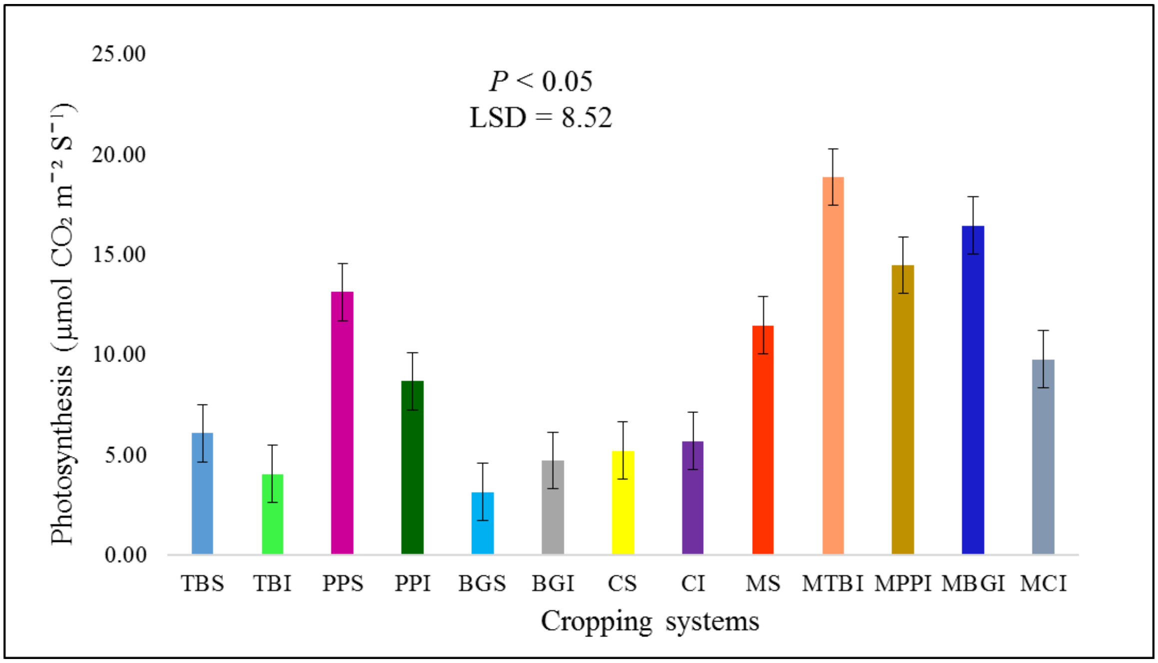

Figure 3.5: Effect of intercropping on photosynthetic rate of different crops. LSD: least significance difference

3.2 Water use efficiency

Cropping systems significantly ($P < 0.05$) affected WUE. In legumes, pigeon pea (1.06 µmol CO2 mol^{-1} H_2O) monocrop had the highest WUE. This WUE was greater than that of cowpea (0.89 µmol CO2 mol^{-1} H_2O), tepary beans (0.58 µmol CO2 mol^{-1} H_2O) and bambara groundnut monocrop (0.46 µmol CO2 mol^{-1} H_2O) (Table 3.2). However, there was no significance difference between monocrop and intercrop WUE in legumes. Maize in the intercrops of tepary beans (1.24 µmol CO2 mol^{-1} H_2O) and bambara groundnut (1.11 µmol CO2 mol^{-1} H_2O) had the highest WUE compared to other cropping systems.

Table 3.2: Effect of intercropping system on WUE of different crops.

Cropping systems	WUE (µmol CO_2 mol^{-1} H_2O)
TBS	0.58b
TBI	0.44b
PPS	1.06a
PPI	1.03a
BGS	0.46b
BGI	0.29b
CS	0.89a
CI	0.93a
MS	0.75a
MTBI	1.24a
MPPI	0.75a
MBGI	1.11a
MCI	1.05a
***P*-value**	0.02
LSD	0.53

Means that share the same letter are insignificant from each other.

LSD: least significance difference

3.3 Soil moisture

Soil moisture was influenced by cropping systems and varied significantly with different soil depths (Table 3.3). A significance difference ($P < 0.05$) between cropping systems at 50 and 80 days after planting (DAP) was observed. At 65 DAP soil moisture at 12 cm depth was insignificant ($P > 0.05$). Pigeon pea (21.95 %) and tepary beans (19.29 %) monocrops had a high soil moisture. This was observed at both soil depths. Soil moisture in maize monocrop ranged between 3.92 and 24.07 %. In the intercrops highest soil moisture value was observed in maize-tepary beans and maize-pigeon pea. Intercrops of maize cowpea had high soil moisture at 50 DAP. Maize-bambara groundnut had the lowest soil moisture at most sampling times and soil depths. Lowest soil moisture was observed in cropping systems of bambara groundnut at certain sampling times and depth. At 50 and 65 DAP, soil moisture at 20 cm was higher than that of 12 cm depth in all cropping systems.

Table 3.3: Effect of cropping systems on soil volumetric water content (%).

Time	Initial		50 DAP		65 DAP		80 DAP	
Depth	**12 cm**	**20 cm**	**12 cm**	**20 cm**	**12 cm**	**20 cm**	**12 cm**	**20 cm**
TBS	17.89a	27.72a	19.29ab	31.74a	16.19a	17.93ab	10.75a	8.19b
BGS	12.08a	33.39a	13.49c	14.77b	10.97a	14.08b	8.21b	7.38b
CS	14.54a	25.54b	15.99b	27.92a	12.72a	15.92ab	8.17b	6.11b
PPS	19.89a	32.47a	21.95a	29.17a	16.07a	20.11a	10.67a	10.85a
MS	12.80a	18.47bc	17.76ab	24.07a	10.14a	10.96b	7.94b	3.92c
MTB	13.88a	22.85bc	20.18a	28.96a	13.89a	19.46ab	9.53ab	5.94b
MBG	12.28a	31.27a	14.60b	16.99b	10.21a	12.6b	5.74c	6.27b
MC	15.96a	24.55bc	14.56b	26.60a	12.92a	17.46ab	9.11ab	8.78ab
MPP	12.07a	23.59bc	20.21a	27.12a	13.70a	18.24ab	9.24ab	12.20a
***P*-value**	0.29	0.004	0.001	0.018	0.28	0.02	0.04	0.03
LSD	7.22	6.77	3.77	9.31	5.8	5.2	1.91	3.53

Means that share the same letter within the same column are not significantly different from each other. LSD: least significance difference.

4 Discussion

The decrease in stomatal conductance could be due to the plant's response to drought. Muhammad et al. (2015) reported that bambara groundnuts close their stomata as drought response mechanism. Our results are similar to those observed by Cardona-Ayala et al (2013) in cowpea genotypes. The authors reported a decrease in stomatal conductance of cowpea under water stress. Stomatal closure effects transpiration and photosynthesis. In the present study decrease in transpiration rate observed in tepary beans and bambara groundnut could be due to the closure of stomata. Muhammad & Massawe (2015) observed a decrease in stomatal conductance, transpiration rate and photosynthesis in bambara groundnut under drought conditions. Similarly, Mohamed et al (2002) reported that high yielding tepary bean lines decrease their stomatal conductance when exposed to drought. This suggest that plants first response to water stress is through stomatal closure. This minimize the amount of water loss by the plant.

Pigeon pea conducted the stomata and transpiration well, which resulted in high photosynthesis. This occurred during the planting season where there was poor rainfall. Similar results were observed by Wilson et al. (2012) in pigeon pea. A decrease in transpiration rate prevents further water loss within the plant. This is an important drought adaptation trait in plants. Pigeon pea known to perform well under arid and semi-arid conditions (Wilson et al., 2012). Such adaptation traits are vital for plant breeding purposes.

In crops there is a correlation between photosynthesis and yields (Anyia & Herzog, 2004). In intercropped legumes decreased photosynthesis rate could be due to shading by the maize crop. Su et al. (2014) reported that maize shading negatively affected soybean photosynthesis. Bambara groundnut has the lowest photosynthesis, which indicates that they are sensitive to shading. Similarly, Lima Filho (2000) reported a decrease in photosynthesis of cowpea due to maize shading. The decrease in photosynthesis due to shading can negatively affect final yields at harvest. Su et al. (2014) reported a decrease in soybean yields by 32.8 % due to maize shading. Therefore, selecting the right spacing in an intercropping. This will ensure that there is less competition between species as well as reduce shading of the understory crop by the taller plant.

Biomass accumulation is dependent on WUE (Anyia & Herzog, 2004). In plants, photosynthesis is closely related to biomass production (Wilson et al., 2012). With regards to legumes, pigeon pea had the highest photosynthesis and low transpiration rate This translated to a higher WUE compared to the other legumes. Current results are different to those observed by Vimalendran & Latha (2014) in pigeon pea. The variation in WUE could be due to planting dates. Wilson et al. (2012) reported that WUE in pigeon pea increased and decreased with early and late planting, respectively. Genetic variation has been reported to affect crop WUE. For instance, Singh & Reddy (2011) reported genetic variation in cowpea WUE. Photosynthesis influences variation in WUE. According to Singh and Reddy (2011), an increase in photosynthesis induces an increase in WUE.

The greatest WUE observed in maize in intercrops of tepary beans and bambara groundnut suggest that these crops are compatible in the intercropping system. Decreasing competition for growth resources between crops in an intercropping system is vital for increasing WUE. Miriti et al. (2012) reported that maize and cowpea intercrops had low WUE caused by competition for nutrients and water. The highest WUE observed in this study indicates that the crops were able to utilize available water efficiently.

As reported by Sekiya &Yano (2004) intercrops of maize and pigeon pea had a root system that was denser and overlapping each other. Mohamed et al. (2005) reported that tepary bean had a thick root system that can be 48.4 cm in length. Similarly, Mohamed et al. (2002) observed a root length greater than 50 cm in tepary beans. This root system extracts better water in deeper soil layers. Pigeon pea is known to have a profound root system, while for maize is characterized by shallow roots (Makumba et al., 2009). This indicates that the competition between maize and pigeon pea as well as maize and tepary beans for soil water was nominal. The variation root architecture plays important role in the intercropping systems with regards to soil moisture.

5 Conclusion

In pigeon pea and cowpea cropping systems, the stomatal conductance was accompanied by a decline in transpiration rate and an increase in photosynthesis. Hence, an increased WUE of these legumes. Crops with stomatal resistance are known to be adapted to drought conditions. Legumes presented with certain adaptation traits, which enable them to perform well under stress conditions. It is vital for crops to be able to use water effectively while producing optimum yields. High soil moisture was observed in cropping systems of pigeon pea and tepary beans. The root traits of these legumes could be responsible for high soil moisture. Therefore, different root architecture is important in intercropping systems, to ensure exploration of large soil water volumes. In monocrops the best cropping systems were cowpea and pigeon pea as they had the highest WUE. In the intercrops the best cropping system was maize-pigeon pea and maize-tepary beans. This was concluded based on high WUE and soil moisture. Current results suggest that intercropping maize with legumes is beneficial in using water efficiently. This because different crop species will access water at various soil depth with less competition.

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CHAPTER FOUR

EVALUATING AGRONOMIC PERFORMANCE OF MAIZE INTERCROPPED WITH VARIOUS GRAIN LEGUME CROPS

Abstract

The population in the Sub-Saharan Africa is continuously increasing and is projected to increase by 22 % in 2050. This is projected to have significant effect on land available for crop production as well as food security. Therefore, to maintain crop diversity and increase productivity within limited land, agronomic practices such as intercropping is suggested as a solution. An experiment to gain understanding of different legumes response when intercropped with maize was conducted at Ukulinga Research Farm of the University of KwaZulu-Natal in Pietermaritzburg. The experiment was arranged in a randomised complete block design with three replicates. The treatments were monocrops of maize bambara groundnut, pigeon pea, cowpea and tepary beans as well as maize intercrops with each of these legume crops. Data of the following parameters was collected: seedling emergence, days to 50% flowering, grain yield and pod mass. Competition indices were calculated to assess the efficiency of the intercropping system. These were land equivalent ratio (LER), competition ratio (CR), relative crowding, aggressivity (A) and actual yield loss (AYL). There was a significance difference ($P < 0.05$) between cropping systems with regards to grain yield (kg ha^{-1}). The highest grain yield was observed in intercrop of maize with cowpea (2095 kg ha^{-1}), which was greater than of maize-tepary beans (2003 kg ha^{-1}), maize-bambara groundnut (1917 kg ha^{-1}) and maize monocrop (1847 kg ha^{-1}). There was a significance difference ($P < 0.05$) with regards to crop competition indices (LER, CR, A). The LER of maize intercropped with cowpea (1.72) was greater than of maize intercropped with bambara groundnut (1.55), tepary beans (1.51) and maize monocrop (0.97). A similar trend to that of LER was observed in relative crowding. Intercrops of maize with cowpea and tepary beans were the best cropping systems. This implies that these cropping systems were able to efficiently utilise resources such as nutrients, light and water. The reasons for their good performance needs further research.

Keywords: bambara groundnut, cowpea, pigeon pea and tepary beans

1 Introduction

The population in the Sub-Saharan Africa is high, with a projected increase of 22 % by 2050 (OECD/FAO, 2016). As a result, the land size available for small scale farmers is declining (Fuglie & Rada, 2013; Jayne et al., 2014). Furthermore, the increasing population and the demand for food production has resulted in the cultivation of more arid land (Singh et al., 2016; Small, 2014). Maize (*Zea mays*) is a staple crop that forms part of the daily human diet in most parts of the African continent (Ogindo & Walker, 2005). In South Africa, annual maize productions have remained constant over the past decade (DAFF, 2013). This poses major concerns as to whether existing productions will be able to meet the demands of the increasing population.

Cultivation practices such as intercropping, that conserve the environment whilst producing good yields are required. Intercropping is a practice that involves cultivating numerous crops in one field, within the same growth season (Ouma & Jeruto, 2010; Sandler et al., 2015). Diverse intercropping systems exist and are practiced in different countries throughout the world. Maize-legume intercropping is a common cropping system practiced mostly by small-scale farmers in the African continent (Oswald et al., 2002; Marer et al., 2007; Rusinamhodzi et al., 2012). In Mozambique, small-scale farmers usually intercrop maize with cowpea or pigeon pea (Rusinamhodzi et al., 2012). Intercropping maize with cowpea (*Vigna unguiculata* (L.) Walp), bambara groundnut (*Vigna subterranea* (L.) Verdc) and dry beans (*Phaselous vulgaris*) has been reported in countries such as Nigeria, Kenya and South Africa (Tsubo et al., 2004; Miriti et al., 2012; Dania et al., 2014). Intercropping legumes with cereals could be beneficial in providing the companion crop with nitrogen (N) (Wang et al., 2014; Mohale et al., 2014), thus decreasing the amount of synthetic fertiliser used.

Cereal-legume intercropping is beneficial due to the legume supplying most of its nitrogen. This occurs as a result of biological nitrogen fixation, achieved through a symbiotic relationship between the crop and specific Rhizobium (Mohale et al., 2014). Soil N is made available for the following crop. An increase in soil fertility was observed in an intercrop of maize, wheat with faba beans (Wang et al., 2014). These authors reported that benefits of the intercropping system were perceived after a decade, in terms of soil chemical properties. Researchers in different parts of the world have attributed that intercropping maize with legumes, such as bambara groundnut (Mohale et al., 2014), cowpea (Dahmerdeh et al., 2010) and pigeon pea (Dania et al., 2014) as successful means of bio-fertilization in small scale farmers. Intercropping cereal crops such as maize with leguminous crop such as pigeon pea is advantageous as it increases yields, land equivalent ratio (LER), water use efficiency, solar energy and soil nutrients (Long et al., 1999; Rusinamhodzi et al., 2012). The effectiveness of the intercropping system is measured through competition indices such as LER, competition ratio (CR) and Aggressivity (A) (Dhima et al., 2007; Yilmaz et al., 2008; Hirpa, 2014).

The LER determines the efficiency of intercropping versus the monocrop. An LER greater than one indicates an advantage, whereas if it is less than one, it is a disadvantage to the cropping system. Alhassan & Egbe (2014) observed an advantageous intercropping in Nigeria. High LER and Land equivalent coefficient (LEC) obtained in maize-bambara groundnut intercropping compared to monocrop. This indicated that the intercropping was effective. However, plant densities may affect yield as well as LER in intercropping. Although, an LER can indicate the efficiency of the intercropping, other measures such as competition ratio may be used.

Competition ratio give an indication of the individual species competitiveness in the intercrop. This trait is vital in crops for producing optimum yields. Competition ratio when used together with LER, can give the best indication of the intercropping advantages.

There is limited information about crop yield of bambara groundnut, pigeon pea and tepary beans available in South Africa. These grain legumes have been neglected in the past because the research focus in the country was mainly directed to the cultivation of dry bean. Therefore, there is a need for legumes as a source of N in small-scale farms in order to reduce N fertilization and also improve crop productivity per unit area of high protein and high carbohydrate source. To sustain crop diversity, intercropping is recommended as a solution. Thus, such data could be valuable to small scale farmers who have limited land and are unable to grow a variety of crops. The objective of the study is to gain understanding of different legumes response when intercropped with maize

2 Materials and methods

2.1 Experimental design and site description

The experiment was arranged in a randomised complete block design with three replicates. The experiment consists of three blocks with 9 experimental units replicated three times results into 27 experimental units. Field experiments were conducted at Ukulinga Research farm, at the University of KwaZulu-Natal; Pietermaritzburg (29˚37'S; 30˚16'E). Each plot was 15.75 m^2 resulting in a total area of 621 m^2. Maize was planted using the spacing of 75 cm and 50 cm between rows and within the row, respectively. The spacing used for the legumes was 60 cm between rows and 40cm within the row. The same spacing was used for the intercropping.

Climatic data is shown in Table 4.1 and revealed poor precipitation over the six months' period. Total rainfall received during the experimental period was 314.8 mm.

Table 4.1: Mean monthly climatic data for the cropping season

Months	Rainfall (mm)	Temperature (°C)	Relative humidity (RH)	Wind speed ($m\ s^{-1}$)
January	5.79	20.49	87.27	1.93
February	2.90	20.96	84.08	2.05
March	3.03	20.77	84.07	1.68
April	0.85	19.47	77.74	1.64
May	1.19	16.06	72.29	1.54
June	0.00	14.99	61.44	1.68

Average total monthly rainfall received was low and the distribution was poor. Highest and lowest rainfall was observed in January and June, respectively. While precipitation received during the experimental period was low, temperatures and relative humidity on the other hand were relatively high.

2.1.1 Plant material

Planting of maize and the legumes occurred on the 25th January 2015. Maize was intercropped with bambara groundnut, pigeon pea, cowpea and tepary beans (*Phaseolus acutifolius*). Bambara groundnut seeds were purchased from Mc-Donald seeds. Seeds were classified according to colour; red landrace was used in this experiment. Seeds of tepary beans and pigeon pea (*Cajanus cajan* (L.) Millsp landrace were obtained from the University of Zimbabwe. Cowpea seeds used was purchased from Agricol. Maize hybrid (SC701) seeds were purchased from Pannar Seeds.

2.1.2 Field preparation

Field preparation by ploughing using a tractor. Soil samples were collected prior to planting. Samples were sent to Cedara laboratory (Cedara, Pietermaritzburg, South Africa) for analysis. The soil results are illustrated in Table 4.2. Fertilizer application was done based on soil results. Maize received 20 kg/ha of LAN and 20 kg/ha of superphosphate at planting. Another 20 kg/ha of LAN was applied as a top dressing five weeks after planting. Legumes received 20 kg/ha and 20 kg of LAN and superphosphate at planting, respectively.

Table 4.2: Soil characteristics of the experimental site and Ukulinga Research Farm.

Soil properties	values
Bulk density (g/m^3)	1.1
Clay (%)	26
Org. C (%)	2.7
Acid sat. (%)	1.0
pH (KCl)	4.57
N (%)	0.19
P (mg/L)	19
K (mg/L)	217

2.2 Data collection

Seedling emergence of maize and legumes was counted for 30 days, from 5 days after planting (DAP). For each legume, days to flowering, number of pods per plant and number of seed per pod was determined. Above ground biomass of maize and legumes at harvest was oven dried at 60 °C for 72 hours and weighed for dry mass. This was used to determine yield and other agronomic parameters. At the time of research termination, pigeon pea was at pod filling stage. It didn't reach full maturity. Therefore, yields and other agronomic measurements are not reported in this chapter.

2.3 Competition indices

The following five competition indices were calculated to assess the efficiency of the intercropping system:

The LER of a maize-legume intercropping system was computed using Eq. 1 defined by Hirpa (2014).

$$LER = \frac{Y_{ml}}{Y_m} + \frac{Y_{lm}}{Y_l} \qquad (1)$$

Where:

Y_m and Y_l are the yields of monocrop maize and legume, respectively. Y_{ml} and Y_{lm} are the yields of maize and legume in intercrops, respectively. An LER greater than one indicates the intercrop effectiveness, while that less than one designate a disadvantage (Dhima et al., 2007). The competition between species in the intercropping system was evaluated using Eq. 2 and 3 as described by Dhima et al. (2007)

$$CR_{maize} = \frac{LER_m}{LER_l}\ x\ \frac{Z_{lm}}{Z_{ml}} \qquad (2)$$

$$CR_{legume} = \frac{LER_l}{LER_m}\ x\ \frac{Z_{ml}}{Z_{lm}} \qquad (3)$$

Where:

CR_{maize} and CR_{legume} is the competition ratio for both crops. LER_m and LER_l are the LERs for monocrop maize and legume, respectively. Z_{lm} and Z_{ml} are the proportions of maize and legume in the intercrop. To assess the dominance of one species over the other, Relative crowding was used as described by Yilmaz et al. (2008) using Eq. 4.

$$K = K_{maize} x\ K_{legume} \qquad (4)$$

Where: $K_{maize} = \frac{Y_{ml}\ x\ Z_{lm}}{(Z_m - Y_{ml})Z_{ml}}$

And

$K_{legume} = \frac{Ylm\ x\ Zml}{(Yl - Ylm)Zlm}$

Aggressivity (A) was calculated using Eqs. 5 and 6 as described by Banik (1996)

$$A_{legume} = \frac{Y_{lm}}{Y_l\ x\ Z_{lm}} - \frac{Y_{ml}}{Y_m\ x\ Z_{ml}} \qquad (5)$$

and

$$A_{maize} = \frac{Y_{ml}}{Y_m\ x\ Z_{ml}} - \frac{Y_{lm}}{Y_l\ x\ Z_{lm}} \qquad (6)$$

The competitive relationship between two species is determined using the aggressivity. When Alegume is positive, the legume is the dominant crop in an intercrop. When Alegume is negative, the maize is the dominant crop in the intercrop. If Alegume and Amaize equals to zero, both crops are equally competitive. Actual yield loss (AYL) was calculated using Eq. 7 (Banik, 1996)

$AYL = AYL_{maize} + AYL_{legume}$ (7

Where:

$AYL_{maize} = \left(\frac{Y_{ml}/Z_{ml}}{Y_m/X_m}\right) - 1$

and

$AYL_{legume} = \left(\frac{Y_{lm}/Z_{lm}}{Y_l/X_l}\right) - 1$

Y_m and Y_l are yields of monocrop maize and legume. Y_{ml} and Y_{ml} are yields of maize and legume in intercrops. Z_{ml} and Z_{lm} are sown proportions of maize and legume in an intercrop. A positive and negative AYL indicates an intercropping advantage and disadvantage, respectively.

2.4 Statistical analysis

Data was subjected to analysis of variance (ANOVA) using Genstat® version 17 (VSN International, Hemel Hempstead UK) statistical software. Fischer's least significance difference (LSD) was used to separate means at $P \leq 0.05$.

3 Results

Highest seedling emergence percentage was observed in cowpea monocrop (96.3 %) (Figure 4. **1**). There was a significance difference ($P < 0.05$) between cropping systems with regards to percentage seedling emergence.

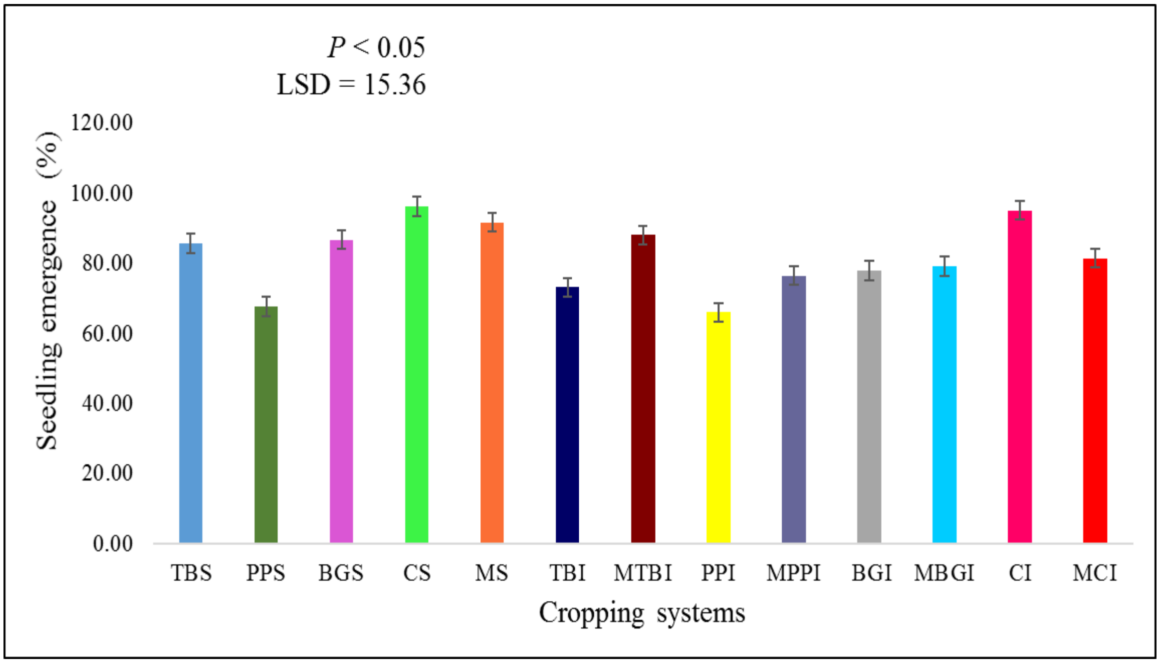

Figure 4. 1: Percentage seedling emergence of different crops. LSD: least significance difference.

Key:

TBS: Tepary beans monocrop

PPS: Pigeon pea monocrop

BGS: Bambara groundnut monocrop

CS: Cowpea monocrop

MS: Maize monocrop

TBI: Tepary beans intercrop

MTBI: Maize in tepary beans intercrop

PPI: Pigeon pea intercrop

MPPI: Maize in pigeon pea intercrop

BGI: Bambara groundnut intercrop

MBGI: Maize in bambara groundnut intercrop

CI: Cowpea intercrop

MCI: Maize in cowpea intercrop.

In the intercrop, cowpea had the highest percentage of seedling emergence (95.2 %). The percentage seedling emergence of maize in intercrops of bambara groundnut and cowpea was similar. Lowest, seedling emergence percentage was observed in pigeon pea both in monocrop and intercrop.

There was a significance difference ($P < 0.05$) in the number of days to 50 % flowering of crops. Tepary beans reached 50 % flowering in 45 days (Figure 4. 2). However, there was no difference in days to 50 % flowering of bambara groundnut and cowpea. The longest time for 50 % flowering was observed in pigeon pea.

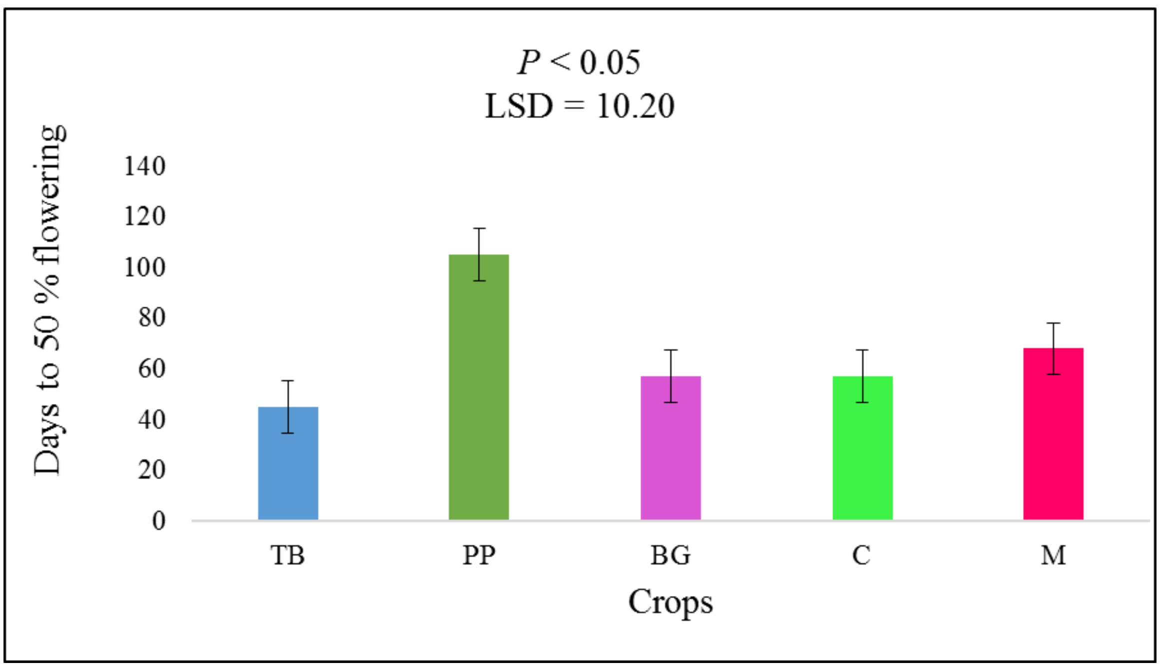

Figure 4. 2 : Effect genotype on days to 50 % flowering of tepary beans, bambara groundnut, cowpea and maize. LSD: least significance difference.

Key:

TB: Tepary beans

PP: Pigeon pea

BG: Bambara groundnut

C: Cowpea

M: Maize

A significance difference ($P < 0.05$) was observed between cropping system, with regards to grain yield and harvest index. In legumes, the highest grain yield was observed in cowpea (568 kg ha^{-1}) monocrop, which was greater than tepary bean (415 kg ha^{-1}) and bambara groundnut (267 kg ha^{-1}) monocrops (Table 4.3). The trend is similar in the legume intercrops. Intercrops of maize-cowpea (2094.6 kg ha^{-1}) had the highest grain yield. This yield was greater than of maize-tepary beans (2003.0 kg ha^{-1}), maize-bambara groundnut (1917.1 kg ha^{-1}) and maize-monocrop (1847.3 kg ha^{-1}). With regards to maize, current results indicate that grain yields of maize in intercrops of pigeon pea, tepary beans and bambara groundnut were not affected by the cropping system. In legume, grain yield was affected by the cropping system.

Table 4.3: Effect of cropping system on crop grain yield and harvest index of maize, tepary beans, bambara groundnut and cowpea

Crops	**Grain yield kg ha^{-1}**	**HI**
TBS	415.00bc	0.75a
BGS	267.00c	0.67ab
CS	568.00b	0.57b
MS	1847.30a	0.41b
TBI	268.00c	0.62a
MTBI	1735.00a	0.43b
BGI	221.00c	0.71a
MBGI	1696.10a	0.32bc
CI	462.00b	0.49b
MCI	1632.60a	0.43b
***P*-value**	< 0.05	< 0.001
LSD	254	0.17

Means that share the same letter are not significantly different from each other.

With regards to legumes, the highest HI was observed in tepary bean monocrop (0.75) (Table 4.3). A significance difference ($P < 0.05$) was observed between cropping systems in HI. The HI of tepary beans was greater than bambara groundnut (0.67), cowpea (0.57) and maize (0.41) monocrops. Maize had the lowest HI across all cropping systems, which was less than 0.50. Across all cropping systems the highest and lowest HI was observed in tepary beans monocrop and maize in cowpea intercrops.

In monocrop legumes, bambara groundnut had a significantly higher hundred seed mass (38.54 g), which was followed by cowpea (15.47 g) and lastly tepary bean (8.39 g). The trend was similar in the intercrops (Figure 4. 3). There was a significance difference ($P < 0.05$) in legumes 100 seed mass. The intercropping system had an effect on hundred seed mass of legumes. Seed mass was superior in monocrops compared to intercrops.

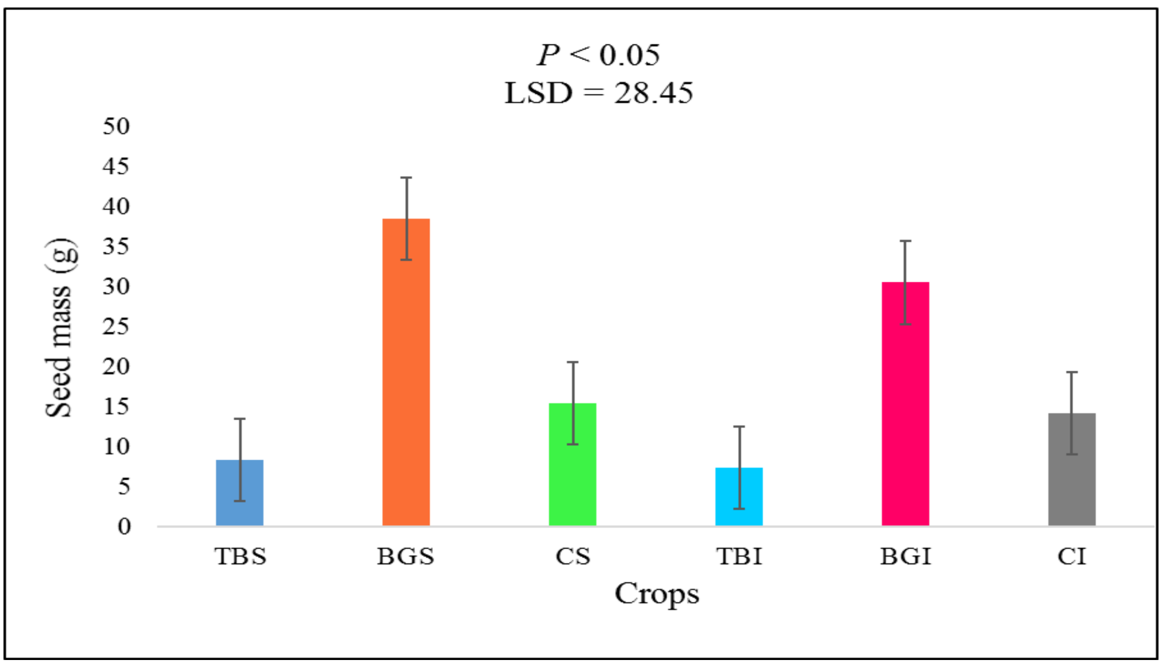

Figure 4. 3 : Effect of cropping systems on one hundred seed mass of legumes. LSD: least significance difference.

The number of pods per plant and number of seeds per pod were significantly different ($P < 0.05$). there was a significance difference in the number of pods per plant between tepary beans monocrop

(61.17) and intercrop (267.00). There was no significance difference between the intercrops and monocrops of bambara groundnut and cowpea with regards to number of pods per plant (Table 4.4). The number of seed per pod of cowpea (13.08) monocrop was not significantly different to that of intercrop (12.67). A similar trend was observed in bambara groundnut and tepary beans. With regards to the number of seed per pod there was no significance difference between monocrops and intercrops of bambara groundnut, cowpea and tepary beans. However, all legumes monocrops had highest number of seeds per plant than the intercrop. Bambara groundnut was observed to have the lowest number of seed per pod compared to the other legumes.

Table 4.4: Effect of cropping systems on the number of seed per plant and number of seeds per pod of legumes

Crops	Number of pods per plant	Number of seeds per pod
TBS	61.17a	4.54b
BGS	14.58bc	1.27c
CS	25.58b	13.08a
TBI	27.00b	4.48b
BGI	8.22c	1.02c
CI	20.08b	12.67a
***P*-value**	< 0.001	< 0.001
LSD	10.29	1.81

Means that share the same letter are not significant different from each other. LSD: least significance difference.

All intercrops had an LER greater than one (Table 4.5), while for monocrop crops it was less than one. A significance difference ($P < 0.05$) between competition indices (LER, CR, A) of the cropping system was observed. The most efficient intercrop was maize and cowpea which had an LER of 1.72. For legumes, the highest competition ratio was observed in bambara groundnut (9.71) and the least was in cowpea (4.93). There was no distinct difference in the competition ratio of maize intercropped with tepary beans and cowpea. Legumes (tepary beans & cowpea) had a positive aggressivity, compared to the bambara groundnut which was negative. A negative aggressivity was perceived in maize. This showed that the legumes were the most dominant species in the intercrop. Intercrops of maize with tepary beans had a positive actual yield loss, while those of maize and bambara groundnut was negative. In legumes the partial yield loss was between 7 and 50 %, where as in maize it was 5-45 %. However, in the intercrop, a positive yield was observed in maize tepary bean intercrop.

Table 4.5: Competition indices of tepary beans, bambara groundnut, cowpea and maize

Crop	Land equivalent ratio	Competition ratio	Aggressivity	Relative crowding	Actual yield loss
TB: M	0.57	5.27	1.84	5.44	0.10
BG: M	0.63	9.71	-4.11	12.79	-0.07
C: M	0.83	4.93	1.59	13.50	-0.50
MS	0.97				
M: TB		0.42	-3.09	0.81	-0.05
M: BG		0.27	3.28	0.82	-0.45
M: C		0.45	-1.76	0.53	-0.23
M + TB	1.51			2.92	0.05
M + BG	1.55			9.42	-0.52
M + C	1.72			1.07	-0.72
***P*-value**	< 0.001	< 0.05	< 0.05	> 0.05	
LSD	0.22	1.20	2.63	25.24	

LSD: least significance difference.

4 Discussion

High seedling emergence is important in crops, as it influences final yield. Current results are comparable to those of Touré et al. (2012) in bambara groundnut. However, they are dissimilar to those observed by Tayyab et al. (2015) in pigeon pea. These authors reported a seedling emergence above 90 % in pigeon pea. The alteration could be attributed to the hereditary variation between and within species. Under dryland cropping, high seedling emergence is important for optimum yields.

In the present study bambara and cowpea took 57 days to reach 50 % flowering. These results are similar to those reported by Abu & Buah (2011) in a bambara groundnut study conducted in Ghana, where days to flowering was between 51 and 68 for different landraces. However, distinct results were previously reported by Berchie et al. (2010), where early maturing bambara groundnut were evaluated in Ghana. The study revealed that bambara groundnut took 40 days to reach 50 % flowering. The results of pigeon pea are analogous to those observed by Singh et al. (2016) in a pigeon pea study conducted in India. The difference could be due to genetic variation and environmental conditions. Current results indicate that tepary beans is early maturing; bambara groundnut and cowpea are medium maturity; while pigeon pea is medium to late maturity.

Our results of grain yield are similar to those reported by Baldé et al. (2011) in Brazil. The authors reported that maize yields were not significantly affected by intercropping maize with pigeon pea and brachiaria. Nevertheless, opposing results were observed by Lingaraju et al. (2008) in a maize-pigeon pea intercropping in Karnataka. Researchers reported that yields of monocrop maize crop were greater than those of intercrop. However, yield of combined maize and legume in intercrops was greater than the monocrops. The decrease in yields of legume intercrops could be attributed to the cereal crop. Maize is a taller crop, the canopy shaded the legume. This might have triggered a reduction in light interception. Thus, a decline in photosynthesis rate and consequently reducing yields of legumes.

Harvest index is one of the essential measures in agronomy. It provides an indication of the potential yields in crops. The HI of legumes was greater than that of maize both in monocrop and intercrops. An average HI of 0.40 is indicative of the crops physiological adaptation to the environmental conditions. Bhardwaj et al. (2002) reported that tepary beans was adapted to the environmental conditions in Virginia as the HI was 0.47. The legumes had the uppermost HI compared to maize, which indicates they more adapted to Pietermaritzburg agro-climatic conditions.

Current results of tepary beans 100 seed mass is similar to those of Edje & Dlamin (2015). However, they are in contrast to those perceived by Hirpa (2014) in intercrops of haricot bean and maize. Variation in seed mass could be attributed to the plant population and the ratio of the legumes occupying the cropping area in intercrops. Prasad et al (2014) reported that plant density affected pigeon pea gran mass.

In Nigeria, Alhassan & Egbe (2014) reported comparable results in a maize-bambara groundnut intercropping experiment. However, contrasting results were observed by Hirpa (2014) in maize-haricot bean intercrop in Ethiopia, where the number of pods per plant in intercrops was greater than in monocrop crops. The difference in the number of pods per plant in these legumes could be attributed to interspecific competition for growth resources such as nutrients, water and light, between the maize and legumes. The number of pod per plant and seed per plant influences the final grain yield. High number of pod per plant in cowpea monocrop and intercrop was accompanied by high number of seeds per plant. This resulted in high yields. These yields were high compared to other legumes. Bambara groundnut on the other hand had the lowest number of pods per plant as well as number of seeds per plant. This resulted in low grain yield in bambara groundnut.

The competition ratio in the present study illustrates that the legumes were more competitive than the maize. Bambara groundnut was more competitive than the other legumes. Present results are different to those of Alhassan & Egbe (2014) in maize-bambara groundnut intercropping. In the study, maize was more competitive than the bambara groundnut. Our results of aggressivity further confirms the intercropping advantage. Present results indicate that the legumes were the utmost competitive and dominant crops in the intercropping system. The intercropping effectiveness was observed through the competition indices (LER, CR & A). The LER of intercrops was greater than one which indicates a positive effect of intercrop. The results of the present study are similar to that of Hirpa (2014) on maize haricot bean intercrop. The author revealed that intercrops were more effective than monocrops. The relative crowding of maize in intercrops of tepary beans and cowpea, additional indorses the advantage of these intercropping systems. This indicated that the crops were able to efficiently use all growth resources.

5 Conclusion

High seedling emergence was observed in cowpea which was followed by tepary beans. This translated into high yields observed in these legumes. Tepary reached 50 % in a shortest period of time (days). This indicates that optimum yields can be produced in a short period of time by growing tepary beans. The results of this study revealed that intercropping maize with tepary beans and cowpea had an advantage over monocrop cropping. This was evident through grain yield, and competition indices. Legumes were perceived to be more competitive than maize. All intercrops produced an LER greater than one. Intercrops of cowpea and maize produced the highest and LER compared to other intercrops. Additionally, maize and tepary bean intercrop showed a yield gain. Therefore, under droughtconditions optimum production and effective utilization of resources such as water and nutrients, can be achieved through intercropping maize with tepary beans and cowpea.

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

1 Key findings

Current results revealed that pigeon pea monocrop and intercrop had high photosynthesis and low transpiration rate. A similar trend was observed in cowpea cropping systems. Cropping systems of bambara groundnut, tepary beans had an opposite behavior as they had high transpiration rate and low photosynthesis. Cropping system of maize had high photosynthesis and low transpiration rate. These results affected the WUE of these cropping systems.

Water use efficiency is an important drought adaptive trait in plants. WUE is influenced by photosynthesis and transpiration as well as available soil moisture. The highest WUE was observed in pigeon pea monocrop, maize-tepary bean and maize-bambara groundnut intercrops. An increase in photosynthesis and a decrease in transpiration rate will results in high WUE. Therefore, it is important for plants to transpire less while have a high photosynthetic rate. Genetic variation between and within species exist and affects WUE.

Plant root traits are important as a drought adaptation trait mechanism. Soil moisture was influenced by cropping systems and varied at different soil depth. High soil moisture was observed in the cropping system of pigeon and tepary bean both monocrop and intercrop. Cropping system of bambara groundnut had lowest soil moisture at different soil depths. Root architecture played an important role in extracting water and reducing competition between crops in an intercropping system.

Tepary bean had the shortest time with regards to days to 50 % flowering. This translated into high yields observed in these legumes. Early flowering in plants is an important characteristic which indicates early maturity. Due to climate change it is important for plants to mature early whilst producing good yields. Tepary beans is a drought escaping crop and matured in 65 days. In the current study grain yield of cowpea was significantly not affected by the cropping system. Tepary beans and bambara groundnut were affected by the cropping systems as yields of monocrop were higher than that of intercrop. Maize-cowpea intercrops had the highest grain yield, which was greater than maize-tepary beans, maize-bambara groundnut and maize-sole.

The competition ratios in the present study revealed that the legumes were more competitive and more dominant than the maize. The most efficient intercrop was maize and cowpea which had the highest LER. Bambara groundnut was more competitive than the other legumes. Our results of aggressivity further confirms the intercropping advantage. Legumes (tepary beans & cowpea) had a positive aggressivity, whilst for maize it was negative. In legumes the partial yield loss was between 7 and 50 %, where as in maize it was 5-45 %. The relative crowding of maize in intercrops of tepary beans and in cowpea, additional indorses the advantage of the intercropping systems. This indicates that the crops were able to efficiently use all growth resources.

2 Conclusion

Seedling emergence in plants effects yields at harvest. Cowpea and tepary beans had the highest seedling emergence. Early flowering plants mature early. The shortest days to 50 % flowering was observed in tepary beans which matured within 65 days. This was early compared to other crops in the experiment. This indicates that under unfavourable conditions optimum yields can be produced in a short period of time. This crop also allows for optimum use of the land especially where farmers have a small farming area. Planting this legume which matures early will allow for relay cropping.

Agriculture currently consume more water than any other sector. With climate change projection indicating variations in mean precipitation. Identifying crops that can perform well under unfavorable weather conditions is important. In pigeon pea and cowpea cropping systems, the stomatal conductance was accompanied by a decline in transpiration rate and increase in photosynthesis. Hence, an increased WUE of these legumes.

High soil moisture was observed in cropping systems of pigeon pea and tepary beans. The root traits of these legumes could be responsible for high soil moisture. Pigeon pea hydraulic lift could be responsible for supplying moisture to the maize companion crop. Therefore, different root architecture is important in intercropping system. This allows for full exploration of large water volumes in the soil. Current results suggest that intercropping maize with legumes is beneficial in using water efficiently.

Our results of the current study revealed that intercropping maize with tepary beans and cowpea had an advantage over sole cropping. This was advocated by yield and competition indices. Legumes were more competitive than maize. The LER of all legume-maize intercrops was greater than one. Maize-cowpea intercrop had the highest LER compared to other cropping systems. Intercrops of maize with cowpea and tepary beans were the best cropping systems. This indicates that they were able to efficiently utilise growth resources such as nutrients, light and water. The reasons for their good performance needs further research.

3 Recommendations

Determining the physiological traits of the crop is vital as it will provide valuable knowledge for plant breeders. Plant breeding of drought resistance cultivars is required in tepary beans and pigeon pea landraces. Currently the bambara groundnut, pigeon pea and tepary beans are cultivated usinglocal landraces; breeding of varieties for agricultural growth purposes is required.

Base on the conclusion of the current study the following can be recommended:

- Cultivation of cowpea and tepary beans in drought prone areas
- There is a need to evaluate early maturing bambara groundnut germplasm in an intercropping system.
- Studies to evaluate a variety of genotypes of bambara groundnut, cowpea, pigeon pea and tepary beans under different environmental conditions are recommended.
- Future research should look at a relay intercropping maize with tepary beans and pigeon pea
- Research aimed at evaluating the nutritional aspects of the legumes with farmers for adoption is recommended.
- The study should be expanded to evaluate the biological nitrogen fixing of the legumes.