PERFORMANCE OF ELITE CEREAL AND LEGUME GENOTYPES IN VARYING POTENTIAL AGRO-ECOLOGIES IN CENTRAL TANZANIA

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EXTENDED ABSTRACT

Introduction

Grain legumes and cereals are widely grown in many semi-arid areas of the tropics by smallholder farmers who derive from the crops multiple benefits such as nutritious food, soil fertility, and household income. Communities in these areas are highly vulnerable to weather and other natural disaster-related challenges thus facing a problem of low crop productivity. Field experiments were conducted during the 2019-2020 cropping season in different sub agro-ecologies of central Tanzania aiming to: - (i) identify legume and cereal genotypes of higher productivity in varying potential agro-ecologies (ii) determine the stability and GxE interaction of the legume and cereal genotypes in the different agro-ecologies (iii) identify relatively more efficient and productive cropping system in varying potential agro-ecologies of central Tanzania.

Methods

Experiments were laid down in two villages of each potential agro-ecology following an incomplete randomized block design with farmers as replications. Grain yield, yield components and growth data on fourteen genotypes in total of the four crops (groundnut, pigeon pea, sorghum and pearl millet) were collected and Land equivalent ratios (LERs) calculated for intercrops amongst the crops.

Findings

Results from the experiments generally revealed that G x M x E interactions were insignificant ($p \leq 0.05$) in terms of grain yield for all the crop genotypes studied. For groundnut and pigeon pea genotypes, significant differences ($p \leq 0.05$) were observed across the sub-ecologies while significant genotypic effects were observed in both sorghum and pearl millet genotypes. Genotype ICGV-SM 05650 of groundnut had the highest grain yield of 2105.08 kg ha^{-1}, while ICGV-SM 02724 recorded the lowest grain

yield of 1538.87 kg ha^{-1} in the high potential sub-ecology. Pearl millet genotype IP 8774 had the highest yield of 1049.4 kg ha^{-1} and the local check had the lowest yield of 388.9 kg ha^{-1}. Though non-significant differences ($P \leq 0.05$) among genotypes tested for grain yield were observed in pigeon pea and sorghum genotypes however, pigeon pea genotype ICEAP 00040 had a slightly higher grain yield of 779.17 kg ha^{-1} compared to ICEAP 00557 with 770.83 kg ha^{-1} grain yield and sorghum genotype GAMBELLA 1107 outperformed the other genotypes with grain yield of 1420.8 kg ha^{-1} followed by IESV 23010 DL of 1038.0 kg ha^{-1}. Early planting outperformed late planting for the crop genotypes tested however, non-significant differences ($p \leq 0.05$) in planting dates were observed. Furthermore, crop genotypes in the high potential generally out performed those under the moderate and low potential sub-ecologies. In terms of LERs, pigeon pea - sorghum, pigeon pea - groundnut and pigeon pea - pearl millet intercrops had higher LER values of 1.59 (high), 1.65 (moderate) and 2.36 (low potential agro-ecologies), respectively compared to LERs of 1.00 in their respective sole crops.

Conclusion

Findings of the study revealed that generally elite materials outperformed the local landraces. Furthermore, intercropping systems proved to be more efficient and productive compared to sole cropping systems. From the above findings, ICGV-SM 05650 (groundnut), ICEAP 00040 (pigeon pea), GAMBELLA 1107 (sorghum) and IP8774 (pearl millet) were recommended for deployment in these varying potential agro-ecologies due to their stable and superior performance in terms of grain yield. Intercrops Pigeon pea - Sorghum, Pigeon pea - Groundnut and Pigeon pea - Pearl millet were the more efficient and productive cropping systems therefore recommended for deployment in the high, moderate and low potential agro-ecologies respectively.

DECLARATION

I, SIMON WABWIRE, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted at any other institution.

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The above declaration is confirmed;

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LIST OF PAPER CHAPTERS

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DEDICATION

This dissertation is dedicated to my father Jackson Musanya, my mother Deborah Musanya, my wife Rebecca Tumainieli Temba, my daughter Abigail Simon Wabwire and my sons Melchizedek Simon Wabwire and Adrian Simon Wabwire who have remained a source of motivation for my academic achievements.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percent
/	Per
≤	Less than or equal to
≥	Greater than or equal to
AEZ	Agro-ecological zone
AMMI	Additive main effects and multiplicative interaction
ANOVA	Analysis of Variance
C.V	Coefficient of Variation
df	Degree of freedom
DLR	Doubled up legume rotations
FAO	Food and Agricultural Organization
g	Gram
G x E	Genotype by Environment Interaction
GGE	Genotype main effects and genotype x environment interaction effects
i.e.	That is
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ISFM	Integrated soil fertility management
Kg	Kilogram
Kg ha^{-1}	Kilogram per hectare
LER	Land equivalent ratio
Lsd	Least significant difference
m^2	Meter squared
MAFC	Ministry of Agriculture, food and cooperatives

masl	Meters above sea level
MET	Multi-environment trials
mm	Millimeter
N	Nitrogen
P-value	Probability value
SAT	Semi-Arid Tropics
SSA	Sub- Saharan Africa
URT	United Republic of Tanzania

ORGANIZATION OF THE DISSERTATION

This dissertation is organized in the "Publishable manuscript format" comprising of six main chapters as follows;

a. Chapter one is the general introduction
b. Chapter two is a literature review
c. Chapters three to five are three manuscripts out of each specific objective;
    i. To identify legume and cereal genotypes of higher productivity in varying potential agro-ecologies of Tanzania.
    ii. To determine the stability and GxE interaction of the legume and cereal genotypes in different agro-ecologies of Tanzania.
    iii. To identify relatively more efficient and productive cropping system in varying potential agro-ecologies of Tanzania.
d. Chapter six is the general conclusions and recommendations chapter.

Chapter four has been published in the Journal of Current Opinion in Crop Science Vol. 2 (1) pp. 102-109, March 2021.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Grain legumes and cereals are widely grown by smallholder farmers in many semi-arid areas of the tropics (Mihale *et al.,* 2009; Shiferaw *et al.*, 2008). These farmers derive multiple benefits from diversification of production into grain legumes and cereals, including nutritious food, soil fertility, and household income. Dry-land food legumes including pigeon pea, chickpea, groundnut, and soybean provide protein-rich supplementary food to many poor families that could not afford the costly animal-based foods. This helps overcome severe nutritional deficiencies that result from diets lacking in proteins and oils especially in growing children who according to Shiferaw *et al.* (2008) and Maphosa and Jideani (2017) cannot consume sufficient quantities of staple cereals to meet their protein requirements.

In addition, legumes fix atmospheric nitrogen that benefits both the legume and subsequent crops (Vitousek *et al.*, 2002). Soil fertility benefits are a major consideration throughout the region as cash-constrained poor farmers cannot afford costly inputs or the returns to inorganic fertilizer use on staple cereals are low or risky to encourage widespread fertilizer adoption. Despite their potentially high economic and environmental benefits, several pro-poor crops have largely been neglected in public policy, research and development investments, which emphasized major cereals like maize and sorghum for food security (Joshi *et al.,* 2001; Lo Monaco, 2003).

On the other hand, cereal grains have been the principal component of the human diet and have played a major role in shaping human civilization for thousands of years. Around the world; rice, wheat, maize, and to a lesser extent, sorghum and millet are important staples and critical to the daily survival of billions of people. They are grown in greater quantities and provide more food energy worldwide than any other type of crops. In their natural form (as in whole grain), they are a rich source of vitamins, minerals, carbohydrates, fats, oils and proteins. However, when refined by the removal of the bran and germ, the remaining endosperm is mostly carbohydrate and lacks the majority of the other nutrients. As human food, grain cereals are usually marketed in raw grain form or as ingredients of food products. As animal feed, they are consumed mainly by livestock and poultry, which are eventually rendered as meat, dairy and poultry products for human consumption. They are also used industrially in the production of a wide range of substances, such as glucose, adhesives, oils and alcohols (Sarwar *et al*., 2013).

1.2 Problem Statement and Justification

1.2.1 Problem statement

Okori (2014) observed that many farming communities of the semi-arid zone districts of Kongwa and Kiteto in Tanzania practise agro-pastoralism, growing maize, sorghum and pearl millet along with drought-hardy legumes such as groundnuts, bambara nuts and pigeon pea. The household surveys and pastoral system studies showed that in these communities, legumes and cereals initially sustain food, nutrition, and income security. People living in these arid and semi-arid regions of Tanzania depend exclusively on livestock and crop production and face relatively high levels of poverty.

Studies show that Dodoma among the semi-arid zones of Tanzania has one of the highest percentages of people living below the food poverty line at 35.5% and up to 51.4% based on expenditures (Mkenda *et al*., 2004). These communities are also highly vulnerable to weather and other natural disaster-related challenges thus face a problem of low productivity of crops and livestock sub-sectors (Okori, 2014). Nevertheless, legume-cereal production is still low and does not meet the increasing demand. The low yield is mostly due to the use of unimproved varieties. Munthali *et al*. (2018) further reported that in Dodoma and Manyara regions, less than 10% of smallholder farmers use improved seed, especially of dryland cereals and legumes due to unavailability of seeds of improved varieties in these areas compelling farmers to use and/or recycle the locally available landraces with low yield potential. This has stalled production of legumes and cereals in these areas hence call for more breeding efforts to curb the problem (Bucheyeki and Mmbaga, 2013).

1.2.2 Justification

Legumes are often grown as rotation crops and/or intercrops with cereals because of their role in nitrogen fixation. Over the past few decades, yields and production of these crops have been stagnant in the developing countries of sub-Saharan Africa. In sub-Saharan Africa and Tanzania in particular, Hatibu *et al*. (2000) observed that most of the crop failures were due to a deficit in soil moisture caused by dry spells. Climate change impact brought severe drought due to unreliable and erratic rainfall. Therefore, these changes in rainfall patterns led to low crop production in the different sub agro-ecological zones of central Tanzania and hence the need for new improved varieties that could adapt to harsh climatic conditions in the region (Field *et al*., 2014; Mkonda and He, 2016). Mkonda and He (2017) further proposed the use of drought-resistant crops like sorghum, millet, sunflower, pigeon peas and groundnuts. Predominantly produced in the area, these crops would optimize yield and increase household income for the smallholder farmers in this region.

Also according to Okori (2014), the Africa RISING team has developed varieties that produce over 50% yield advantage compared to local landraces. Among genotypes with a reputation, some will be tested in this research. This study therefore aims at identifying the best performing genotype (s) of selected cereals and legumes across selected agro-ecologies to increase yields, productivity and lower crop losses hence improve food and nutrition security and household incomes for the farmers in the regions.

1.3 Objectives

1.3.1 Overall objective

Elevating food and nutritional security in the study areas through identification of high yielding legume and cereal genotypes and investigate their interaction patterns with the environment in various agro-ecologies.

1.3.2 Specific objectives

i. To identify legume and cereal genotypes of higher productivity in varying potential agro-ecologies of Tanzania.

ii. To determine the stability and GxE interaction of the legume and cereal genotypes in different agro-ecologies of Tanzania.

iii. To identify relatively more efficient and productive cropping system in varying potential agro-ecologies of Tanzania.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Agro-ecological Zones of Tanzania

Tanzania's agro-ecological zones (AEZs) range from higher rainfall areas on the coast and highlands in the north, far west, south and southwest, to arid and semi-arid areas in the interior of the country. The agro-ecological zones include alluvial plains, northern highlands, plateau, semi-arid lands, southwestern highlands, southern highlands and western highlands. The semi-arid lands cover central Dodoma, some part of Arusha (Manyara) and northern Iringa (De Pauw, 1984; Senkoro *et al*., 2017). These semi-arid agro-ecological zones of undulating plains with rocky hills and low scarps are elevated at an altitude of 1000-1500 masl consisting of well-drained soils with low fertility and are characterized by unimodal and unreliable rainfall (300-800mm/year) with a December-March cropping season (Msuya, 2015; URT, 2007; MAFC, 2014). Due to these climatic conditions of low and unreliable rainfall patterns, farming communities in these regions grow drought-resistant cereal and legume crops to a large extent and keep livestock for food and household income. According to the URT (2006) report, more than 70% of farmers in these regions are involved in crop production and less than 30% of farmers are involved in both crop and livestock production.

The dominant cropping patterns in the semi-arid lands are intercropping, mixed cropping and to a lesser extent rotational cropping. Intercropping is often associated with the goal of obtaining higher returns per unit input of land and/or labour and is also a strategy to manage risks associated with rainfall uncertainties and ensure food security. Farmers therefore combine crops with different levels of drought tolerance and length to maturity. For instance, farmers intercrop cereals like sorghum and maize, so that if there is high rainfall they can harvest the maize, but if the rains are scanty they can at least reap sorghum. On the other hand, Livestock keeping is practised in almost all the production/farming systems, being important both for food and financial security (a form of savings). The main livestock kept are cattle, sheep, goats, donkeys and poultry. However, not all livestock keepers own the livestock that they keep. Some livestock owners entrust non-livestock owners with the care of their animals according to a specified agreement. Generally, the custodian of the livestock has access to the milk and is given ownership of calves born alternatively under his/her custody. Livestock is also important for seed security, in that its keepers sometimes exchange a live animal for seed, or sell livestock for cash to buy seed (Lazaro and Bisanda, 2005).

2.2 Role of Legume and Cereal in Crop Production Systems

Proper integration of cereals with legumes can improve the nutritive value of crop residues, feed intake and animal production thereby increase resource-use efficiency if carefully designed and managed. Legume-cereal intercropping is thus important in subsistence farmer communities as a means of improving soil fertility and increasing land-use intensity in situations where land availability is limited (Saidi *et al.*, 2010). Farmers more often use these intercrop systems as strategies for maximizing utilization of cultivable land and managing risk through diversification of food supplies on small landholdings (Barrett *et al.*, 2002).

Furthermore, legume-cereal rotation is one of the most used and sustainable systems of increasing food production under small scale farming (Dakora and Keya, 1997). The sustainability of the system results from the ability of most legumes to contribute to the soil Nitrogen (N) budget through symbiotic biological N2 fixation. Legumes differ in their efficiency with which they channel the fixed N2 to grain, and hence in the quantity of N returned to the soil for a subsequent crop. For instance, Rao and Mathuva (2000) observed higher maize yields under rotation with cowpea than under pigeon pea attributed due to differences between the legumes in N_2 fixation and the quantity and quality of residue between the two legume types. Cereal crop yield improvements following legume rotations have been reported to be attributed both to improvements of the soil N status and other positive rotational effects such as control of weeds and diseases (Bruulsema and Christie, 1987; McVay *et al.,* 1989).

2.3 Constraints to Legume and Cereal Production in Tanzania

2.3.1 Climate

Fluctuations in climate between and within seasons have a significant impact on crop yields. These climate-related changes were reported to increase food insecurity and poverty due to their potential to irreversibly damage the natural resource base on which agriculture depends and adversely affect agricultural productivity, for instance, changes in temperature, rainfall patterns and drought (Ahmed *et al*., 2009).

2.3.2 Insect pests and diseases

Major constraints to legume-cereal production systems are insect pests and diseases. Important pathogens include several viruses, fungi-causing root rots, anthracnose, angular leaf spot, bean rust, white mould and web blight, and the bacteria responsible for common bacterial blight and halo blight in legumes and maize stalk borers, larger grain borer, fall armyworm, cotton bollworm, stem borers, sorghum midge, maize lethal necrosis disease, bacterial leaf blight of rice, rice blast in cereals. These biotic stresses cause low crop productivity (Kelly *et al*., 2003; Minja *et al.,* 2011).

2.3.3 Weeds

Intercropping systems have been used to control weeds, pests and diseases compared to monocrops. Weed growth depends on the competitive ability of the whole crop community, which in intercropping largely depends on the competitive abilities of the component crops and their respective plant populations. For example, intercropping of cereals and cowpea has been observed to reduce Striga infestation significantly (Khan *et al.*, 2003). This was attributed to the soil cover of cowpea that created unfavourable conditions for Striga germination (Massawe *et al*., 2002; Musambasi *et al*., 2002). Mashingaidze (2004) found that maize-bean intercropping reduced weed biomass by 50-66 per cent when established at a density of 222 000 plants ha^{-1} for beans equivalent to 33 per cent of the maize density (37 000 plants ha^{-1}).

2.3.4 Soil fertility

Low yields realized by smallholder farmers in the semi-arid areas and other parts of the country are mainly caused by declining soil fertility (Kafiriti, 2004; Kashenge-Killenga, 2010; Wickama and Mowo, 2001). Moreover, the majority of farmers in these regions lack financial resources to purchase sufficient amount of mineral fertilizers to replace soil nutrients removed through harvested crop products (Jama *et al*., 2000), crop residues, and through loss by runoff, leaching. Therefore, it is necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security (Landers, 2007; Gruhn *et al.*, 2000). Such technologies include the use of integrated soil fertility management practices (ISFM) which have intercropping cereals with legumes as one of its main components (Mucheru-Muna *et al.,* 2010; Sanginga and Woomer, 2009). This practice is an attractive strategy to smallholder farmers for increasing productivity and land labour utilization per unit area of available land through intensification of land use (Seran and Brintha, 2010). Furthermore, intercropping cereals with legumes have a huge capacity to replenish soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen (Mapfumo and Giller, 2001).

2.3.5 Un-improved genotypes or landraces

Landraces are dynamic population(s) of cultivated plants having a historical origin, distinct identity and lack formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems. Though the above characteristics are usually present, they are not always present for any individual landrace (Camacho *et al*., 2005). Landrace material offers a potential source for crop improvement although these traits are highly interactive with their environment, particularly developmental stage, soil conditions and other organisms affecting roots and their environment (Newton *et al*., 2011). Landraces differ from modern or elite cultivars because the latter is a result of formal crop breeding programmes. Modern cultivars are bred to be mono-genotypic as inbred or pure lines for self-pollinating species or one-way hybrids in cross-pollinating species and thus are genetically homogeneous. They are bred to exploit high-input environments with increased yield levels and with an emphasis on broad or wide adaptation (Newton *et al*., 2011).

2.4 Genotype x Environment Interaction (GEI)

According to Bernardo (2002), the term genotype refers to individuals (e.g. families, recombinant inbreds, test-crosses or hybrids) that differ in their genotypes at many loci than those at a single locus. Chaudhary (1984), described environment as the sum of external conditions which affect growth and development of an organism and interaction as the influence of environment upon the genotypes and response of genotypes upon the environment.

Kang and Gorman (1989) stated that genotype by environment interaction in multi-environment trials refers to differential responses of genotypes across a range of environments. It occurs when differences between genotypes are not the same in all locations within and across years (Edmeades *et al*., 1989). G x E interactions greatly affect the phenotype of a variety, so the stability analysis is required to characterize the performance of varieties in different environments, to help plant breeders in selecting varieties (Jusuf *et al.,* 2008; Lone *et al.,* 2009). Therefore, Genotype x Environment interaction is present whether varieties are pure lines, single crosses, double-crosses, top-crosses or any other material with which the breeder is working on (Dabholkar, 1999).

2.5 Stability of Genotype Performance

Stability of genotypes connotes consistency in performance that would mean minimum variation among environments for a particular genotype. It is central to all types of analyses of Genotype x Environment interactions in plant breeding (Chahal and Gosal, 2002). A successfully developed new cultivar should have a stable performance and broad adaptation over a wide range of environments in addition to high yielding potential (Fikere *et al.*, 2008). The fact that cultivar development is a time-consuming endeavour, stable cultivars are of paramount importance. In this context, research on yield stability, or genotype x environment interaction (GEI), is therefore necessary to evaluate the consistency of yield for plant breeders to develop cultivars that respond optimally and consistently across years and diverse agro-ecological conditions (Berzsenyi and Dang, 2008).

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CHAPTER THREE

Paper One

3.0 Identification of Legume and Cereal Genotypes of Higher Productivity in Varying Potential Agro-Ecologies of Central Tanzania

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3.1 Abstract

Legumes and cereals are widely grown by smallholder farmers in many semi-arid areas of the tropics due to their multiple benefits such as provision of nutritious food, soil fertility and household income. Field experiments were conducted during the 2019-2020 cropping season to identify legume and cereal genotypes of higher productivity in different sub agro-ecologies of central Tanzania. The agro-ecologies are classified into high, moderate and low potential agro-ecologies based on the amount of precipitation received annually (i.e. >500mm, 400-500mm and < 350mm of rainfall respectively). An incomplete randomized block design with farmers as replications was used at each sub agro-ecology. Yield, yield components and growth data of fourteen genotypes in total of the four crops (groundnut, pigeon pea, sorghum and pearl millet) were collected in the study and subjected to analysis of variance (ANOVA) with mean separation. Results showed significant differences ($P \leq 0.05$) among groundnut and pearl millet genotypes tested for grain yield while for pigeon pea and sorghum genotypes the differences were insignificant ($P \leq 0.05$). Genotype ICGV-SM 05650 of groundnut had the highest grain yield of 2105.08 kg ha^{-1}, while the lowest grain yield of 1538.87 kg ha^{-1} was recorded in ICGV-SM 02724 in the high potential agro-ecology. Pearl millet genotype IP 8774 ranked highest in terms of yield performance (1049.4 kg ha^{-1}) and the local check had the lowest yield of 388.9 kg ha^{-1}. Though non-significant differences ($P \leq 0.05$) among genotypes tested for grain yield were observed in pigeon pea and sorghum genotypes however, pigeon pea genotype ICEAP 00040 had a slightly higher grain yield of 779.17 kg ha^{-1} and sorghum genotype GAMBELLA 1107 outperformed the other genotypes with grain yield of 1420.8 kg ha^{-1}. The findings reveal that generally elite materials outperformed the local landraces proving to be more suited to these environments. Genotypes ICGV-SM 05650, ICEAP 00040, GAMBELLA 1107 and IP8774 were therefore recommended for deployment in these varying potential agro-ecologies due to their superior performance in terms of grain yield.

Keywords**:** Legumes and cereal genotypes**;** productivity**;** grain yield

3.2 Introduction

Grain legumes and cereals are widely grown by smallholder farmers in many semi-arid areas of the tropics. These farmers derive multiple benefits from diversification of production into grain legumes and cereals, including nutritious food, soil fertility, and household income (Mihale *et al.,* 2009; Shiferaw *et al.*, 2008). Grain legumes include crops such as cowpea, chickpea, groundnut, common bean, faba bean, pigeon pea and soybean whose edible parts are the grain (Singh *et al*., 2007). They are important components of sustainable agricultural production, food, nutrition and income systems of developing countries. Despite their importance, legume production is still being challenged by a number of biotic (pests and diseases) and abiotic stresses (drought, heat, frost and salinity), edaphic factors (associated with soil nutrient deficits) and policy issues (where less emphasis is put on legumes compared to priority starchy staples) (Ojiewo *et al*., 2019).

On the other hand, cereal grains include such crops as wheat, rice, maize, sorghum, millet, barley and rye, whose starchy grains are used as food. Cereal grains are grown in greater quantities and provide more food energy than other types of crops worldwide (Sarwar *et al*., 2013). In spite of this, cereals benefit from the legumes in these intercropping systems as they utilize atmospheric N fixed in symbiotic association with the rhizobia.

The ability of legumes to fix soil nitrogen and improve soil health enhances farm productivity and smallholder incomes while reducing the high costs of production incurred through exogenous application of inorganic fertilizers. The fixed nitrogen is gradually released from decaying root (and shoot) biomass, thereby improving the soil fertility and making the nitrogen available for the subsequent crop (Crews and Peoples, 2005). The subsequent cereal crop will give higher grain yields for both human consumption and livestock feed. Legume haulm itself is nutritionally rich as livestock feed which improves let-down and meat quality in crop livestock-producing communities. The livestock manure goes back to the crop production fields to improve the soil structure and fertility and ensures sustainable management land resource. Thus, legumes support the crop-livestock system that enhances system efficiency and sustainability as well as resilience of smallholder farmers to climate shocks (Ojiewo *et al*., 2015).

A number of cereal crops including sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*) and legumes such as chickpea (*Cicer arietinum*), groundnut (*Arachis hypogaea*) and pigeon pea (*Cajanus cajan*) were observed to be grown in the semi-arid tropics (SAT) (Serraj *et al*., 2003). These crops are also produced in the semi-arid ecologies of central Tanzania because of their relative ability to withstand periods of water-limited conditions and still produce grain and biomass (Serraj *et al*., 2003; Okori, 2014). In a report published by Okori (2014), low crop productivity of less than 50% of the expected yields for legumes (groundnuts, bambara nuts) and cereals (sorghum, pearl millet and maize) in the farming communities of Kongwa and Kiteto districts in the semi-arid zone of central Tanzania was cited. However, the Africa RISING team has developed new highly productive and resilient varieties of legumes (groundnut, pigeon pea and bambara nut); cereals (drought tolerant Quality Protein Maize (QPM), sorghum and pearl millet) which when supported with appropriate scaling models will provide farmers with new options for production and are thought to increase productivity by 2-3 fold thereby enhancing options for land management, nutrition and income for smallholder farming communities (Okori *et al*., 2017).

Research studies on the newly developed elite legumes and cereal genotypes are still being implemented in these three sub agro-ecologies of central Tanzania classified based on the amount of precipitation received annually i.e. high potential zone which receives more than 500mm of rainfall; moderate potential zone receives between 400-500mm of rainfall and low potential zone receives less than 350mm of rainfall (Hoeschle-Zeledon, 2019). These newly adapted genotypes of groundnut, pigeon pea, sorghum and pearl millet are targeted in these sub agro-ecologies to increase productivity, income, nutrition, food security as well as improve soil health (Okori *et al*., 2017). Therefore, this study aims at identifying legume and cereal genotypes of higher productivity in these varying potential agro-ecologies.

3.3 Materials and Methods

3.3.1 Description of experimental sites

The study was conducted during the 2019-2020 cropping season in the Central zone of Tanzania in three sub agro-ecologies i.e., high potential zone (Manyusi and Mlali villages in Kongwa district) which receives ≥500mm of rainfall; moderate potential zone (Njoro-1 and Njoro-2 villages in Kiteto district) which receives 400-500mm of rainfall and low potential zone (Laikala and Moleti villages in Kongwa district) which receives ≤ 350mm of rainfall (Hoeschle-Zeledon, 2019). Kongwa district lies between latitudes 5° 30' to 6° 00' S and longitudes 36°15' to 36°00' E with altitude stretching between 900 and 1000 masl (URT, 2016). The average temperature is 26.5°C though sometimes gradually changes up to 11°C. The cool weather occurs between January and June when temperature ranges between 20 – 33°C and the highest temperature recorded is 31°C while the lowest temperature is 18° C (PORA and LGOVT, 2016).

Kiteto district lies between latitudes 05°52'00"S and longitudes 36°51'00"E with altitude stretching between 500 and 1200 masl. The average day and night temperature is 22°C. The cool months are March, April, May and June while the hot months are July, August, September, October and November (PO-RALG, 2018). These areas consist of mainly well-drained sandy loamy soils (see Appendix 1) with low fertility and are characterized by unimodal and unreliable rainfall of 300-800mm/year with a December-March cropping season (URT, 2007; MAFC, 2014; Msuya, 2015).

3.3.2 Materials

Ten elite genotypes in total (of groundnut, pigeon pea, sorghum and pearl millet) proposed for release and four local checks (one for each crop) were used in this study (Table 3.1). The elite genotypes were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT-MALAWI) including one local check (ICEAP 00040) and the remaining three local checks were obtained from the local market in Dodoma.

Table 3.1: Description of test materials used in the study

	Crop	Genotype	Maturity duration (days)	Source
1.	Groundnut	ICGV-SM 02724	Medium (120)	ICRISAT-MALAWI
		ICGV-SM 05650	Short (90)	ICRISAT-MALAWI
		LOCAL CHECK (Mnanje)	Short (110)	DODOMA MARKET
2.	Pigeon pea	ICEAP 00554	Medium (150-180)	ICRISAT-MALAWI
		ICEAP 00557	Medium (150-180)	ICRISAT-MALAWI
		CHECK- ICEAP 00040 (Mali)	Long (190-240)	ICRISAT-MALAWI
3.	Sorghum	GAMBELLA 1107	Short (70)	ICRISAT-MALAWI
		IESV 92028 DL	Medium (90)	ICRISAT-MALAWI
		IESV 23010 DL	Medium (90)	ICRISAT-MALAWI
		LOCAL CHECK (Lugugu)	Long (110)	DODOMA MARKET
4.	Pearl millet	IP 8774	Short (70)	ICRISAT-MALAWI
		SDMV 96053	Medium (90)	ICRISAT-MALAWI
		SDMV 94005	Medium (90)	ICRISAT-MALAWI
		LOCAL CHECK (Uwele)	Long (110)	DODOMA MARKET

3.3.3 Methodology and experimental design

One experiment was laid down in each village in the high potential (Manyusi and Mlali); moderate potential (Njoro-1 and Njoro-2) and low potential (Laikala and Moleti) sub ecologies to test the effect of one sub agro-ecological condition in Kongwa and Kiteto district. A total of 4 crops (sorghum, pearl millet, groundnut and pigeon pea) with test varieties were evaluated against the local landrace (Appendix 2). The groundnut experiments were conducted in all the sub ecologies, pigeon pea in the high and moderate, sorghum in the high and low and pearl millet occurred only in the low potential agro-ecology. All experiments at these sites were established following an incomplete randomized block design with two farmers selected per sub agro-ecology as replications. The plot size was 7 rows, 8 m long spaced at 75 cm between ridges. The field layout of the sole crops and intercrops are as shown in Appendix 3 and Appendix 4 respectively.

Table 3.2: General treatment structure

Crops	Varieties	Environments
1. Groundnut	V_1,V_2,V_c	1. Low potential
2. Pigeon pea	V_1,V_2,V_c	2. Moderate potential

3. Sorghum	V_1,V_2,V_3,V_c	3. High potential	
4. Pearl millet	V_1,V_2, V_3,V_c		

V_c - Local check

3.4 Data Collection

Collected data included days to 50% flowering and grain yield (assessed based on the whole plot); plant height, pod weight (collected from ten plants per plot); 100 grain weight (obtained by counting 100 seeds at random from each net plot and their weight was recorded); Disease severity for leaf spots was scored based on a 1-9 severity scale according to Subrahmanyam *et al.* (1995). Disease score 1 means 0% foliar infection; 2 for 1–5%; 3 for 6–10%; 4 for 11–20%, 5 for 21–30%; 6 for 31–40%; 7 for 41–60%, 8 for 61–80% and 9 for 81–100% of foliar area infection with plants having almost all leaves defoliated leaving bare stems. Percentage severity of leaves infected by leaf spots per plant was recorded on five middle plants at 90 days after sowing from each plot and averaged for each genotype. Insect pest damage for aphids was scored based on a 0 to 5 rating scale by Souleymane *et al.* (2013) as follows: 0 = no aphids, 1= a few individual aphids, 2 = few small individual colonies, 3 = several small colonies, 4= large individual colonies, 5 = large continuous colonies). Scoring was done on five plants from each plot at 90 days after sowing and average score recorded for each genotype.

3.5 Data Analysis

Yield and yield components data were subjected to analysis of variance (ANOVA) using GenStat 16th Edition. Mean separation was done using Tukey’s and LSD tests at 5% probability level.

3.6 Results

3.6.1 ANOVA summary for crop performance in different potential agro-ecologies in Kongwa and Kiteto districts

Table 3.3 provides analysis of variance summary for performance of the groundnut genotypes in the three different potential agro-ecologies in Kongwa and Kiteto districts. Within the high potential, significant genotypic effects ($P \leq 0.05$) were observed in days to 50% flowering, leaf spot severity, aphids damage and 100 seed weight while number of pods per plant, pod weight and grain yield were non-significant. In the moderate potential, significant genotypic effects ($P \leq 0.05$) were observed in days to 50% flowering, leaf spot severity, aphids damage and 100 seed weight while number of pods per plant, pod weight and grain yield were non-significant. In the low potential, significant genotypic effects ($P \leq 0.05$) were observed in days to 50% flowering, leaf spot severity, aphids damage, 100 seed weight and grain weight while number of pods per plant and pod weight were non-significant. For performance of the groundnut genotypes across the varying potential agro-ecologies (Table 3.4). Results showed significant genotypic effects ($P \leq 0.05$) for days to 50% flowering, leaf spot severity, aphids damage, 100 seed weight and grain yield while number of pods per plant and pod weight were insignificant. Sub ecology on the other hand showed significant genotypic effects for days to 50% flowering, pod weight, 100 seed weight and grain yield while other parameters including leaf spot severity, aphids damage and number of pods per plant were insignificant. For the genotype x sub ecology interactions all the studied parameters were insignificant.

Table 3.3: Analysis of variance summary for performance of groundnut genotypes in the various potential agro-ecologies

Source of variation	df	Mean sum of squares ANOVA values						
		Days to 50% flowering	**Leaf spot severity**	**Aphids damage**	**No. of pods/plant**	**Pod weight (kg)**	**100 Seed weight (g)**	**Grain yield (kg/ha)**
High								
Rep	1	5.333	1.3333	0.0833	114.1	9.452	43.32	2346873
Genotype	2	87.250*	6.2500*	1.5833*	128.6	1.861	241.79*	342673
Error	8	9.896	0.6458	0.2083	216.1	1.813	11.79	323636
Total	11							
Moderate								
Rep	1	0.083	0.3333	0.3675	408.33	5.4675	32.01	53507
Genotype	2	36.083*	3.2500*	4.0000*	49.82	2.0575	285.56*	274540
Error	8	1.083	0.1458	0.2794	66.43	0.5756	23.05	96905
Total	11							
Low								
Rep	1	12.000	1.3333	0.08333	410.67	2.708	376.32	301396
Genotype	2	122.333*	5.3333*	1.75000*	15.16	3.469	277.32*	885612*
Error	8	4.750	0.2083	0.08333	72.04	2.058	13.52	228112
Total	11							

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

Table 3.4: Analysis of variance summary for performance of groundnut genotypes in varying potential agro-ecologies with interactive effects of environment

Source of Variation	df	Mean sum of squares ANOVA values						
		Days to 50% flowering	**Leaf spot severity**	**Aphids damage**	**No. of pods / plant**	**Pod weight (kg)**	**100 Seed weight (g)**	**Grain yield (kg/ha)**
Rep	1	11.111	2.7778	0.00000	295.8	0.276	17.08	491484
Genotype	2	213.083*	13.8611*	6.86111*	48.5	6.538	695.45*	1258326*
Sub ecology (SE)	2	104.333*	0.7778	0.19444	86.7	11.661*	202.52*	4402471*
Genotype x Sub ecology	4	11.417	0.4861	0.23611	72.5	0.425	54.61	122249
Error	26	4.823	0.3162	0.09615	133.6	2.036	31.59	284597
Total	35							

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

Table 3.5 provides analysis of variance summary for performance of the pigeon pea genotypes in the two different potential agro-ecologies in Kongwa and Kiteto districts. Within the high potential, significant genotypic effects ($P \leq 0.05$) for days to 50% flowering, plant height, leaf spot severity and 100 seed weight were observed while pod weight and grain yield were non-significant. In the moderate potential, significant genotypic effects ($P \leq 0.05$) were observed in days to 50% flowering, plant height and leaf spot severity while pod weight, 100 seed weight and grain yield were not significant. For performance of the pigeon pea genotypes across the varying potential agro-ecologies (Table 3.6). Results showed significant genotypic effects ($P \leq 0.05$) for days to 50% flowering, plant height, leaf spot severity while other parameters such as pod weight, 100 seed weight and grain yield were insignificant. Sub ecology on the other hand showed significant influence on plant height while other parameters including days to 50% flowering, leaf spot severity, pod weight, 100 seed weight and grain yield were insignificant. Significant genotype x sub ecology interactions was observed in 100 seed weight only.

Table 3.5: Analysis of variance summary for performance of pigeon pea genotypes in the various potential agro-ecologies

Source of variation	df	Mean sum of squares ANOVA values					
		Days to 50% flowering	Plant height (cm)	Leaf spot severity	Pod weight (kg)	100 Seed weight (g)	Grain yield (kg/ha)
High							
Rep	1	432.00	1438.8	0.3333	30.560	30.720	38912
Genotype	2	3116.33*	8293.7*	5.3333*	0.178	39.203*	10278
Error	8	21.12	323.9	0.5833	1.346	2.635	154242
Total	11						
Moderate							
Rep	1	10.08	65.8	0.08333	3.521	0.333	47084
Genotype	2	3252.08*	4985.2*	4.08333*	1.708	0.480	194257

Error	8	33.08	873.2	0.08333	1.462	5.968	137182
Total	11						

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

Table 3.6: Analysis of variance summary for performance of pigeon pea genotypes in varying potential agro-ecologies with interactive effects of environment

Source of Variation	df	Mean sum of squares ANOVA values					
		Days to 50% flowering	Plant height (cm)	Leaf spot severity	Pod weight (kg)	100 Seed weight (g)	Grain yield (kg/ha)
Rep	1	155.04	444.6	0.0417	6.668	18.727	85801
Genotype	2	6365.04*	13024.5*	9.0417*	0.711	15.622	103915
Sub ecology (SE)	1	84.37	8843.5*	0.3750	5.273	5.607	492398
Genotype x Sub ecology	2	3.37	254.3	0.3750	1.174	24.062*	100620
Error	17	42.39	625.7	0.3358	2.934	4.774	137152
Total	23						

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

Table 3.7 provides analysis of variance summary for performance of the sorghum genotypes in the two different potential agro-ecologies in Kongwa district. Within the high potential, significant genotypic effects (P ≤ 0.05) were observed in plant height and leaf spot severity while non-significant genotypic effects were observed in days to 50% flowering, aphids damage, dry panicle weight and grain weight. In the low potential, significant genotypic effects were observed in days to 50% flowering, plant height, leaf spot severity and grain yield while non-significant genotypic effects were observed in aphids damage and dry panicle weight. For performance of the sorghum genotypes across the varying potential agro-ecologies (Table 3.8). Results showed significant genotypic effects (P ≤ 0.05) for days to 50% flowering, plant height, leaf spot severity and aphids damage while non-significant genotypic effects were observed in dry panicle weight and grain yield. Sub ecology on the other hand differed significantly for days to 50%

flowering, plant height, dry panicle weight and grain yield while leaf spot severity and aphids damage were non-significant. Genotype x sub ecology interactions displayed significant genotypic effect for aphids damage only.

Table 3.7: Analysis of variance for performance of sorghum genotypes in the various potential agro-ecologies

Source of variation	Df	Mean sum of squares ANOVA values					
		Days to 50% flowering	Plant height (cm)	Leaf spot severity	Aphids damage	Dry panicle weight (kg)	Grain yield (kg/ha)
High							
Rep	1	72.25	10065.1	2.2500	0.0625	21.150	1033611
Genotype	3	175.50	4387.2*	3.4167*	1.0625	4.410	795926
Error	11	68.39	690.2	0.2955	0.2443	4.224	641364
Total	15						
Low							
Rep	1	182.25	1188.53	1.5625	0.0625	2.6814	158031
Genotype	3	481.17*	6381.95*	2.7292*	6.2292	1.6264	304250*
Error	11	32.20	71.86	0.5625	0.3807	0.7974	64097
Total	15						

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

Table 3.8: Analysis of variance for performance of sorghum genotypes in the varying potential agro-ecologies with interactive effects of environment

Source of Variation	df	Mean sum of squares ANOVA values					
		Days to 50% flowering	Plant height (cm)	Leaf spot severity	Aphids damage	Dry panicle weight (kg)	Grain yield (kg/ha)
Rep	1	75.03	4282.8	3.1250	0.0000	1.088	234067
Genotype	3	278.70*	3712.2*	5.2083*	5.5833*	3.417	485552
Sub ecology (SE)	1	1140.03*	3536.4*	0.1250	1.1250	17.850*	1719081 *
Genotype x Sub ecology	3	29.86	1076.9	0.3750	1.7083*	1.135	141507
Error	23	37.42	713.1	0.3859	0.3043	2.418	290678
Total	31						

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

Table 3.9 provides analysis of variance summary for performance of pearl millet genotypes in the low potential agro-ecology in Kongwa district. The results showed significant genotypic effects (P ≤ 0.05) in days to 50% flowering, plant height, leaf spot severity and grain yield while there was no significant genotypic effect observed in dry panicle weight.

Table 3.9: Analysis of variance for performance of pearl millet genotypes in the low potential agro-ecology in Kongwa district

Source of Variation	df	Mean square ANOVA values				
		Days to 50% flowering	**Plant height (cm)**	**Leaf spot severity**	**Dry panicle weight (kg)**	**Grain yield (kg/ha)**
Rep	1	182.25	1188.53	1.5625	2.6814	158031
Genotype	3	481.17*	6381.95*	2.7292*	1.6264	304250*
Error	11	32.20	71.86	0.5625	0.7974	64097
Total	15					

Key: df = Degrees of freedom, * Significant at P ≤ 0.05

From the summaries of analysis of variance in general, significant genotypic effects were observed in groundnuts, sorghum and pearl millet but not in pigeon pea. In groundnuts, significant genotypic effect seems to have been cumulative over the different sub-ecologies but it was not significant in the high and moderate potential agro-ecologies, while in sorghum it was in the contrary not cumulative but significant only in the low potential sub-ecology. This means that localized genotypic effect for all the crops involved if significant was significant only in the low potential agro-ecology. Overall, no significant genotype x sub-ecology (G x E) interaction existed for grain yield in all the crops.

3.6.2 Performance of crop genotypes in different potential agro-ecologies in Kongwa and Kiteto districts

3.6.2.1 Groundnut

Three genotypes (ICGV-SM 05650, ICGV-SM 02724 and Local check) were evaluated in the different potential agro-ecologies of Kongwa and Kiteto districts (Table 3.10). Within the high potential; significant differences ($P \leq 0.05$) were observed in days to 50% flowering, leaf spot severity, aphids damage and 100 seed weight while number of pods per plant, pod weight and grain yield were non-significant. In the moderate potential; significant differences ($P \leq 0.05$) were observed in days to 50% flowering, leaf spot severity, aphids damage and 100 seed weight while number of pods per plant, pod weight and grain yield were non-significant. In the low potential agro-ecology; significant differences ($P \leq 0.05$) were observed in days to 50% flowering, leaf spot severity, aphids damage, 100 seed weight and grain yield while number of pods per plant and pod weight were non-significant. Performance results across the varying potential agro-ecologies (Table 3.11) showed significant differences ($P \leq 0.05$) among the genotypes tested for grain yield, days to 50% flowering, 100 seed weight, leaf spot severity and aphids damage while pod weight and number of pods per plant were insignificant. Even though genotypic differences were not significant at high and moderate potential agro-ecologies, genotype ICGV-SM 05650 had the highest grain yields of 2105.08 kg ha^{-1}, 1014.07 kg ha^{-1} and 1487.08 kg ha^{-1} respectively in all the ecologies, while the lowest grain yields (1538.87 kg ha^{-1}, 506.19 kg ha^{-1} and 670.67 kg ha^{-1}) respectively were recorded in ICGV-SM 02724. The high potential agro-ecology generally had the best grain yield performance in all the genotypes tested compared to the other sub agro-ecologies.

Table 3.10: Performance of elite groundnut genotypes in the various potential agro-ecologies

Treatments	Days to 50% Flowering	Leaf spot severity	Aphids damage	No. of pods/ plant	Pod weight/ plot (kg)	100 Seed weight (g)	Grain yield (kg/ha)
High							
ICGV-SM 02724	40.50 b	2.250 a	2.000 ab	41.15	3.862	50.15 b	1539
ICGV-SM 05650	31.25 a	3.500 ab	1.250 a	30.40	5.225	50.52 b	2105
Local Check	34.75 ab	4.750 b	2.500 b	38.90	4.600	36.88 a	1951
Grand mean	35.50	3.50	1.92	36.8	4.56	45.85	1864.88
SE±	1.573	0.402	0.228	7.35	0.673	1.717	284.445
P-value	0.009	0.007	0.014	0.574	0.401	0.001	0.391
LSD (0.05)	5.671	1.557	0.5247	ns	ns	6.56	ns
CV (%)	8.9	23.0	23.8	39.9	29.5	7.5	30.5
Moderate							
ICGV-SM 02724	44.50 c	2.250 a	2.675 b	38.20	2.375	52.70 b	506.2
ICGV-SM 05650	38.50 a	2.750 a	1.675 a	36.25	3.550	39.70 a	1014.1
Local Check	41.25 b	4.000 b	3.675 c	31.35	2.250	36.85 a	648.5
Grand mean	41.42	3.00	2.68	35.3	2.73	43.1	722.94
SE±	0.520	0.191	0.264	4.08	0.379	2.40	155.648
P-value	0.001	0.001	0.002	0.503	0.078	0.004	0.117
LSD (0.05)	2.214	0.664	0.2112	ns	ns	9.09	ns
CV (%)	2.5	12.7	19.8	23.1	27.8	11.1	43.1
Low							
ICGV-SM 02724	43.50 c	2.500 a	2.000 b	30.15	2.638	46.57 b	670.7 a
ICGV-SM 05650	32.50 a	2.500 a	1.000 a	30.80	4.088	36.70 a	1487.1 b
Local Check	37.00 b	4.500 b	2.250 b	33.80	2.350	30.02 a	673.5 a
Grand mean	37.67	3.17	1.750	31.6	3.02	37.8	943.76
SE±	1.090	0.228	0.1443	4.24	0.717	1.84	208.805
P-value	0.001	0.001	0.001	0.815	0.245	0.001	0.016
LSD (0.05)	1.626	1.049	0.5247	ns	ns	6.52	515.829
CV (%)	5.8	14.4	16.5	26.9	47.4	9.7	32.6

Means with the different letter(s) in the same column for each sub ecology are significantly different ($P \leq 0.05$) following separation by Tukey's Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

Table 3.11: Performance of elite groundnut genotypes in the varying potential agro-ecologies in Kongwa and Kiteto districts

Treatments	Days to 50% Flowering	Leaf spot severity	Aphids damage	No. of pods/ plant	Pod weight / plot (kg)	100 Seed weight (g)	Grain yield (kg/ha)
High							
ICGV-SM 02724	40.50 de	2.250 a	2.000 b	41.15	3.86	50.15 cd	1538.87 ab
ICGV-SM 05650	31.25 a	3.500 abc	1.250 a	30.40	5.22	50.53 d	2105.08 b
Local Check	34.75 abc	4.750 c	2.500 bc	38.90	4.60	36.88 abc	1950.67 b
Moderate							
ICGV-SM 02724	43.50 e	2.250 a	2.000 b	38.20	2.37	52.70 d	506.19 a
ICGV-SM 05650	38.50 cde	2.750 ab	1.000 a	36.25	3.55	39.70 abcd	1014.07 ab
Local Check	42.00 de	4.000 bc	3.000 c	31.35	2.25	36.85 abc	648.55 a
Low							
ICGV-SM 02724	43.50 e	2.500 a	2.000 b	30.15	2.64	46.58 bcd	670.67 a
ICGV-SM 05650	32.50 ab	2.500 a	1.000 a	30.80	4.09	36.70 ab	1487.08 ab
Local Check	37.00 bcd	4.500 c	2.250 b	33.80	2.35	30.03 a	673.53 a
Grand mean	38.17	3.222	1.889	34.6	3.44	42.23	1177.19
SE±	0.634	0.1623	0.0895	3.34	0.412	1.623	154.001
P-value	0.001	0.001	0.001	0.699	0.057	0.001	0.022
LSD $_{(P=0.05)}$	1.843	0.4719	0.2602	ns	ns	4.717	447.675
CV (%)	5.8	17.5	16.4	33.5	41.5	13.3	45.3

Means with the different letter(s) in the same column for each sub ecology are significantly different (P ≤ 0.05) following separation by Tukey's Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

The relationship between sub ecology and grain yield of groundnut genotypes (Figure 3.1) showed that ICGV-SM 05650 recorded the highest grain yield followed by the Local (Mnanje) and ICGV-SM 02724.

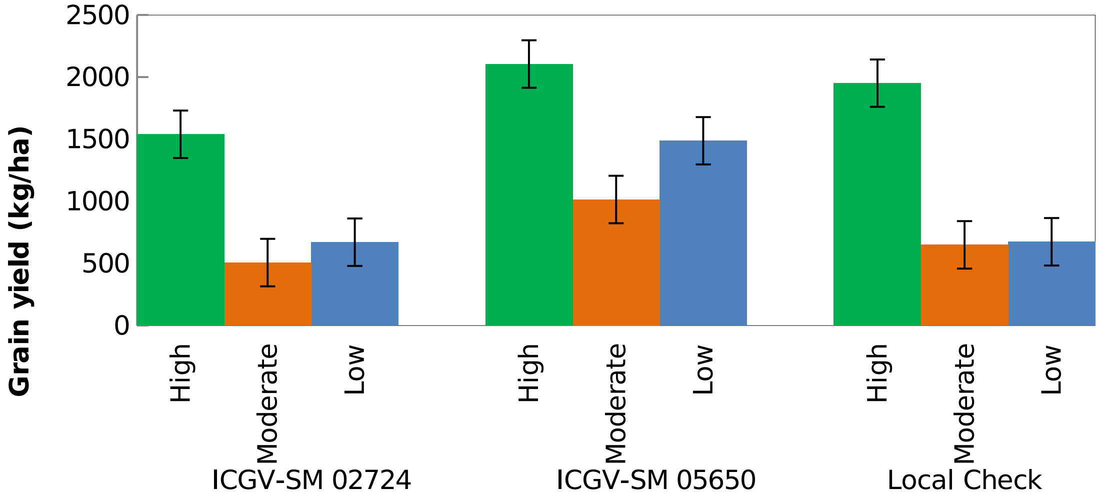

Figure 3.1: Yield performance of groundnut genotypes in different potential agro-ecologies in Kongwa and Kiteto districts

3.6.2.2 Pigeon pea

Three genotypes (ICEAP 00554, ICEAP 00557 and ICEAP 00040-Local) were evaluated in the high and moderate potential agro-ecologies of Kongwa and Kiteto districts respectively (Table 3.12). In the high potential; significant differences ($P \leq 0.05$) were observed in days to 50% flowering, plant height, leaf spot severity and 100 seed weight while pod weight and grain yield were non-significant. In the moderate potential; significant differences ($P \leq 0.05$) were observed in days to 50% flowering, plant height and leaf spot severity while pod weight, 100 seed weight and grain yield were non-significant. Performance results across the varying potential agro-ecologies (Table 3.13) showed significant differences ($P \leq 0.05$) among the genotypes tested for days to 50% flowering, plant height, leaf spot severity and 100 seed weight while pod weight and grain yield were non-significant. Even though genotypic differences in grain yield were insignificant, genotype ICEAP 00040-Local had the highest grain yields of 779.17 kg ha^{-1}

and 673.73 kg ha^{-1} at high and moderate potential agro-ecologies respectively compared to the others.

Table 3.12: Performance of elite pigeon pea genotypes in the various potential agro-ecologies

Treatments	Days to 50% Flowering	Plant height (cm)	Leaf spot severity	Pod weight/ plot (kg)	100 Seed weight (g)	Grain yield (kg/ha)
High						
ICEAP 00554	75.00 a	127.0 a	0.500 a	3.250	24.75 b	687.5
ICEAP 00557	78.50 a	125.9 a	0.500 a	3.638	18.75 a	770.8
ICEAP 00040-local	125.00 b	205.3 b	2.500 b	3.300	20.20 a	779.2
Grand mean	92.8	152.7	1.17	3.40	21.2	745.83
SE±	2.30	9.00	0.382	0.580	0.94	196.368
P-value	0.001	0.005	0.033	0.881	0.015	0.925
LSD (0.05)	8.87	39.33	1.557	ns	3.43	Ns
CV (%)	5.3	14.2	73.4	34.4	8.9	48.2
Moderate						
ICEAP 00554	72.00 a	98.8 ab	0.0000 a	2.100	21.80	470.9
ICEAP 00557	73.25 a	89.5 a	0.7500 b	2.062	22.40	233.4
ICEAP 00040-local	122.00 b	154.8 b	2.0000 c	3.212	22.40	673.7
Grand mean	89	114.4	0.917	2.46	22.2	459.36
SE±	1.8	3.35	0.204	0.331	1.15	249.565
P-value	0.001	0.028	0.001	0.430	0.913	0.098
LSD (0.05)	8.8	45.71	0.5247	ns	ns	Ns
CV (%)	5.5	22.0	31.5	53.1	10.2	49.0

Means with the different letter(s) in the same column for each sub ecology are significantly different (P ≤ 0.05) following separation by Tukey’s Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

Table 3.13: Performance of elite pigeon pea genotypes in the varying potential agro-ecologies in Kongwa and Kiteto districts

Treatments	Days to 50% Flowering	Plant height (cm)	Leaf spot severity	Pod weight/ plot (kg)	100 Seed weight (g)	Grain yield (kg/ha)
High						
ICEAP 00554	75.00 a	127.0 ab	0.50 a	3.25	24.8 b	687.50
ICEAP 00557	78.50 a	125.9 ab	0.50 a	3.64	18.8 a	770.83
ICEAP 00040-local	125.00 b	205.3 c	2.50 c	3.30	20.2 ab	779.17
Moderate						
ICEAP 00554	72.00 a	98.8 ab	0.00 a	2.10	21.8 ab	470.91
ICEAP 00557	73.25 a	89.6 a	0.75 ab	2.06	22.4 ab	233.44
ICEAP 00040-local	122.00 b	154.8 b	2.0000 c	3.212	22.40 a	673.7
Grand mean	91	133.6	1.04	2.93	21.7	602.60
SE±	2.3	8.84	0.205	0.606	0.77	130.935
P-value	<.001	<.001	<.001	0.787	0.019	0.484
LSD (0.05)	6.9	26.39	0.611	ns	2.30	Ns
CV (%)	7.2	18.7	55.6	58.5	10.1	61.5

Means with the different letter(s) in the same column for each sub ecology are significantly different ($P \leq 0.05$) following separation by Tukey's Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

The relationship between sub ecology and grain yield of pigeon pea genotypes (Figure 3.2) showed that generally ICEAP 00040-Local recorded the highest grain yield in both agro-ecologies compared to the other genotypes.

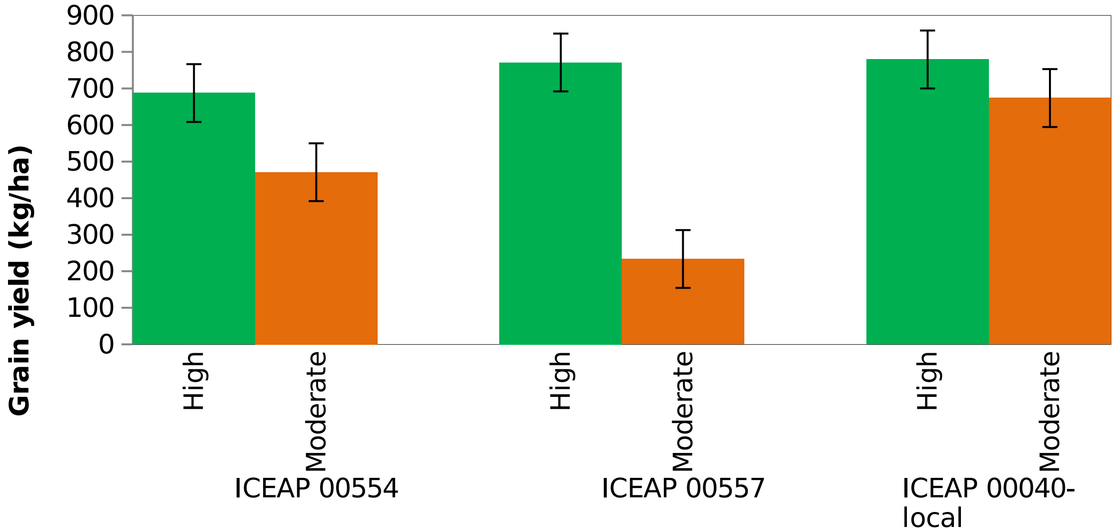

Figure 3.2: Yield performance of pigeon pea genotypes in different potential agro-ecologies in Kongwa and Kiteto districts

3.6.2.3 Sorghum

Table 3.14 shows results of performance of the four genotypes (GAMBELLA 1107, IESV 92028 DL, IESV 23010 DL and Local check) in high and low potential agro-ecologies. In the high potential; significant differences were observed in days to 50% flowering, plant height and leaf spot severity while aphids damage, dry panicle weight and grain yield were insignificant. In the low potential; significant differences were observed in days to 50% flowering, plant height, leaf spot severity, aphids damage and grain yield while dry panicle weight was insignificant. Performance results across the varying potential agro-ecologies (Table 3.15) showed significant differences ($P \leq 0.05$) among the genotypes tested for days to 50% flowering, plant height, leaf spot severity, aphids damage while dry panicle weight and grain yield were insignificant. Even though genotypic differences were not significant at both high and low potential agro-ecologies, GAMBELLA 1107 had the highest grain yields of 1420.8 kg ha^{-1} and 642.0 kg ha^{-1} in these potential agro-ecologies respectively compared to the other genotypes. Lower grain yields were recorded in the Local check (Lugugu) of 562.2 kg ha^{-1}(in the high) and 429.9 kg ha^{-1}(in the low) potential agro-ecologies respectively.

Table 3.14: Performance of elite sorghum genotypes in the various potential agro-ecologies

Treatments	Days to 50% Flowering	Plant height (cm)	Leaf spot severity	Aphids damage	Dry panicle weight/plot (kg)	Grain yield (kg/ha)
High						
GAMBELLA 1107	67.25 bc	141.3 ab	2.000 a	1.500	3.800	1420.8
IESV 92028 DL	62.00 ab	143.2 ab	2.000 a	1.000	1.825	759.6
IESV 23010 DL	58.25 a	119.7 a	1.750 a	1.500	2.525	1038.0
LOCAL CHECK	73.50 c	197.4 b	3.750 b	2.250	3.875	562.2
Grand mean	65.25	150.4	2.38	1.56	3.01	945
SE±	4.13	13.14	0.272	0.247	1.028	400.4
P-value	0.002	0.038	0.009	0.101	0.542	0.597
LSD (0.05)	5.818	49.97	1.048	ns	ns	ns
CV (%)	5.3	19.9	26.4	37.8	75.5	96.3
Low						
GAMBELLA 1107	73.75 a	127.7 ab	2.250 ab	1.000 a	1.863	642.0 b
IESV 92028 DL	75.50 a	125.4 ab	1.500 a	1.750 a	1.000	327.2 a
IESV 23010 DL	73.75 a	120.6 a	2.000 ab	1.250 a	1.638	527.4 ab
LOCAL CHECK	85.75 b	143.7 b	3.250 b	3.750 b	1.550	429.9 ab
Grand mean	77.19	129.3	2.25	1.94	1.51	482
SE±	2.84	4.24	0.375	0.308	0.446	126.587
P-value	0.005	0.050	0.036	0.001	0.167	0.023
LSD (0.05)	5.909	16.10	1.095	0.758	ns	224.0
CV (%)	4.6	7.4	29.1	23.4	26.4	27.8

Means with the different letter(s) in the same column for each sub ecology are significantly different ($P \leq 0.05$) following separation by Tukey's Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

Table 3.15: Performance of elite sorghum genotypes in the varying potential agro-ecologies in Kongwa district

Treatments	Days to 50% Flowering	Plant height (cm)	Leaf spot severity	Aphids damage	Dry panicle weight/plot (kg)	Grain yield (kg/ha)
High						
GAMBELLA 1107	67.25 ab	141.3ab	2.000 ab	1.500	3.800	1420.8
IESV 92028 DL	62.00 ab	143.2ab	2.000 ab	1.000	1.825	759.6
IESV 23010 DL	58.25 a	119.7a	1.750 a	1.500	2.525	1038.0
LOCAL CHECK	73.50 bc	197.4b	3.750 c	2.250	3.875	562.2
Low						
GAMBELLA 1107	73.75 bc	127.7 a	2.250 ab	1.000 a	1.862	642.0
IESV 92028 DL	75.50 bc	125.4a	1.500 a	1.750 a	1.000	327.2
IESV 23010 DL	73.75 bc	120.6a	2.000 ab	1.250 a	1.637	527.4
LOCAL CHECK	85.75 c	143.7ab	3.250 bc	3.750 b	1.550	429.9
Grand mean	71.2	139.9	2.31	1.750	2.26	713
SE±	2.16	9.44	0.220	0.1950	0.550	190.6
P-value	0.001	0.007	0.001	0.005	0.265	0.201
LSD (0.05)	6.33	27.62	0.643	0.8070	ns	ns
CV (%)	8.6	19.1	26.9	31.5	68.8	75.6

Means with the different letter(s) in the same column for each sub ecology are significantly different (P ≤ 0.05) following separation by Tukey's Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

The relationship between sub ecology and grain yield of sorghum genotypes (Figure 3.3) showed that GAMBELLA 1107 recorded the highest grain yield in both agro-ecologies compared to the Local (Lugugu) with the lowest.

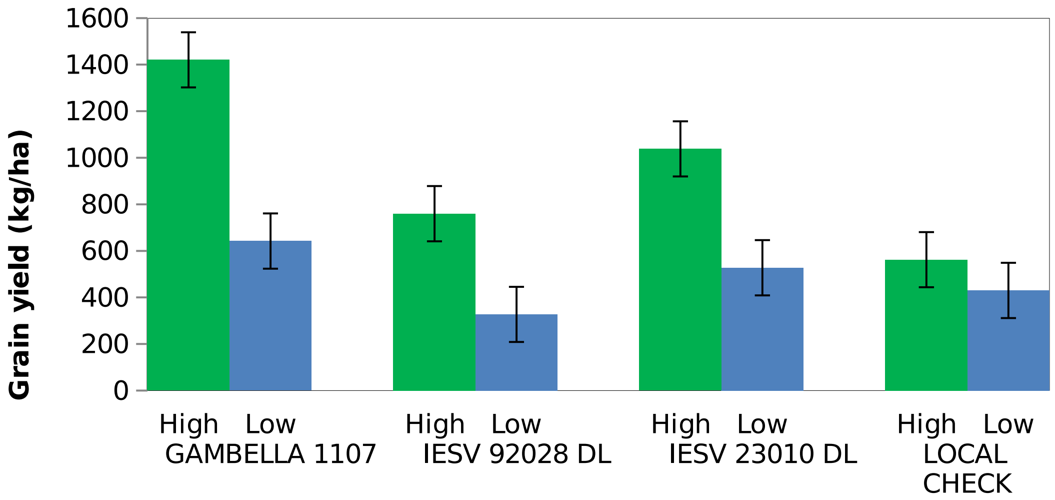

Figure 3.3: Yield performance of sorghum genotypes in different potential agro-ecologies in Kongwa district

3.6.2.4 Pearl millet

Performance results of the four genotypes (IP 8774, SDMV 94005, SDMV 96053 and Local check) in the low potential agro-ecology showed significant differences ($P \leq 0.05$) among the genotypes tested for grain yield, days to 50% flowering, plant height and leaf spot severity while dry panicle weight was non-significant (Table 3.16). Genotype IP 8774 was the highest in grain yield (1049.4 kg ha^{-1}) and was significantly superior ($P \leq 0.05$) to the local check (Uwele) that was lowest in yield (388.9 kg ha^{-1}).

Table 3.16: Performance of elite pearl millet genotypes in the low potential agro-ecology in Kongwa district

Treatments	Days to 50% Flowering	Plant height (cm)	Leaf spot severity	Dry panicle weight (kg)	Grain yield (kg/ha)
IP 8774	54.25 a	116.7a	2.250 ab	2.413	1049.4 b
SDMV 96053	54.50 a	113.0 a	2.500 ab	1.662	813.6 ab
SDMV 94005	58.00 a	99.3 a	1.500 a	1.725	824.7 ab
Local Check	77.25 b	188.1 b	3.500 b	3.013	388.9 a
Grand mean	61.0	129.3	2.44	2.20	769.14
SE±	3.18	4.59	0.324	0.483	102.167
P-value	0.004	0.001	0.020	0.245	0.015
LSD (0.05)	10.65	15.34	1.083	ns	341.654
CV (%)	10.4	7.1	26.6	43.9	26.6

Means with the different letter(s) in the same column for each sub ecology are significantly different ($P \leq 0.05$) following separation by Tukey's Test. CV = Coefficient of variation, S.E± = Standard error, LSD (Least significant difference), ns (Not significant). Mean separation test values also indicated.

The relationship between sub ecology and grain yield of pearl millet genotypes (Figure 3.4) indicated that IP 8774 recorded the highest grain yield, followed by SDMV 94005 and SDMV 96053 while the Local (Uwele) had the lowest.

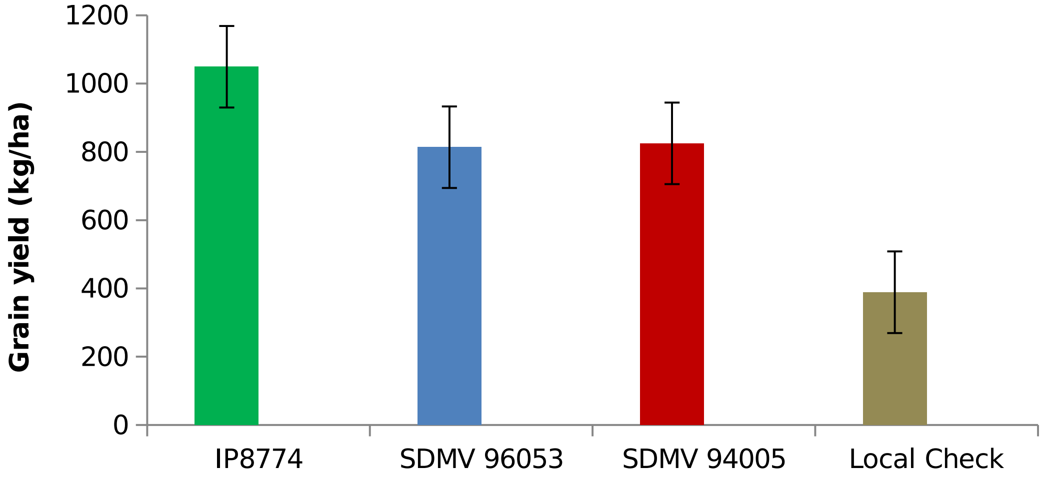

Figure 3.4: Yield performance of pearl millet genotypes in the low potential agro-ecology in Kongwa district

3.7 Discussion

3.7.1 Performance of legume genotypes

The findings of the study revealed that groundnut genotypes had non-significant differences both in the high and moderate potential agro-ecologies in grain yield, but significant variations were observed in the low potential agro-ecology. ICGV-SM 05650 with the highest grain yield of 1487.08 kg ha^{-1} was superior to ICGV-SM 02724 and the Local check (Mnanje). These results show that groundnut ICGV-SM 05650 is more adapted to these potential agro-ecologies. The above findings are in agreement with the report of Hoeschle-Zeledon (2019), who reported that elite materials had superior genetics and indeed outperformed the local landraces. Kamut *et al*. (2013) reported that existence of genetic variability among genotypes for grain yield raises the possibilities of identifying high yielding genotypes under varying environments which is in conformity with this study.

On the other hand, pigeon pea showed non-significant differences ($P \leq 0.05$) among the genotypes tested yet ICEAP 00040 (local) had the highest grain yield of 779.17 kg ha^{-1} compared to genotypes ICEAP 00557 and ICEAP 00554 with relatively lower yields of 770.83 kg ha^{-1} and 687.50 kg ha^{-1} respectively. The findings agree with the report of Okori (2014) and Hoeschle-Zeledon (2019), who observed non-significant reaction of the pigeon pea genotypes in relation to stress due to the fact that the three materials were all improved genotypes.

3.7.2 Performance of cereal genotypes

Performance results in the sorghum genotypes though showed non-significant differences among the tested materials for grain yield, GAMBELLA 1107 outperformed the other genotypes in both agro-ecologies indicating that it is more adapted to these environments and therefore more drought-resistant. This trait makes it able to perform even in stressful environments e.g. in Laikala and Moleti with very low precipitation of about 350 mm of rainfall per annum. The Africa RISING team through its baseline studies further confirmed that indeed drought hardy cereals such as pearl millet and sorghum can be cultivated in these semi-arid areas (Ganga Rao *et al.,* 2013). For the pearl millet, results showed significant differences among genotypes in terms of grain yield in the low potential agro-ecology evaluated. Elite material IP 8774 outperformed the other genotypes including the Local landrace. This shows that IP 8774 is the most adapted to these micro-environments and also drought tolerant genotype since it performs better in the test site of Kongwa district receiving little amount of rainfall (about 350 mm). These findings confirm what Hoeschle-Zeledon (2019) reported that the Africa RISING team developed varieties with high yield advantage compared to the local landraces and further observed that the extra-early maturing material IP 8774 performed better when compared to the other test materials.

3.8 Conclusions and Recommendation

The study has played an important role in identifying legume and cereal genotypes of higher productivity in the various sub ecologies of central Tanzania. Findings reveal that generally elite materials outperformed the landrace controls. The study generally recommends genotypes ICGV-SM 05650 (Groundnut), ICEAP 00040 (Pigeon pea), GAMBELLA 1107 (Sorghum) and IP8774 (Pearl millet) for deployment in these varying potential agro-ecologies due to their superior performance in terms of grain yield.

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CHAPTER FOUR

Paper Two

4.0 Determination of Stability and GxE Interaction of Legume and Cereal Genotypes in Different Agro-Ecologies of Central Tanzania

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4.1 Abstract

Legumes and cereals are important components of sustainable agricultural production systems and are vital in sustaining food, nutrition, income security as well as improving soil health status in the semi-arid tropics. Field experiments were conducted during the 2019-2020 cropping season in different sub agro-ecologies of central Tanzania to determine stability and genotype x environment interaction (GEI) of legume and cereal genotypes for grain yield in the different sub agro-ecologies. An incomplete randomized block design with farmers as replications was used at each sub agro-ecology. Grain yield data of the fourteen genotypes in total of the four crops (groundnut, pigeon pea, sorghum and pearl millet) was collected. Results from the experiments generally revealed that G x M x E interactions were insignificant ($p \leq 0.05$) in terms of grain yield for all the crop genotypes studied. Among the groundnut and pigeon pea genotypes, significant differences ($p \leq 0.05$) were observed across the sub-ecologies while significant genotypic effects were observed in both sorghum and pearl millet genotypes. Although early planting outperformed late planting for the crop genotypes tested in terms of grain yield, non-significant differences ($p \leq 0.05$) in planting dates were observed. Furthermore, crop genotypes in the high potential generally out performed those under the moderate and low potential sub-ecologies. The above findings revealed that genotypes ICGV-SM 05650, ICEAP 00040, GAMBELA 1107 and IP8774 with superior grain yield performance were more adapted thus, recommended for deployment in these sub agro-ecologies of central Tanzania.

Keywords: Legumes; Cereals, Stability; Genotype x Environment interactions; Grain yield

4.2 Introduction

Legumes and cereals are important components of sustainable agricultural production systems of developing countries especially in the sub-Saharan Africa (SSA) (Ojiewo *et al.*, 2019). In the semi-arid tropics (SAT) particularly central Tanzania, they have been vital in sustaining food, nutrition, income security as well as improving soil health status. Though low production of these crops has been observed in the region mainly due to weather and other natural disaster-related challenges which lower the crop yields (Okori, 2014). This calls for a need to develop varieties possessing stable performance as genotypes in segregated generations with allelic variation express themselves differently in response to different environments (Gauch and Zobel, 1996).

Therefore exploitation of good adaptation and stability of yield and its components in legume and cereal genotypes would make it possible to develop/identify high yielding and well-adapted genotypes since developing high yielding varieties with wide adaptability is the ultimate aim of plant breeders. Though attaining this goal is made more complicated by genotype-environment interactions (GEI) (Rad *et al*., 2013). GEI is of major concern to plant breeders because a large interaction can reduce gains from selection and make identification of superior genotypes difficult. Assessing GEI is thus important in determining an optimum strategy for selecting genotypes adapted to target environments (Kamila *et al*., 2016). Kang (1998) discussed broadly the causes of GEI and ways to exploit or minimize it. An understanding of the causes of GEI is vital for the implementation of efficient selection and evaluation networks (Ramburan and Zhou, 2011).

Evaluation of different genotypes in a multi-environment and/or year is not only important to determine high-yielding cultivars but also to identify sites that best represent the target environment (Yan *et al.*, 2001). Moreover, the successfully developed high-yielding potential new cultivar is recommended to have stable performance and broad adaptation over a wide range of environments (Wachira *et al*., 2002). A genotype is considered stable if it has adaptability for a trait of economic importance across diverse environments. The environmental component (E) generally represents the largest component in analyses of variance, but it is not relevant to cultivar selection, only G and GE are relevant to meaningful cultivar evaluation and must be considered concurrently for making selection decisions (Yan and Kang, 2003). Though there is no single method developed so far that equally satisfies plant breeders for the study of G x E interactions, there are many different statistical analyses in use today, including parametric and non-parametric, to study the nature of interactions of genotypes with environments (Kaya *et al*., 2006). Two commonly used statistical analyses are the additive main effects and multiplicative interaction (AMMI) model and the genotype main effects and genotype x environment interaction effects (GGE) model (Gauch, 2006). AMMI in multi-environment trials (MET) data analysis partitions the GEI matrix into individual genotypic and environmental scores (Bocianowski *et al*., 2019; Zobel *et al*., 1988). Therefore, this study aims at determining stability and GxE interaction of legume and cereal genotypes in different potential agro-ecologies.

4.3 Materials and Methods

4.3.1 Description of experimental sites

The study was conducted during the 2019-2020 cropping season in the Central zone of Tanzania in three sub agro-ecologies i.e., high potential zone (Manyusi and Mlali villages in Kongwa district) which receives ≥500mm of rainfall; moderate potential zone (Njoro-1 and Njoro-2 villages in Kiteto district) which receives 400-500mm of rainfall and low potential zone (Laikala and Moleti villages in Kongwa district) which receives ≤ 350mm of rainfall (Hoeschle-Zeledon, 2019). Kongwa district lies between latitudes 5° 30' to 6° 00' S and longitudes 36°15' to 36°00' E with altitude stretching between 900 and 1000 masl (URT, 2016). The average temperature is 26.5°C though sometimes gradually changes up to 11°C. The cool weather occurs between January and June when temperature ranges between 20 – 33°C and the highest temperature recorded is 31°C while the lowest temperature is 18° C (PORA and LGOVT, 2016).

Kiteto district lies between latitudes of 05°52'00"S and longitudes of 36°51'00"E with altitude stretching between 500 and 1200 masl. The average day and night temperature is 22°C. The cool months are March, April, May and June while the hot months are July, August, September, October and November (PO-RALG, 2018). These areas consist of mainly well-drained sandy loamy soils (see Appendix 1) with low fertility and are characterized by unimodal and unreliable rainfall of 300-800mm/year with a December-March cropping season (URT, 2007; MAFC, 2014; Msuya, 2015).

4.3.2 Materials

Ten elite genotypes in total (of groundnut, pigeon pea, sorghum and pearl millet) proposed for release and four local checks (one for each crop) were used in this study (Table 4.1). The elite genotypes were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT-MALAWI) including one local check (ICEAP 00040) and the remaining three local checks were obtained from the local market in Dodoma.

Table 4.1: Description of test materials used in the study

	Crop	Genotype	Maturity duration (days)	Source
1.	Groundnut	ICGV-SM 02724	Medium (120)	ICRISAT-MALAWI
		ICGV-SM 05650	Short (90)	ICRISAT-MALAWI
		LOCAL CHECK (Mnanje)	Short (110)	DODOMA MARKET
2.	Pigeon pea	ICEAP 00554	Medium (150-180)	ICRISAT-MALAWI
		ICEAP 00557	Medium (150-180)	ICRISAT-MALAWI
		CHECK- ICEAP 00040 (Mali)	Long (190-240)	ICRISAT-MALAWI
3.	Sorghum	GAMBELLA 1107	Short (70)	ICRISAT-MALAWI
		IESV 92028 DL	Medium (90)	ICRISAT-MALAWI
		IESV 23010 DL	Medium (90)	ICRISAT-MALAWI
		LOCAL CHECK (Lugugu)	Long (110)	DODOMA MARKET
4.	Pearl millet	IP 8774	Short (70)	ICRISAT-MALAWI
		SDMV 96053	Medium (90)	ICRISAT-MALAWI
		SDMV 94005	Medium (90)	ICRISAT-MALAWI
		LOCAL CHECK (Uwele)	Long (110)	DODOMA MARKET

4.3.3 Methodology and experimental design

One experiment was laid down in each village in the high potential (Manyusi and Mlali); moderate potential (Njoro-1 and Njoro-2) and low potential (Laikala and Moleti) sub ecologies to test the effect of one sub agro-ecological condition in Kongwa and Kiteto districts. A total of 4 crops (sorghum, pearl millet, groundnut and pigeon pea) with test varieties were evaluated against the local landrace (Appendix 3). The groundnut experiments were conducted in all the sub ecologies, pigeon pea in the high and moderate, sorghum in the high and low while pearl millet occurred in the low potential sub ecology. Two planting dates (early planting vs 2 weeks after first planting) were executed under each environment as shown in Table 4.2. All experiments at these sites were established following an incomplete randomized block design with two farmers selected per sub agro-ecology as replications. The plot size was 7 rows, 8 m long spaced at 75 cm between ridges. The field layout of the sole crops and intercrops are as shown in Appendix 3 and Appendix 4 respectively.

Table 4.2: General treatment structure

Crops	Varieties	Environments	Time of planting
1. Groundnut	V_1,V_2,V_c	1. Low potential	1. Early planting
2. Pigeon pea	V_1,V_2,V_c	2. Moderate potential	2. Late planting
3. Sorghum	V_1,V_2,V_3,V_c	3. High potential	
4. Pearl millet	V_1,V_2,V_3, V_c		

V_c - Local check

4.4 Data Collection

Grain yield data assessed based on the whole plot (12 m^2) was collected in kg/plot and then converted to hectare (10 000 m^2) to determine the grain yield in kg/ha.

4.5 Data Analysis

Grain yield data was analysed by using GenStat statistical package 16th Edition in order to determine genotype by management by environment interaction of the test materials.

4.6 Results

4.6.1 Effect of genotype by management by environment interaction on grain yield of crop genotypes

4.6.1.1 Groundnut

Significant differences in reaction ($P \leq 0.05$) of genotypes (ICGV-SM 05650, ICGV-SM 02724 and Local check) were found among the genotypes and across the three sub ecologies, while non-significant differences ($P \leq 0.05$) in planting dates were observed as shown in Table 4.3. Genotype x management x environment (GME) interaction on the other hand showed non-significant differences ($P \leq 0.05$) for sub ecology x planting date, sub ecology x genotype, planting date x genotype and sub ecology x planting date x genotype interactions. Nonetheless, early planting outperformed late planting in all the sub ecologies. Genotype performance was superior in the high potential compared to the other sub ecologies. ICGV-SM 05650 genotype with the highest yield of 2484.00 kg ha^{-1} ranked first in all the potential agro-ecologies. In the high potential sub-ecology however, its relative yield losses were higher (30.51%) compared to the Local landrace with 11.30% yield losses due to late planting. In the moderate potential, ICGV-SM 05650 genotype registered higher (36.78%) yield losses compared to 17.22% of the Local landrace and in the low potential agro-ecology the Local landrace had higher (52.69%) compared 50.48% of ICGV-SM 05650 genotype.

Table 4.3: Genotype by management by environment interaction of selected elite groundnut genotypes in Kongwa and Kiteto districts

Sub ecology	Management	Genotype	Yield (kg/ha)	Yield loss (%)
High	Early planting	ICGV- SM 02724	1577.42	0
		ICGV- SM 05650	2484.00	0
		Local check	2067.50	0
	Late planting	ICGV- SM 02724	1500.33	4.89
		ICGV- SM 05650	1726.17	30.51
		Local check	1833.83	11.30
Moderate	Early planting	ICGV- SM 02724	537.75	0
		ICGV- SM 05650	1242.58	0
		Local check	709.67	0
	Late planting	ICGV- SM 02724	474.64	11.74
		ICGV- SM 05650	785.56	36.78
		Local check	587.43	17.22
Low	Early planting	ICGV- SM 02724	883.83	0
		ICGV- SM 05650	1989.17	0
		Local check	914.42	0
	Late planting	ICGV- SM 02724	457.50	48.24
		ICGV- SM 05650	985.00	50.48
		Local check	432.64	52.69

Fpr-Sub ecology (SE) = <0.001, Fpr-Planting date (PD) = 0.066, Fpr-Genotype (G) = 0.013, Fpr -SE x PD = 0.538, Fpr - SE x G = 0.656, Fpr - PD x G = 0.300, Fpr -SE x PD x G = 0.998.

The statistics restricted to yield not yield loss.

Yield loss is computed as a proportionate reduction in grain yield from the optimally managed crop, i.e., early vs late planting in each sub ecology

4.6.1.2 Pigeon pea

Significant differences in reaction (P ≤ 0.05) of the genotypes (ICEAP 00554, ICEAP 00557 and ICEAP 00040-Local) across the two sub ecologies were observed while non-significant differences were observed between planting dates and genotypes reactions as shown in Table 4.4. Genotype x management x environment (GME) interaction on the other hand showed non-significant differences (P ≤ 0.05) for sub ecology x planting date, sub ecology x genotype, planting date x genotype and sub ecology x planting date x genotype interactions. Within the high potential sub-ecology, ICEAP 00557 genotype registered high yield losses of 61.94%, ICEAP 00554 (36.63%) and ICEAP 00040 (14.85%) due to late planting. While in the moderate potential sub-ecology, ICEAP 00554 genotype registered 81.73%, ICEAP 00040 (63.08%) and ICEAP 00557 (57.01%) yield losses due to late planting. Genotype ICEAP 00040 with relatively higher yields of 841.67 kg ha^{-1} ranked second in the high potential and first (984.13 kg ha^{-1}) in the moderate potential sub-ecology.

Table 4.4: Genotype by management by environment interaction of selected elite pigeon pea genotypes in Kongwa and Kiteto districts

Sub ecology	Management	Genotype	Yield (kg/ha)	Yield loss (%)
High	Early planting	ICEAP 00554	841.67	0
		ICEAP 00557	1116.67	0
		ICEAP 00040- Mali	841.67	0
	Late planting	ICEAP 00554	533.33	36.63
		ICEAP 00557	425.00	61.94
		ICEAP 00040- Mali	716.67	14.85
Moderate	Early planting	ICEAP 00554	796.33	0
		ICEAP 00557	326.51	0
		ICEAP 00040- Mali	984.13	0
	Late planting	ICEAP 00554	145.49	81.73
		ICEAP 00557	140.37	57.01
		ICEAP 00040- Mali	363.33	63.08

Fpr-Sub ecology (SE) = 0.013, Fpr-Planting date (PD) = 0.065, Fpr-Genotype (G) = 0.371, Fpr -SE x PD = 0.679, Fpr - SE x G = 0.381, Fpr - PD x G = 0.940, Fpr -SE x PD x G = 0.265.

The statistics restricted to yield not yield loss.

Yield loss is computed as a proportionate reduction in grain yield from the optimally managed crop, i.e., early vs late planting in each sub ecology

4.6.1.3 Sorghum

Significant differences in reaction ($P \leq 0.05$) of the genotypes (GAMBELLA 1107, IESV 92028 DL, IESV 23010 DL and Local check) were found across the two sub ecologies, while non-significant differences ($P \leq 0.05$) were observed between sub ecologies and planting dates respectively as shown in Table 4.5. Genotype x management x environment (GME) interaction on the other hand showed non-significant differences ($p \leq 0.05$) for sub ecology x planting date, sub ecology x genotype, planting date x genotype and sub ecology x planting date x genotype interactions. The local landrace (Lugugu) lost up to 71.42% of its grain yield when planted late in the high potential sub-ecology compared to 32.85% for IESV 23010 DL, 32.71% for IESV 92028 and 12.66% for GAMBELLA 1107. While in the low potential sub-ecology, the local landrace lost about 21.21% of its grain yield, IESV 23010 DL (11.42%), IESV 92028 DL (39.31%) and GAMBELLA 1107 (3.67%) when late planted. GAMBELLA 1107 with the highest yield of 1517.00 kg ha^{-1} ranked first in both potential sub-ecologies. The lowest yield losses in GAMBELLA 1107 compared to the Local landrace demonstrates the advantage of elite genotypes even under harsh conditions.

Table 4.5: Genotype by management by environment interaction of selected elite sorghum genotypes in Kongwa and Kiteto districts

Sub ecology	Management	Genotype	Yield (kg/ha)	Yield loss (%)
High	Early planting	GAMBELLA 1107	1517	0
		IESV 92028 DL	908	0
		IESV 23010 DL	1242	0
		Local Check	875	0
	Late planting	GAMBELLA 1107	1325	12.66
		IESV 92028 DL	611	32.71
		IESV 23010 DL	834	32.85
		Local Check	250	71.42
Low	Early planting	GAMBELLA 1107	654	0
		IESV 23010 DL	407	0
		IESV 92028 DL	499	0
		Local Check	481	0
	Late planting	GAMBELLA 1107	630	3.67
		IESV 23010 DL	247	39.31
		IESV 92028 DL	556	11.42
		Local Check	379	21.21

Fpr-Sub ecology (SE) = 0.098, Fpr-Planting date (PD) = 0.719, Fpr-Genotype (G) = 0.034, Fpr -SE x PD = 0.789, Fpr - SE x G = 0.362, Fpr - PD x G = 0.898, Fpr -SE x PD x G = 0.919.

The statistics restricted to yield not yield loss.

Yield loss is computed as a proportionate reduction in grain yield from the optimally managed crop, i.e., early vs late planting in each sub ecology

4.6.1.4 Pearl millet

Significant differences in reaction ($p \leq 0.05$) of the genotypes (IP 8774, SDMV 94005, SDMV 96053 and Local check) were observed, while non-significant differences ($P \leq 0.05$) were observed in the planting dates as shown in Table 4.6. Genotype x management (GM) interaction on the other hand showed non-significant differences ($P \leq 0.05$) for planting date x genotype interactions. The local landrace (Uwele) lost up to 25% of its grain yield when planted late compared to 38.26% for SDMV 94005, 11.20% for SDMV 96053 and 38.10% for IP 8774. IP 8774 genotype with grain yield of 1296.30 kg ha^{-1} ranked first and the local landrace (345.68 kg ha^{-1}) ranked last.

Table 4.6: Genotype by management interaction of selected elite pearl millet genotypes in low potential agro-ecology in Kongwa district

Management	Genotype	Yield (kg/ha)	Yield loss (%)
Early planting	IP 8774	1296.30	0
	SDMV 96053	861.73	0
	SDMV 94005	1019.75	0
	Local Check	345.68	0
Late planting	IP 8774	802.47	38.10
	SDMV 96053	765.43	11.20
	SDMV 94005	629.63	38.26
	Local Check	432.10	25.00

Fpr-Planting date (PD) = 0.065, Fpr-Genotype (G) = 0.015, Fpr - PD x G = 0.253.
The statistics restricted to yield not yield loss.

Yield loss is computed as a proportionate reduction in grain yield from the optimally managed crop, i.e., early vs late planting in each sub ecology

4.7 Discussion

4.7.1 G x M x E interaction on grain yield of legume and cereal genotypes

Genotype x environment interaction (GEI) has been widely reported to impede the speed at which desirable cultivars are made (Caliskan *et al.*, 2007). In this study, findings reveal the effect of genotype by management by environment interaction on these test materials.

Generally, non-significant G x M x E interactions existed in the genotypes of all the four crops indicating that all these test materials were stable in these varying potential sub-ecologies. In groundnuts, significant differences in genotype reactions of the test materials and across the sub ecologies were observed. Genotype ICGV-SM 05650 outperformed the other genotypes in all the sub-ecologies showing that this elite material is more adapted to these semi-arid environments and hence can be deployed to all these villages. These results agree with previous reports by Hoeschle-Zeledon (2019) who noted that short duration Spanish ICGV-SM 05650 genotype out yielded the Virginia genotype (ICGV-SM 02724) by almost 300 kg/ha and the highest grain yield was found in Mlali, Moleti and Manyusi (Kongwa district) whereas the lowest yields were in Igula (Iringa district), Njoro and Kiperesa (Kiteto district).

For pigeon pea, significant differences were observed in both sub-ecologies, while non-significant genotypic effects occurred in the three genotypes tested confirming the fact that all these materials are improved. Nevertheless, ICEAP 00040- Mali had relatively higher yields (984.13 kg ha^{-1}) compared to ICEAP 00554 (796.33 kg ha^{-1}) and ICEAP 00557 (326.51 kg ha^{-1}) in the moderate potential sub-ecology. The findings agree with Hoeschle-Zeledon (2019) who reported that ICEAP 00040, a long-duration variety, was the most adapted genotype across the different environments.

Significant genotypic effects were observed in the four sorghum test materials evaluated. GAMBELLA 1107 had superior grain yield performance compared to the other genotypes. Hoeschle-Zeledon (2019), also reported similar findings that GAMBELLA 1107 was more stable and adapted to these semi-arid environments compared to the other genotypes implying that it was the most drought resistance genotype.

As for the pearl millet, significant genotypic reactions were observed in the four genotypes although non-significant differences occurred due to planting dates. IP 8774 out yielded the other genotypes with grain yield of 1296.30 kg ha^{-1} and the local check had the lowest grain yield of 345.68 kg ha^{-1}. This agrees with Hoeschle-Zeledon (2019) who reported that IP 8774 an extra early maturing genotype performed well in Laikala and Moleti villages. The local check and SDMV 94005 were low yielding in these villages indicating that they are highly influenced by the environment and thus their performance is environment-specific.

4.7.2 Grain yield stability of legume and cereal genotypes

Grain yield is the most important agronomical trait because it is the one that gives an economic benefit to the consumers. Eze *et al.* (2020) stated that good hybrids should be stable and high yielding across different environments in which they are grown. Nevertheless, crop varieties show wide fluctuations in their yielding abilities when grown over varied environments or agro-climatic zones (Fan *et al*., 2007). In this study based on the genotype x management x environment interactions of the selected elite legume and cereal genotypes, non-significant G x M x E interactions existed in the genotypes of all the four crops indicating that all these test materials were stable in these varying potential sub-ecologies. These findings agree with previous studies reported by Hoeschle-Zeledon (2019) who stated that elite materials proposed for release were stable with superior genetics and indeed fitted well in the micro-environments earlier detected.

4.8 Conclusions and Recommendations

The study revealed that the test materials used were stable as there was no significant G x M x E interactions in the genotypes of all the four crops studied. Generally, early planting outperformed late planting for all the test materials in the crops evaluated. Furthermore, genotypes in the high potential sub-ecology outperformed those in the moderate and low potential sub-ecologies as expected. The above findings recommend genotypes ICGV-SM 05650 (groundnut), ICEAP 00040 (pigeon pea), GAMBELLA 1107 (sorghum) and IP8774 (pearl millet) for use or deployment in these varying potential sub-ecologies due to their superior performance in the respective potential sub-ecologies. Further evaluation of these genotypes is required before release in order to determine their genotype x years and genotype x environments x years interactions.

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CHAPTER FIVE

Paper Three

5.0 Identification of Relatively More Efficient and Productive Cropping System in Varying Potential Agro-Ecologies of Central Tanzania

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5.1 Abstract

Intercropping of legumes and cereals in our production systems is vital because it improves the use of resources like water, light and nutrients for crop growth compared to sole cropping. Field experiments were conducted during the 2019-2020 cropping season in different sub agro-ecologies of central Tanzania to identify relatively more efficient and productive cropping system in varying potential agro-ecologies. An incomplete randomized block design with farmers as replications was used at each sub agro-ecology. Data on grain yield were collected and land equivalent ratios (LERs) calculated for Pigeon pea-Groundnut, Pigeon pea-Sorghum and Pigeon pea-Pearl millet intercrops with their respective sole crops. Results showed that in the high sub ecology, Pigeon pea-Sorghum intercrop had the highest LER value of 1.59. In the moderate, Pigeon pea-Groundnut highest LER value was 1.65 and in the low sub ecology Pigeon pea-Pearl millet highest LER value was 2.36 compared with LER values of 1.00 for the respective sole crops which indicated the superiority of intercropping over monoculture. The above findings revealed that increased productivity can be achieved through intercropping and therefore recommended that Pigeon pea-Sorghum, Pigeon pea-Groundnut and Pigeon pea-Pearl millet are the more efficient and productive cropping systems in the high, moderate and low sub ecologies respectively.

Keywords: Intercropping systems; Land equivalent ratio; Grain yield

5.2 Introduction

In sub-Saharan Africa (SSA), smallholder farmers practising rain-fed agriculture face recurring episodes of food insecurity, and food demand is expected to increase in the coming decades (Thornton *et al*., 2011). Also, climate change appears to alter patterns of temperature and rainfall in SSA that may cause many areas to develop climate regimes with no present-day analogue. With the threat of climate change and increasing demands placed on agro-ecosystems, farmers will need to adapt to new conditions and the unrelenting requirement of soil fertility inputs to improve food production. In this respect, intercropping of cereals and legumes should be adopted because it improves the use of resources for crop growth compared to sole cropping and often leads to more productivity per unit area (Saxena *et al*., 2018; Saidia *et al*., 2019).

The productivity of intercropping is greater than that of the sole cropping systems because the limiting resources like water, light, and nutrients are efficiently utilized in intercropping systems as against their respective sole cropping leading to higher yields (Layek *et al*., 2014; Lithourgidis *et al*., 2011; Bedoussac *et al*., 2015). Continuous sole cropped systems for instance maize produced low yields of less than one tonne per hectare on average compared to intercropping systems involving a legume in the rotation which gave rise to maize yields of up to 1.5 tonnes per hectare (Latati *et al*., 2016; Njira *et al*., 2013).

Therefore, incorporation of legumes into cereal-based cropping systems has frequently been advocated as a means of increasing soil fertility and agro-ecological resilience for farmers with limited access to nutrient resources (Snapp *et al*., 1998; Thierfelder *et al*., 2012; Saidia *et al*., 2019). Consequently, recent farmer-participatory research efforts have focused on incorporating soil fertility building legumes into maize-based cropping systems using approaches that do not compromise food crop production (Snapp *et al*., 2010). Njira *et al*. (2013) suggested the use of Doubled-up Legumes Rotation (DLR) system. This technology involves intercropping two legumes with complementary growth habits and then rotating them with crops such as maize, sorghum or millet to take advantage of the fertility left behind by the legumes. In the doubled-up legume technology for instance; pigeon pea intercropped with soybean or groundnut and then rotated with maize produced the best returns to land and labour invested. It also led to very high fertilizer use efficiency (Smith *et al*., 2016). Njira *et al*. (2013) further noted that since a lot of smallholder farmers in SSA are poor and unable to afford the high price of inorganic fertilizer, the technology will help them achieve multiple benefits of improved soil fertility, enhanced crop productivity and better family nutrition.

This study, therefore, aims at identifying relatively more efficient and productive cropping system in varying potential agro-ecologies.

5.3 Materials and Methods

5.3.1 Description of experimental sites

The study was conducted during the 2019-2020 cropping season in the Central zone of Tanzania in three sub agro-ecologies i.e., high potential zone (Manyusi and Mlali villages in Kongwa district) which receives ≥500mm of rainfall; moderate potential zone (Njoro-1 and Njoro-2 villages in Kiteto district) which receives 400-500mm of rainfall and low potential zone (Laikala and Moleti villages in Kongwa district) which receives ≤ 350mm of rainfall (Hoeschle-Zeledon, 2019). Kongwa district lies between latitudes 5° 30' to 6° 00' S and longitudes 36°15' to 36°00' E with altitude stretching between 900 and 1000 masl (URT, 2016). The average temperature is 26.5°C though sometimes gradually changes up to 11°C. The cool weather occurs between January and June when temperature ranges between 20 – 33°C and the highest temperature recorded is 31°C while the lowest temperature is 18° C (PORA and LGOVT, 2016).

Kiteto district lies between latitudes 05°52'00"S and longitudes 36°51'00"E with altitude stretching between 500 and 1200 masl. The average day and night temperature is 22°C. The cool months are March, April, May and June while the hot months are July, August, September, October and November (PO-RALG, 2018). These areas consist of mainly well-drained sandy loamy soils (see Appendix 1) with low fertility and are characterized by unimodal and unreliable rainfall of 300-800mm/year with a December-March cropping season (URT, 2007; MAFC, 2014; Msuya, 2015).

5.3.2 Materials

Four elite genotypes proposed for release of the crops obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT-MALAWI) were used in this study (Table 5.1).

Table 5.1: Description of test materials used in the study

	Crop	Genotype	Maturity duration (days)	Source
1.	Groundnut	CG-7	Short (110)	ICRISAT-MALAWI
2.	Pigeon pea	ICEAP 00557	Medium (150-180)	ICRISAT-MALAWI
3.	Sorghum	IESV 23010 DL	Medium (90)	ICRISAT-MALAWI
4.	Pearl millet	IP 8774	Short (70)	ICRISAT-MALAWI

5.3.3 Methodology and experimental design

A total of 4 crops (groundnut, pigeon pea, sorghum and pearl millet) were evaluated. The Pigeon pea-Groundnut intercrop versus pigeon pea and groundnut sole crops experiment was laid down in the high (Manyusi and Mlali) and moderate (Njoro-1 and Njoro-2) potential sub ecologies; Pigeon pea-Sorghum intercrop versus pigeon pea and sorghum sole crop experiment laid in all the potential ecologies sub ecologies i.e. high (Manyusi and Mlali), moderate (Njoro-1 and Njoro-2) and low (Laikala and Moleti) and the Pigeon pea-Pearl millet versus pigeon pea and pearl millet sole crops were laid in the low (Laikala and Moleti) potential sub ecology. The plot size was 7 rows, 8 m long spaced at 75 cm between ridges. All experiments at these sites were established following an incomplete randomized block design with two farmers selected per sub agro-ecology as replications (Appendix 3 and Appendix 4 for field layouts).

5.4 Data Collection

Three central rows of each plot (12 m^2) were harvested to determine grain yield per hectare i.e. weight of grains/plot (kg) was converted to hectare (10 000 m^2) to determine grain yield in kg/ha, partial and total LERs were calculated.

5.5 Data Analysis

The index commonly used to evaluate the relative advantage of intercropping compared with sole culture is the land equivalent ratio (LER). LER is defined as the relative land area required as sole crops to produce the same yields as intercropping. LER is determined as the sum of the two fractions of the yield of the intercrops relative to their sole crop yields according to the following formula (Willey, 1979):

LER = [(Yab/ Yaa) + (Yba/ Ybb)]

Where: Yaa and Ybb means: Pure stand yield of crop (a) and (b), respectively. Yab and Yba means: Intercrop yield of crop (a) and (b), respectively.

5.6 Results and Discussion

Performance of different intercropping systems in the different potential agro-ecologies in Kongwa and Kiteto districts

Table 5.2 shows performance results of different intercropping systems in the different agro-ecologies in Kongwa and Kiteto districts of central Tanzania. In the high potential agro-ecology, the highest LER value (1.59) was obtained from Pigeon pea-Sorghum intercrop at Mlali village which indicated the superiority of intercropping over monoculture. This showed a yield advantage of 59% (i.e. 59% more land required as sole crops to produce the same yields as intercropping). For the Pigeon pea-Groundnut intercrop, LER value of 1.44 was obtained in Mlali village. This implies that 44% more land is required for sole crops to produce the same yields as in the intercrop system. The findings are in conformity with Kermah *et al*. (2017), who reported that complementary use of resources for growth by the intercrop components led to greater crop yields and productivity of intercrops relative to sole crops. Midmore (1993), further argued that complementarity is likely as intercropped cereal crop uses N from the soil for growth whilst the legume can rely more on atmospheric N-fixation for growth. These however, are influenced by soil fertility status, spatial planting arrangements and choice of intercrop components.

Nevertheless, the legume-cereal intercrops (Pigeon pea-Sorghum) performed better than the Doubled-up legumes (Pigeon pea-Groundnut) intercropping systems. Smith *et al.* (2016) also reported similar findings that DLR systems were only beneficial in appropriate agro-ecological zones. Ibid further indicated that benefits of DLR systems were reduced in the agro-ecological zone with greatest water limitation due to poor performance of pigeon pea in intercrop with a grain legume under those conditions.

In the moderate potential agro-ecology results of the study showed the highest LER value of 1.65 obtained from Pigeon pea-Groundnut intercrop at Njoro 2 village. This showed a yield advantage of 65%. For the Pigeon pea-Sorghum intercrop, there was almost no yield advantage as the LER was low (1.07). In Njoro-1 village results showed that Pigeon pea-Sorghum intercrop had a LER value of 1.63 while Pigeon pea-Groundnut intercrop recorded a LER value of 1.36 which implied that on a unit of land basis these two crops produced 63% and 36% more when intercropped than when monocropped in the Pigeon pea-Sorghum and Pigeon pea-Groundnut cropping systems respectively.

The above findings revealed that intercrop systems generally increased productivity as they had higher LERs compared to their respective monocrops or sole crops. Khan *et al*. (2017) and Saidia *et al*. (2019) reported similar findings that intercropping systems had superior yields compared to the monocrops. Dahmardeh *et al.* (2010), also observed higher LERs of intercropping systems and therefore concluded that intercropping was more beneficial compared to monoculture.

In the low potential agro-ecology results from the study showed that Pigeon pea-Pearl millet in Laikala village had the highest LER value of 2.36 and Pigeon pea-Sorghum had a LER value of 1.44. This indicated a 136% yield advantage of the Pigeon pea - Pearl millet and 44% yield advantage of the Pigeon pea-Sorghum intercrops over their respective monocrops. On the other hand, in Moleti village Pigeon pea-Pearl millet had a LER of 1.97 and Pigeon pea-Sorghum had a LER value of 1.49. This showed a yield advantage of 97% and 49% for the respective intercrop systems. It was observed that the Pigeon pea-Pearl millet intercrop system outperformed the Pigeon pea-Sorghum intercrop in the low potential agro-ecology.

Findings above indicate increased productivity in the intercrop systems compared to the sole crops. Similar findings were also reported by Khan *et al*. (2017) that intercropping gives superior yields when compared with monocropping systems. Kermah *et al*. (2017) further reported that LER values for the different intercrop patterns were all greater than unity which confirmed that intercropping led to more productive use of land than sole cropping. Furthermore, Willey (1979) and Saidia *et al*. (2019) observed LERs greater than 1 in intercrops showing advantages derived from land utilization efficiency of intercropping over sole cropping and therefore deduced that more land would be required in monoculture of either of the component crops to produce the same yield obtained from their intercropping.

Table 5.2: Effects of different intercropping systems on grain yield, LERs of Pigeon pea-Groundnut, Pigeon pea-Sorghum and Pigeon pea-Pearl millet crop combinations in the different potential agro-ecologies in Kongwa and Kiteto districts

Villages	Treatments	Intercrop yield (kg/ha)		Sole crop yield (kg/ha)		Partial LERs		Total LER
	Cropping systems	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	
High								
Manyusi	PP-GN	761.90	476.19	2428.57	682.54	0.31	0.70	1.01
	PP-SG	1206.35	746.03	1984.13	1428.57	0.61	0.52	1.13
Mlali	PP-GN	535.71	714.29	940.48	821.43	0.57	0.87	1.44
	PP-SG	483.33	1845.24	1228.57	1535.71	0.39	1.20	1.59
Moderate								
Njoro 1	PP-GN	984.13	873.02	2142.86	968.25	0.46	0.90	1.36
	PP-SG	1619.05	1539.68	2000.00	1888.89	0.81	0.82	1.63
Njoro 2	PP-GN	412.70	603.17	1206.35	460.32	0.34	1.31	1.65
	PP-SG	396.83	1761.90	1142.86	2444.44	0.35	0.72	1.07
Low								
Laikala	PP-SG	523.81	1761.90	1365.08	1666.67	0.38	1.06	1.44
	PP-PM	714.29	476.19	1031.75	285.71	0.69	1.67	2.36
Moleti	PP-SG	297.62	750.00	571.43	773.81	0.52	0.97	1.49
	PP-PM	511.90	678.57	654.76	571.43	0.78	1.19	1.97

Crop 1= Pigeon pea (PP); Crop 2= Groundnut (GN), Sorghum (SG), Pearl millet (PM)

5.7 Conclusions and Recommendation

The above findings revealed that increased productivity can be achieved through intercropping and therefore recommended that Pigeon pea-Sorghum, Pigeon pea-Groundnut and Pigeon pea-Pearl millet are the more efficient and productive cropping systems in the high, moderate and low potential agro-ecologies respectively. Thus, these intercropping systems should be adopted for better productivity with maximum profit for the farmers of the semi-arid districts in central Tanzania instead of relying on sole culture.

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CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions

In conclusion, the study revealed that generally elite materials outperformed the local landrace controls. The effect of G x M x E interactions revealed non-significant interactions for all the test materials evaluated thereby proving that all the elite materials proposed for release were stable, adapted and with superior performance in terms of grain yield. On the other hand, early planting outperformed late planting of these test materials in the semi-arid areas since in early planting, the crops take advantage of the limited moisture available to germinate and establish well. The test materials identified with superior performance in terms of grain yield in the varying potential sub-ecologies were ICGV-SM 05650, ICEAP 00040, GAMBELLA 1107 and IP8774 for the Groundnut, Pigeon pea, Sorghum and Pearl millet crops respectively.

The study further showed that intercropping systems should be adopted for better productivity with maximum profit for the farmers in the semi-arid districts in central Tanzania instead of sole cropping. However, certain conditions must be met such as adequate soil moisture and fertilizer applications. Intercropping being a much intensified system, special care should be taken to assure that these conditions are sufficient to realize increased productivity in an intercropping pattern and species to be intercropped should be compatible to minimize shading and competition for other growth requirements. Thus, Pigeon pea - Sorghum, Pigeon pea - Groundnut and Pigeon pea - Pearl millet were the best intercropping patterns for the high, moderate and low potential sub-ecologies respectively.

6.2 Recommendations

Based on the study genotypes ICGV-SM 05650 (groundnut), ICEAP 00040 (pigeon pea), GAMBELLA 1107 (sorghum) and IP8774 (pearl millet) were recommended for use or deployment in these varying potential agro-ecologies due to their superior performance in terms of grain yield.

The study also recommends good management practices such as early planting to farmers in these drought-prone areas in order to maximize the scarce moisture available for the crops to germinate and establish well in the cropping season.

In the future evaluation of stability and G x E interaction experiments, it is recommended to employ the aspect of seasons or years and more sites in order to partition genotype x environment variance further into genotype x location x year interaction in order to have reliable and precise information on given genotypes or varieties.

Practical experimentation with farmers (Farmer participatory research) through use of the mother-baby approach is advocated to allow resource-limited farmers to determine the technology that suits their conditions as part of a strategy to build soil fertility while providing immediate household needs.

APPENDICES

Appendix 1: Selected physical and chemical properties of topsoils in Kongwa and Kiteto districts experimental sites

Experimental site	Clay (%)	Silt (%)	Sand (%)	Textural class	TN (%)	OC (%)	P (mg/ kg soil)	K cmol(+) /kg soil	Ca cmol(+) /kg soil	Mg cmol(+) /kg soil l	pH (water)	EC mS/cm	CEC cmol(+) /kg soil	% BS
LAIKALA	16.00	6.00	78.00	SL	0.05	0.32	5.16	0.51	1.17	0.36	6.30	0.06	3.08	68.33
MOLETI	26.00	5.33	68.67	SCL	0.04	0.51	4.69	0.66	2.20	1.05	5.87	0.09	7.25	57.67
NJORO-1	20.67	8.00	71.33	SCL	0.05	0.54	6.39	0.80	3.87	1.09	6.33	0.08	8.72	68.33
NJORO-2	16.00	6.00	78.00	SL	0.05	0.32	5.16	0.51	1.17	0.36	6.30	0.06	3.08	68.33
MANYUSI	16.67	10.00	73.33	SL	0.08	0.72	7.16	0.76	3.47	1.06	6.17	0.12	8.20	68.00
MLALI	28.00	6.00	66.00	SCL	0.05	0.50	5.38	0.86	1.90	1.46	6.20	0.08	6.32	67.67

Appendix 2: Technology x location description

		TRIALS	High potential (Kongwa District)		Moderate potential (Kiteto District)		Low potential (Kongwa District)	
			Manyusi	**Mlali**	**Njoro-1**	**Njoro-2**	**Laikala**	**Moleti**
Crop	1	Groundnut	√	√	√	√	√	√
	2	Pigeon pea	√	√	√	√		
	3	Sorghum	√	√			√	√
	4	Pearl millet					√	√
Cropping Systems	1	Pigeon pea+groundnut	√	√	√	√		
	2	Pigeon pea+sorghum	√	√	√	√	√	√
	3	Pigeon pea+pearl millet					√	√

Appendix 3: Performance of crop genotypes in different potential agro-ecologies in Kongwa and Kiteto districts

A. LAYOUT FOR GROUNDNUT

Specifications

- To be planted in all agro-ecologies
- 7 rows, 8 m long spaced at 75 cm
- One seed per station at 10 cm apart

Planting date	Varieties		
	Plot 1	**Plot 2**	**Plot 3**
1	ICGV-SM 02724	ICGV-SM 05650	Local
	Plot 4	**Plot 5**	**Plot 6**
2	ICGV-SM 02724	ICGV-SM 05650	Local

B. LAYOUT FOR PIGEON PEA

Specifications

- To be planted in the high and moderate agro-ecologies
- 7 rows, 8m long at 75 cm
- Three seeds per station at 90cm apart to be thinned to two

Planting date	Varieties		
	Plot 1	**Plot 2**	**Plot 3**
1	ICEAP 00554	ICEAP 0557	ICEAP 00040
	Plot 4	**Plot 5**	**Plot 6**
2	ICEAP 00554	ICEAP 0557	ICEAP 00040

C. LAYOUT FOR SORGHUM

Specifications

- To be planted in the high and low agro-ecologies
- 7 rows, 8 m long at 75 cm
- Four to five seeds per station at 25 cm apart to be thinned to two

Planting date	Varieties			
	Plot 1	**Plot 2**	**Plot 3**	**Plot 4**
1	Gambella 1107	IESV 92028	IESV 23010	Local
	Plot 5	**Plot 6**	**Plot 7**	**Plot 8**
2	Gambella 1107	IESV 92028	IESV 23010	Local

D. LAYOUT FOR PEARL MILLET

Specifications

- To be planted only the low potential agro-ecology

- 6 rows, 8 m long at 75 cm
- Four to five seeds per station at 25 cm apart to be thinned to two

Planting date	Varieties			
	Plot 1	**Plot 2**	**Plot 3**	**Plot 4**
1	IP 8774	SDMV 96053	SDMV 94005	Local
	Plot 5	**Plot 6**	**Plot 7**	**Plot 8**
2	IP 8774	SDMV 96053	SDMV 94005	Local

Appendix 4: Performance of different legume-cereal cropping systems different potential agro-ecologies in Kongwa and Kiteto districts

A. LAYOUT FOR PIGEON PEA+ GROUNDNUT INTERCROP

Specifications

- To be planted only in high and moderate sub-ecologies
- Technologies being evaluated: 1.) 1:2 pigeon pea to groundnut and 2.) Pure stands of each variety
- One seed of groundnut at 10 cm
- Three seeds of pigeon pea at 90 cm to be thinned to 2
- All rows are spaced at 75cm with a row length of 6 meters
- Intercrops and pure stands consist of seven rows

Plot 1	Plot 2	Plot 3
ICEAP 00557 at 90 + CG 7	ICEAP 00557 Pure stand at 90cm	CG 7 Pure stand

B. LAYOUT FOR PIGEON PEA+ SORGHUM INTERCROP

Specifications

- To be planted in all sub-ecologies
- Two technologies being evaluated: 1.) 1:2 pigeon pea to Sorghum and 2.) Pure stands of each variety
- Four to five seeds of sorghum at 25 cm to thinned to 2
- Three seeds of pigeon pea at 90 cm to be thinned to 2
- All rows are spaced at 75cm with a row length of 6 meters
- Intercrops and pure stands consist of seven rows

Plot 1	Plot 2	Plot 3
ICEAP 00557 +Sorgh-IESV 23010 - (1-2)	Sorgh-IESV 23010 Pure Stand	ICEAP 00557 pure stand at 90cm

C. LAYOUT FOR PIGEON PEA+ PEARL MILLET INTERCROP

Specifications

- To be planted only in low potential sub-ecology
- Two technologies being evaluated: 1.) 1:2 pigeon pea to Pearl millet and 2.) Pure stands of each variety
- Four to five seeds of Pearl millet at 25 cm to thinned to 2
- Three seeds of pigeon pea at 90 cm to be thinned to 2
- All rows are spaced at 75cm with a row length of 6 meters
- Intercrops and pure stands consist of seven rows

Plot 1	Plot 2	Plot 3
ICEAP 00557 at 90cm + P/M-IP8774 - (1-2)	P/M- IP8774 Pure stand	ICEAP 00557 pure stand at 90cm