Effect of population density and row orientation on weed density in sorghum-cowpea intercropping systems in semi-arid Zimbabwe

by

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A research project submitted in the partial fulfilment of the requirements for the degree of Masters of Science in Crop Protection

Midlands State University
Faculty of Natural Resources Management and Agriculture
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DECLARATION BY STUDENT

I declare that this is my own work and effort and it has not been submitted anywhere for any award. Where other sources have been used, they have been acknowledged.

Signed………………………………………………………………

Date…………………………………………………………………

MIDLANDS STATE UNIVERSITY

FACULTY OF NATURAL RESOURCES MANAGEMENT AND AGRICULTURE

DEPARTMENT OF HORTICULTURE

THESIS APPROVAL

The undersigned certify that they have read and recommend to the Department of Horticulture, the thesis entitled:

Effect of population density and row orientation on weed density and yield of sorghum-cowpea intercropping systems in semi-arid Zimbabwe

Submitted by **Haripo Tafadzwa Talent** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN CROP PROTECTION**

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DEDICATION

I dedicate this project to my late father Mr S. Haripo, my beloved mother Mrs M. Haripo, my family and friends.

ABSTRACT

Sorghum plant densities in semi-arid areas are generally lower than in wetter environments leaving lots of bare ground which promotes weeds. Intercropping using the optimum plant density of the minor crop and the most effective row orientation for weed control in these areas is one important step in integrated weed control management (IWM). Information on the cowpea population density and row orientation effects on weed density, growth and yields of sorghum-cowpea cropping systems is however scanty or unavailable for tropical Africa. This study was carried out to assess farmers' perceptions on intercropping and to determine the effects of population density and row orientation on weed density and yield of sorghum-cowpea intercropping systems in semi-arid Zimbabwe. The research consisted of a survey and a field experiment. The survey was conducted in Ward 15 and Ward 25 of Matobo district. A multistage sampling technique was used to select the sampling units for the interview. Matobo district was purposively selected since the on-station trials were conducted within this district. The two wards (Ward 15 and 25) were also purposively selected and two villages from each ward were randomly selected. The villages were Mkhokha and Nyumbani in Ward 15 and Foxfarm and Phakama in Ward 25. Within each village, 15 households were randomly selected to get a total of 60 households. Snowballing approach was used to identify farmers practising intercropping. The questionnaires were randomly administered to the selected households. The results showed that adoption of intercropping by the farmers was 60.0 % and 46.7 % for Ward 15 and 25 respectively. Some of the farmers who practised intercropping were using the old paradigms which generally result in soil resource exploitation thereby making sustainable land use impossible socially, ecologically and economically. Farmers in Matobo do not use scientifically proven intercropping methods. The field experiment was carried out at Matopos Research Station which is located in Natural Region IV. The experiment was laid in a 2 x 7 factorial arrangement of a Randomised Complete Block Design with three replications. The treatments consisted of sorghum planted at a constant population of 55 556 plants/ha (90 x 20 cm) intercropped with cowpea at varying populations of 111 111 plants/ha (45 x 20 cm), 166 667 plants/ha (30 x 20 cm) and 222 222 plants/ha (22.5 x 20 cm) in East-West (E-W) and North-South (N-S) row orientation with the main crop and the intercrops being planted simultaneously in the plots.The results revealed that at 3 weeks after crop emergency (3WACE) prior to first weeding, the interaction of population density and row orientation and individual factors did not significantly affect the weed density or number of weeds per m^2. The weed species which were more prevalent were *Tagetis minuta, Schkuria pinnata, Cyperus tridens* and *Cyperus rotundus*. Weed density was significantly affected by the interaction of cowpea population density and row orientation at 6 weeks after crop emergency (6WACE). The weed density was higher in the treatments with combination of sole crops at lower population density and EW row orientation compared to the treatments combination which had intercropped crops at higher population density and NS row orientation. Mean comparisons showed that the lowest weed density was 10 plants/m^2 and was obtained by a combination of the highest cowpea intercrop population of 222 222 plants per hectare and NS row orientation which produced the best results in supressing weeds. The highest weed density of 48 plants/m^2 was obtained in the treatment with sole sorghum and EW row orientation. There was no interaction between cowpea population density and row orientation in determining density of *C. rotundus*. Effects of individual factors were not significant in determining the density of *C. rotundus*. The interaction of cowpea population density and row orientation significantly (P<0.05) influenced density of *S. pinnata* and *T. minuta* and *C. tridens*. Lower cowpea population density of 111 111 plants/ha in EW row orientation had the least effects in weed suppression while the highest cowpea density of 222 222 plants/ha in both NS and EW row orientation had the greatest effects in weed suppression. From these results, it can be concluded that 222 222 plants/ha (highest cowpea population density) and both NS and EW row orientation were more effective in controlling some weed species. A LER which is above a unit for both EW and NS row orientation and population densities ranging from 111 111 to 166 667 plant/ha was obtained. The LER for the cowpea intercrop population of 222 222 plant/ha in both EW and NS was less than a unit to show that intercropping was not advantageous. Farmers in Matobo district should plant sorghum-cowpea intercrops in EW row orientation for increased cowpea grain yield but NS row orientation for sole sorghum.

Key words: intercropping, intercrop population, row orientation, weed frequency, weed density, sorghum, cowpea, growth, yields, LER

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background and Justification of the Study

Zimbabwe is divided into five Natural Farming Regions I-V based on rainfall amount, distribution and reliability (Vincent and Thomas, 1960). Natural Region I and II receive the highest rainfall of at least 750 mm per annum and are suitable for intensive farming. Natural Region III receives moderate rainfall (650-800 mm per annum) and is suitable for semi-intensive farming. Natural Region IV and V receiving fairly low annual rainfall (450-650) and is suitable for extensive farming (Vincent and Thomas, 1960). In most of NR IV, livestock rearing is dominant and cropping is limited to drought tolerant crops such as sorghum [*Sorghum bicolor* (L.)] and pearl millet [*Pennisetum glaucum* (L.)]. Farmers living in NR IV experience food insecurity owing to erratic and unevenly distributed rainfall, often resulting in total crop failures and livestock deaths (Nyamangara *et al*., 2013) that occur three out of every five years (Mugabe *et al*., 2012). Although sorghum is recommended for cultivation NR IV, about 58 % of farmers grow maize [*Zea mays* (L.)], a crop which is more prone to drought (Nyamudeza, 1998).

Long term studies carried out between 1984 and 1989 in these areas, indicate that the optimum plant density for maize and sorghum fall short of the general recommendation of 37 000 plants ha^{-1} and 300 000 plants ha^{-1} for maize and sorghum respectively (Nyamudeza *et al*., 1994). This leaves a lot of bare ground that results in inefficient use of radiation and encourages weed growth. Intercropping has been found to improve water use efficiency, radiation use efficiency, can help smother weeds in many cropping systems and help cover bare ground, thereby reducing soil erosion (Nyamudeza, *et al*., 1994). Furthermore, intercropping cereals with legumes has huge capacity to replenish soil mineral nitrogen through the ability of most legumes to biologically fix atmospheric nitrogen (Fujita, *et al*., 1992; Giller, 2001). Common crops used in intercropping maize or sorghum in sub Saharan Africa (SSA) include cowpea [*Vigna unguiculata* (L.)], groundnuts [*Arachis hypogea* (W.)], sugarbeans [*Phaseolus vulgaris* (L.)], cucurbits (*Cucurbitacae spp*.) and bambaranuts [*Vignia subterranean* (L.) Verdic] (Matusso *et al*., 2014).

Although a lot of research on intercropping maize or sorghum with various minor crops has been done, this work has been on spatial arrangements (Addo-Quaye, Darkwa and Ocloo, 2011; Ayisi and Mposi, 2001), optimum plant densities between major and minor crop (Bamigboye, 2011). Limited research work has been done on optimum plant density and row orientation in SSA. A lot of other work has been done on water use efficiency (Fedelibus. 2005; Hulugalle and Lal, 1986), effect of intercropping on weed control (Gliessman, 1983; Zuofa, Tariah and Isirimah, 1992; Olasantan, Lucas and Ezumah, 1994; Hulagelle and Lal, 2005; Fanadzo *et al*., 2010; Mashingaidze *et al*., 2012) and RUE (Evans and Wardlaw, 1976; Reddy and Willey, 1981). Reducing space between rows or row orientation to right angles to the sunlight direction (north-south row orientation) at a latitude of 32 ^{o}C in Australia have been reported by Fedelibus (2005) to increase weed shading, Water Use Efficiency (WUE) and crop yield. In field trials on sorghum in Isfahan university Bam City, Iran at latitude 28 ^{o}C, Naser and Shamsaddi reported an increase in number of tillers, grain yield, 1000 seed weight and dry matter in high sorghum densities oriented in North-South direction.

In crop mixtures, competition for growth factors is a major aspect affecting yields (Hauggaard-Nielsen *et al*., 2006) including row orientation as it determines the interception of solar radiation by the crop canopy, soil moisture and nutrient uptake by the crops. Information on the cowpea population density and row orientation effects on weed density, growth and yields of sorghum-cowpea cropping systems is however scanty or unavailable for tropical Africa. Therefore, an understanding of these interactions through a study to evaluate the effects of cowpea population density and row orientation will give better insight on how best to manipulate plant population by small scale farmers in semi-arid regions of Zimbabwe.

1.2 Objectives

1.2.1 Overall objectives

- To establish intercropping practices and farmers' perspectives about intercropping in Matobo district of Zimbabwe.
- To determine the effect of population density and row orientation on weed density and yield of sorghum-cowpea intercropping systems under semi-arid conditions.

1.2.2 Specific objectives

i. To establish intercropping practices of smallholder farmers in Matobo District.

ii. To determine smallholder farmers' perspective about intercropping.

iii. To determine the effect cowpea population density and row orientation on weed density in sorghum-cowpea intercropping systems.

iv. To determine the effect of cowpea population density and row orientation on sorghum yield (biomass and grain) in sorghum-cowpea intercropping systems.

v. To determine the effect of cowpea population density and row orientation on yield (biomass and grain) and yield components (number of pods per plant and number of grains per pod) of cowpea in sorghum-cowpea intercropping systems.

vi. To compare the productivity of sorghum-cowpea intercropping with that of sole crops using the Land Equivalent Ratio (LER).

1.3 Hypotheses

i. Intercropping is a common farming practice in Matobo District

ii. Farmers in Matobo District have a good perspective about intercropping

iii. Intercropping population density and row orientation have an effect on weed density in sorghum-cowpea intercropping systems

iv. Intercropping population density and row orientation have an effect on sorghum yield (biomass and grain) in sorghum-cowpea intercropping systems

v. Intercropping population density and row orientation have an effect on yield (biomass and grain) and yield components (number of pods per plant and number of grains per pod) of cowpea in sorghum-cowpea intercropping systems

vi. Intercropping has a yield advantage over sole cropping

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Major cropping systems in Sub-Saharan Africa (SSA)

A cropping system refers to growing a combination of crops in space and time. According to Oladeji (2014) a cropping system refers to the production activity of a farm. It comprises of all crops grown on the farm and their interaction with farm resources, other household enterprises and the technological, biological and socio-economic factors or environment (Elemo, Kumar and Olukosi, 1990). An ideal cropping system should allow the efficient use of natural resources, provide stable and high returns and should not damage the environment. There are various terms of cropping systems used by farmers which include sole cropping, multiple cropping, relay cropping, sequential cropping, ratoon cropping and intercropping. Intercropping is the growing of two or more crops simultaneously on the same area of land (Andrew and Kassam, 1976; Ofori and Stern, 1987). The crops are not necessarily sown and harvested at the same time, but usually involve a substantial period of overlap in their growing period. Crop intensification is both in time and space dimensions. Intercropping would have a distinct reproducible spatial arrangement which is not the case in mixed cropping.

2.3 Influence of Cropping Systems on weeds

The canopy of an intercropping system covers the ground quickly because of the presence of two or more crops, and it facilitates suppression of weeds. Several workers reported that weed density and weed growth were less in intercropping than in sole crops (Kondap, 1981; Moody and Shetty, 1981). Several biological factors such as spacing, crop variety, density and fertilization influence weed growth in a cropping system (Moody and Shety, 1981). Spreading genotypes close spacing, high plant density and fertilization generally reduced weed growth in intercropping. Rao and Shetty (1976) noted that weeding requirement can be reduced in widely spaced and slow growing crops such as pigeon pea by introducing quick growing intercrops. Shetty and Rao (1981) observed that weed growth in an intercropping system of very contrasting crops would be intermediate to that observed in the respective sole crops. They found that in a millet-groundnut intercropping, the row arrangement of 1 pearl millet: 3 groundnuts resulted in optimum weed suppression and maximum intercrop advantage.

Light is one of the important factors in the crop-weed balance. Therefore, manipulation of light should be one of the approaches for better management of weeds (Moody and Shetty, 1981; Mugabe *et al*., 1982; Pattersun, 1982). They found that by choosing the suitable components, it was possible to manage certain weeds. Furthermore, their work indicated that shading suppressed propagation of certain weeds, for instance, *Cyperus spp*.

2.4 Sorghum-based cropping systems

Sorghum is a small grain which is recognized for its drought tolerance. The crop is adapted to a wide range of ecological conditions and can also be grown under conditions which are unfavorable for most of the cereals (Onwueme & Sinha, 1991). Sorghum-based cropping systems in which sorghum is the major crop are found predominantly in the sub-humid or savanna zones of West and Central Africa (Obilana, 2005). The commonly practised sorghum-based intercropping system by smallholder farmers in Sub-Saharan Africa (SSA) is cropping where sorghum is the major crop. The common crop combinations in intercropping systems adopted in Zimbabwe are cereal-legume, particularly intercropping cereal with cowpea (Beets, 1982; Rees, 1986a, b), groundnut, soyabeans and pigeon pea with some of these farmers intercropping sorghum with millet and maize (Elemo *et al*., 1990).

Sorghum-based cropping systems are aimed at avoiding dependence on a single crop, improve efficiency of the available resources (labour, fertilisers etc), obtain a variety of products from the same piece of land and increase farm income from small holdings (Lithourgidis *et al*., 2011). However, scientific background of this concept showed that mixtures of sorghum-legume are usually opted for, for copying with problems of nitrogen availability to the main crop, declining levels of soil organic matter, soil erosion or subsequent crop in addition to the extra yield of intercropped legumes.

Sorghum-cowpea cropping systems refer to growing a combination of sorghum and cowpea in space and time in which sorghum is the major crop with cowpea as the minor crop. Sorghum-cowpea intercropping system is an important cropping system practised by smallholder farmers in arid and semi-arid lands of SSA where sorghum is the major crop (Beets, 1982; Rees, 1986a, b). Oseni (2010) used Monetary Advantage Index (MAI) to assess economic returns in sorghum-cowpea intercropping systems and reported that intercropping with two rows of sorghum and one row cowpea gave higher economic return compared to the other planting arrangements and the sole crops. These results suggested that intercropping sorghum with cowpea could help to improve the system's productivity, increase the income for smallholder farmers and compensate losses (Osman *et al*., 2011).

2.5 Planting density in semi-arid areas

Weed suppression, intercrop yields and production efficiencies are determined by the overall intercrop density and the relative proportions of component crops. According to Willey, (1979) the different aspects of plant population for sole crops are well understood. Plant population can be defined as the number of plants per unit area and it determines the size of the area available to the individual plant. For sole crop, plant population is relatively simple and becomes complex in an intercrop situation where both total population (all components) and the population of each component have to be distinguished (Steiner, 1982). The main problem is that a single plant of one crop is seldom directly comparable to a single plant of another crop in terms of population on resource (Willey and Osiru, 1972). According to Willey (1979b) this difficulty can be overcome by regarding the optimum plant population of sole crops as compared to intercrop component populations.

Component populations can be expressed on a single relative basis for example if the optimum sole crop populations are taken as 100, a simple intercrop treatment having half the sole crop optimum of each of the two components is expressed as a 50:50 component population. The optimum total population of intercrops from some experiments may be higher than that of either sole crop (Steiner, 1982). It implies that the optimum population density in all intercropping systems can be increased relative to sole crops where the interference between neighbouring plants in intercrops is less than in sole crops or the intra-crop competition (Mutsaers, 1978; Barker, 1979; IPA, 1981).

The final yield of each crop is mainly determined by component populations. However, there is not enough precise information known about the competitive abilities of crops and the factors affecting them making it impossible to predict yields for changing component populations (Willey, 1979b). Competitive ability depends on the actual population situation and it is not a constant and quantifiable function of a given crop. Willey and Osiru (1972) and Willey (1979b) reported that all component crops become relatively more competitive if they form a larger proportion of the total population and dominant crops become even more dominant when the total population increases. Productivity and efficiency appear to be determined by the more aggressive crop, usually the cereals when the component populations are in approximately equal numbers (Willey and Osiru, 1972).

Beltrao *et al*. (1984b) studying the competitive effect of cowpea in an annual cotton-cowpea intercropping system in alternate row in Northeast Brazil, reported that cowpea reduced cotton yield about 8 % and when the population of cotton was decreased from 50 000 plants per hectare to 25 000 plants per hectare, cotton yield was reduced by 30 %. Bezera-Neto, Terres-Fihlo and de Holanda (1991) in Northeast Brazil reported that the best efficiency of annual cotton-cowpea associations was obtained in the population of 50 000 cotton plants per hectare and 40 000 cowpea plants per hectare. Intercropped cotton yielded 70 % of sole crop yield with a land equivalent ratio of 1.36 in the same system. They concluded that the presence of a legume like cowpea should increase monetary returns and reduce the competition on cotton in the intercrop relative to the sole crop.

2.6 Spatial arrangements of intercrop in semi-arid areas

Spatial arrangement can be defined as the pattern of distribution of plants over the ground, which determines the shape of the area available to the individual plant (Willey, 1979a). Varying the spatial arrangement of the component crops can increase the yield advantage of intercropping. In intercropping systems, the proximity of species in intercropping systems is important because it is one of the factors that affect the degree of intra- and interspecific competition in a crop stand. When the plants are intimately arranged, there is greater competition than when there is more spacing between the species.

According to Steiner (1982) the efficiency with which solar radiation is utilised by the component crops depends strongly on the planting pattern. Grouping rows of crops with diverse heights could be advantageous as more solar radiation would be available to the shorter crops (Waghmare *et al*., 1982). Ofori and Stern (1987) alluded that in contrast to arrangements of component crops, row arrangements improve the amount of light transmitted to the lower crop canopy. In cereal-legume intercrops, such arrangements can enhance legume yields and efficiency (Mohta and De, 1980).

Bezerra-Neto *et al*. (1991), working with annual cotton(C)/cowpea(L) and annual cotton(C)/sorghum(S) in two different spatial arrangements, 2C:1S and 1C:1L, reported that annual cotton yielded more in a 2:1 row arrangement than in a 1:1 row arrangement. The same authors found the best biological efficiency [highest Land Equivalent Ratio (LER)] in the 1C:1L:1C:1S arrangement when they were working with a triple association of annual cotton/cowpea/sorghum in 1C:1L:1C:1S and 2C:1L:2C:1S row arrangements.

In a study of the spatial configuration of annual cotton/sorghum intercrops in North-east Brazil, Beltrao, Vieira and Azevedo (1986) reported that the system with a double row of cotton (0.75 x 0.20 m spacing) and one row of grain sorghum planted in a row 1 m apart from the cotton was the most efficient, having a Land Equivalent Ratio (LER) of 1.16, a cost benefit ratio of 2.39 and a $10.39 increase in net profit. Kumar *et al*., (1987) reported that dry matter production was enhanced when cotton was intersown with maize in double rows as compared with single rows. In another study carried out in North-east Brazil, Morado and Rao (1985) claimed that the proportion of annual cotton in a cotton/maize intercropping system should be high because of the competitive effect of maize. Faria, Luca-Buendia and

Castrol (1980) recommended the use of strip intercropping with four rows of each component crop in sites where even proportions of these crops are used.

The direction of rows (East-West and North-South orientation) is another aspect of plant arrangement that may be of importance (Bezerra-Neto, 1993). According to Donald (1963), yields are generally greater with north-south rows than with east-west rows. He also claimed that this is likely due to differences in the light regimes, with superior lighting in north-south rows as compared with the poor lighting on the north side of east-west rows (for northern latitudes; south of the Equator the situation will be reversed).

2.7 Weed management options for smallholder farmers in semi-arid areas

One major constraint in smallholder agriculture is crop competition with weeds as weeds use water, nutrient and solar radiation resources and yet do not contribute to production but rather reduce crop yields (Makuvaro *et al*., 2014). This has led many smallholder farmers to invest large amounts of labour (35 to 75 % of total labour) required in weeding each year only to produce a lower crop yield compared to the national yields which sometimes exceeds all the operations combined (Chivinge, 1984; Waddington and Karingwindi, 1996). Moreover, farmers have to have to weed more frequently so as to attain high yields because of the reduced effectiveness of hoe and mechanical weeding under wet conditions.

The quality of life in the Zimbabwean smallholder sector particularly in the semi-arid areas has been lowered substantially by the burden of weeding (Mandumbu *et al*., 2011). Farmers are faced with a multiplicity of tasks at peak weeding for early planted crops such as maize and cotton. These multiplicity tasks include land preparation, planting of late crops and herding of livestock. Most of the burden for hoe weeding falls on women and children because of rural urban migration and reduction in the active work force wreaked by HIV/AIDS pandemic (Sibuga, 1999). Children are sometimes deemed the chance to go to school so as to assist in weeding during the peak weeding period. This has resulted in low educational performance (Labrada *et al*., 1994). Weeding has wider social effects because it may lock children from resource poor families in a vicious poverty cycle as they are hindered by weeding chores.

This is the case with smallholder agriculture in Zimbabwe even though various techniques of weed management varying from cultural, chemical to mechanical weed management techniques have been researched with excellent results (Mandumbu *et al*., 2011). These weed management techniques include cultural (intercropping, early planting, tillage and plant population), chemical (reduced herbicide dosages) weed control and hoe weeding.

Cultural weed management refers to a collective term used to describe those measures instituted by farmers to reduce the germination, growth and competitiveness of weeds during the growing or culture of the crop. Itinvolves the use of clean certified seed, optimum plant population and plant arrangement, timeliness of planting, crop cultivars adapted to the ecological region, maintenance of soil fertility, availability of adequate moisture and use of competitive crops (Blackshaw *et al*., 2006). Cultural weed management option for smallholder farmers constitute the first line of defense in the fight against weeds and to gear their crop production systems to minimize weed problems in the short and long terms (Mandumbu *et al*., 2011).

According to Mashingaidze and Chivinge, (1998) cultural weed management methods are based on promoting agronomic and management practises that will give a crop a competitive advantage against weeds. Although smallholder farmers have been utilising cultural weed control methods to a greater extend, yields are still low owing to the reason that most crops are not vigorous to compete with weeds (Chivinge, 1994). Furthermore, the smallholder farmers in the semi-arid areas of Zimbabwe have problems in putting some of these methods into practice to effectively control the weeds. For example, time of planting might be delayed due to a delay in the offset of effective rainfall especially in the semi-arid areas and in some cases there might be enough moisture to encourage weed germination but not crop germination. This will result in germination of the weeds before the crop and yet the farmer may not be in a position to remove these weeds before planting the crop. It is also a fact that most farmers use about half of the recommended plant populations (Agronomy Institute, 1985), hence allowing some of the solar radiation to reach the weed canopy thereby increasing crop/weed competition.

Limited input availability to most communal farmers has lagged the use of the optimum amount of fertiliser for the soil, largely because of lack of soil analysis and shortage of cash (Agronomy Institute, 1985). Some farmers do not fertilise their crops at all and some may prefer to fertilise cotton and maize, but sunflower (*Helianthus annus*), sorghum, finger millet and pearl millet rarely get fertilised. Despite this lack of fertilisation, the weeds always grow vigorously, depriving the crop of the necessary growth resources.

Tillage system may offer a selection pressure on abundance, distribution and weed population. According to Harper, 1977, abundance of weed species has more to do with habitable sites, genetic and phenotypic plasticity that permit a wide range of sites to be occupied. The type of tillage used may offer a selection pressure on the weed population. Moreover, much research has not be done on effect of tillage on weeds, studies by Mandumbu (2008) found that grass weeds, *Setaria spp* and *Corchorous tridens* were under the ripper and basins compared to conventional tillage. Results from same studies revealed that broadleaf weeds were less in minimum tillage compared to conventional tillage.

Manipulation of fertiliser timing and placement can help reduce weed interference of crops. Method of placing fertilisers or manures can affect the distribution of weeds. Studies indicated that more weeds grew vigorously in cases where manure was broadcast compared to banding and spot application (Munguri *et al*., 1995). According to Rupende, Chivinge and Mariga (1995) manure may contain a number of germinable weed seeds. Manure needs to be cured before used in farmer's field. Curing is defined a process where animal manure is heaped for periods ranging from 1-5 months, on the side of the kraal (Mashingaidze and Chivinge, 1998). The procedure of heaping manure generates high temperatures within the manure heap and is accompanied by the release of toxic gases such as methane and ammonia which will kill weed seeds in the heap. It is said that, heaping also improves mineralisation of the manure for example *Amaranthus hybridus, Eleucine indica, Cynodon dactylon* and *Acathospermum hispidium* were associated with uncured manure in Manicaland in Zimbabwe, this was according to Rupende *et al*. (1995).

Weeds have life cycles synchronised to that of the crop such that more weeds emerge with the crop in November or December with the first flush of rains (Mabasa and Rambakudzibgwa, 1993). Investigations have indicated that intermittent wetting and drying of weed seeds brought about by early showers on September and October break seed dormancy. Conventional tillage brings buried weed seeds to the surface where they germinate. It has been said that early planting gives a plant a starting position advantage over the weeds (Mashingaidze and Chivinge, 1998). Early planted crop has a greater advantage in that it gets the highest sunshine and temperatures and grows before the first flush of weeds. By the time weeds emerge in November and December the crop will have established and are strong competitors against weeds.

Crop rotations are said to be a useful tool for weed management (Liebman and Gallandt, 1997). Crop diversification encourages operational diversity that in turn can facilitate improved weed management. According to Sanyal, Bhowmik and Anderson (2008), different planting and harvesting dates among these crops provides more opportunities for producers to prevent either plant establishments or seed production by weeds. Crop diversification encourages operational diversity that in turn can facilitate improved weed management. In the smallholder sector of Zimbabwe diversification of component crops in rotation is limited. The effectiveness of a crop rotation in weed suppression may be enhanced by crop sequences that create varying patterns of resource competition, allelopathy, soil disturbance and mechanical damage to certain species. Many aspects of rotation need to be explored in the Zimbabwean context. Diversified crop rotations are likely to provide best opportunities for exploring diverse sets of tactics and ecological processes to suppress weeds (Westerman *et al*., 2005).

Mechanical weed control defined as the use of machines or mechanical devices driven by animal or fossil fuel energy. Improvements in this method was brought about by the introduction of the plough, spike toothed harrow and animal drawn tyne cultivator (Chivinge, 1990). Acording to Mbanje, Twomlow and O'Nell (2001), a plethora of animal drawn weeding equipment is now available which include reversible tynes, cultivator with hilling blades (BS221) and the BS41 five tined cultivators.

The plough is used primarily for land preparation (which involves heavy duty operations), tilling land to a depth greater than 15cm from the soil surface. For secondary tillage, spike tooth harrows are used to till land to not deeper than 15cm. In addition to land preparation these two implements can also control weeds. Studies have indicated that the oxdrawn plough in Zimbabwe has been used as a weed implement in two ways (Mashingaidze and Chivinge, 1998). Firstly, farmers plough the interow area in opposite directions and weeds in the interow area will be removed but those along the row will be buried. Extra weeding is required to remove further weeds as this is an inefficient process (Ellis Jones *et al*., 1993). The second way is to remove the mouldboard such that the plough share is the operating blade. Three or four passes will be required to completely remove weeds within a row making this process cumbersome.

Most communal and smallholder farmers in Zimbabwe use oxdrawn tyne cultivators. This method is an efficient way of removing weeds in the interow space especially when weeds are less than 15cm in height (Chivinge, 1990). Shortcomings to the use of animal drawn cultivators are their availability and to a less extent, draft power problems. Several disadvantages of tillage have been noted (Tattersfield and Cronin 1958; Chivinge, 1984), notably about 5 percent crop damage each time an implement passes through the land, especially when animals are not well trained, the failure to remove intra-row weeds, the near possibility of adequately controlling some weeds bigger than 15cm; and the inability to employ mechanical implements when crops are about 60cm tall for crop damage.

This is the use of direct human effort to remove weeds and the most common method in both the small scale farmers and the commercial sector. Manual weeding in both sectors can be used to complement other weed management methods such as mechanical or cultural methods or both.

Hoe weeding is one of the earlier and commonly used weed control method in Zimbabwe where weeds are removed by iron blades attached to wooden handle. It is a simple method which does not require investment in expensive equipment and periodic purchase of inputs like herbicides nor does it require the farmer to be literate or numerate (Thembani, 2002). Smallholder farmers spend a lot of time during the cropping season battling to control weeds and get very little for their misery and toil at the end of the season (Akobundu, 1987, Chivinge, 1990). Hoe weeding requires a large labour force which can complete weeding in time before the weeds inflict negative effects on the crop available in rural communities.

According to Mandumbu *et al*., (2011) hoe weeding is going to be present as long as the smallholder sector is present regardless of its demerits but researchers and extension agents should put effort to make sure that there is reduced weeding regime on a single crop during the season by making sure that it is integrated with other control methods. The prevalence of HIV/AIDS on the labour force in the smallholder sector has also worsened the situation. In worst cases, the economically active group is the most affected leaving the aged and children in the household to battle with weeds thereby threatening food security.

Most smallholder farmers use family labour and they hire labour only when it is not sufficient. During critical time hired labour may be unavailable during peak weeding period (November-January period resulting in long periods of crop-weed competition and yield reduction (Chivinge, 1990). Problems encountered with weeding and hoeing by hand is that there are morphological similarities of some weeds with certain crops. For example, finger millet (*Eleusine corocana*) and rapoko grass (*E. indica*) are very similar and difficult to distinguish particularly at the early stages of growth before flowering; other examples are Shamva grass (*Rottboellia conchinchinensis)* in maize and stock rose (*Hibiscus spp.)* in cotton. These weeds commonly escape removal due to similarities in their morphology. There have been encountered problems with this method of controlling weeds; it cannot deal effectively with parasitic, perennial and annual weeds effectively with parasitic perennial and annual weeds which produce vegetatively. *Striga spp* is one of the most common parasitic weed causing considerable economic crop damage to maize and pearl millet (*Pennisetum typhoides*). Mode of damage is brought about by haustoria of parasitic weeds which penetrate the food conducting tissue of the roots of crop plants from such an intimate and damaging relationship by weeding or hoeing.

The adoption of herbicide technology in the small holder sector in Zimbabwe has been low. Farmers and extension agents lack technical knowledge on herbicide usage and resource for the purchase of associated application devices together with the fear phytotoxicity (Chivinge, 1984). Smallholder farmers who adopted herbicide technology were introduced reduced herbicide dosages in Integrated Weed Management (IWM) which helps these resource constrained farmers to effectively control weeds. Reduced herbicide dosages helped to reduce expenditure on herbicides to a fraction of the cost of full label herbicide rates while maintaining efficacy and other benefits derived from herbicide use (Mashingaidze and Chivinge, 1995).

2.8 Intercropping as a weed management strategy in semi-arid areas

Intercropping is a crop mixture that has been said to be more dynamic than sole crops and is less likely to succumb to adversities of nature (Andrews, 1977). The most prevalent and common combinations intercrop systems in the smallholder section of Zimbabwe are cereals and low density pumpkins, cowpeas, groundnuts, cucumber and water melons (Mariga, 1990). Shumba, Dhliwayo and Mukoko (1990) reported that despite the effective discouragement of intercropping in Zimbabwe by pre-independence government extension agencies, the practice could still have a useful role in the small holder sector.

The dimension of weed suppression was improved and added in the mid-1990s when research was initiated on the ability of intercrops to suppress weeds. Investigations from studies by Mashingaidze, Madakadze and Twomlow (2000) and Mashingaidze (2004) revealed that intercrops had lower weed dry matter compared to sole crops although weed density was not affected. Reduced weed biomass shows that weeds have reduced ability to capture resources in intercrops. Experiments with sole crops have shown that large variations in weed suppression exist among genotypes within species. Experiments done by Katsaruware (2006) indicated that upright cowpea varieties were more suitable for intercropping with maize as they suppressed weeds and did not lower cereal yields. This calls for proper selection of varieties within species that suppress weeds.

2.9 Impact of plant density on weed density and yield

In intercropping, the seeding rate of each crop species should be adjusted below its full rate to optimize plant density (Matusso *et al*., 2014). According to Seran and Brintha, (2010) neither of the planted crops would yield well if the full rate of each crop is planted because of intense overcrowding in the crop stand. Morgado and Willey, (2003) reported a decrease in dry matter yield accumulation of individual maize plant with increasing bean plant population. Increasing maize plant density in intercropping, reduced soyabean seed yield by 21 and 23 % at maize plant density of 44 440 and 53 330 plants/ha, respectively, compared with intercropping at 38 000 maize plants/ha (Muoneke *et al*., 2007).

According to Bulson, Snaydon and Stopes, (1997) nitrogen content of wheat grain and whole plant biomass was significantly increased when the density of beans in the intercrops was increased which was reflected in significant increase in grain protein at harvest. Egbe (2010) reported that the competitive ratio of soyabean increased from 0.76 to 1.15 with increasing density of the soyabean in the intercrop combinations indicating higher competitiveness at higher densities than the sorghum component while the competitive ratio of sorghum had the opposite response of 1.23 to 0.76. Rate of accumulation of dry matter and leaf area index of maize increased with increasing maize density resulting in decreasing transmission of light to the intercropped soyabeans (Prasad and Brook, 2005).

2.10 Impact of row orientation on weed density and yield

An important factor in regulating the competitive relationship between crops and weeds is light because light influences the growth and development of neighbouring plants (Ballare *et al*., 1990; Ballare and Casal 2000; Holt 1995; Ghersa *et al*., 1994; Rousseaux *et al*., 1996). There is interference between crop and weed plants during early growth stage because of reflected light. The reflection of far-red photon by the stem of one plant lowers the red to far-red photon ratio of light experienced by the stems of neighbouring plants (Borger *et al*., 2010). The light environment of the stem is thereby modified resulting in an increased stem elongation rate. The crop canopy closes as plants age and mutually shading further thereby increasing the competition for photosynthetic light. This results in the shading of the lower leaves in the canopy making them to access lower levels of Photosynthetically Active Radiation (PAR) and a low red and far-red photon ratio.

Flowering and fruit set is also influenced by light thereby significantly determining crop productivity (Borger, Hashem and Patham, 2010). Manipulation of crop row orientation can be utilised to increase shading of the weeds by the crop canopy to suppress weed growth thereby maximising crop yield. According to Holt (1995) manipulation of crop row spacing and row orientation is one possible way to increase light interception by the crop canopy and to reduce light interception by the weeds. Borger *et al.* (2010) found that reducing the crop row spacing or crop row orientation at a near right angle to the sunlight direction increases the shading of weeds between the rows. Angiras and Sharma (1996); Sharma and Angiras (1996a,b) and Shrestha and Fidelibus (2005) independently reported that the growth of little seed canary grass (*Phalaris minor* Retz.), common vetch [*Vicia sativa* (L.)], wild oat (*Avena fatua*) and poison rye grass [*Lolium temulentum* (L.)] in wheat crops and black nightshade [*Solanum nigrum* (L.)] in vineyards [*Vitis vinifera* (L.)] were significantly influenced by crop row spacing and orientation. Furthermore, row orientation affected crop yield or soil moisture relations in apple (*Malus domestica* Borkh) orchards, olive [(*Olea Europa* (L.)] and oats [*Avena sativum* (L.)] crops (Mohler, 2001; Cannor *et al*., 2009).

According to Borger, Hashem and Patham (2010) the effect of row orientation varies with latitude and seasonal tilt of the earth in relation to the sun. Higher levels of light absorption for most of the year have been reported on north-south row orientation near the equator as opposed to east-west row orientation. Absorption of light is high in north-south crops in summer at higher latitudes of up to 55° and east-west crops for the rest of the year. East-west row orientation from 65º upwards gives the greatest light absorption all year although the differences between row orientation are minor (Mutsaers, 1980).

2.11 Crop interaction in intercropping systems

In intercropping systems, there is need to optimise the plant density to reduce crop competition from overcrowding and underutilisation of land from underpopulation. This can be achieved by adjusting the seedling rate of each crop species on the intercropping mixture below the full planting rate as the crops will yield well in the mixture (Hiesbick, 1980; Prabhakar *et al*., 1983). According to Ouma and Jeurto (2010), staggered maturity dates or developmental periods helps in utilising variations in resource demand for nutrients, water and sunlight making it essential as a planning tool in designing intercropping. Compatible plants should be intercropped to encourage biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment (Bamigboye, 2011). Biodiversity helps in reducing the outbreaks of crop pests by increasing the abundance of natural enemies or biological diversity (Atileri, 1994).

2.12 Advantages and disadvantages of intercropping

Farmers practice intercropping with the principal reasons which include profit maximisation, soil conservation and maintenance, flexibility, risk minimisation against crop failure, balanced nutrition and weed control (Shetty *et al*., 1995). Intercropping also has other advantages which include the potential for increased farm profitability and low fixed costs resulting from the introduction of a second crop in the same field. McCoy (2001) also alluded that intercropping also facilitates the better utilisation of time, labour, management and equipment. According to Viljoen and Allemann (1996), some of the advantages of intercropping are higher yields as compared to sole crop yields which can attributed to less intra-specific competition, higher yield stability, better weed control, efficient use of environmental resources, provision of insurance against crop failure and improved quality of produce by variety considering small grain crops requires a larger land area to produce the same yield as that of maize in an intercropping system.

Mixed cropping of cereals and legumes is widespread practice (Ofori and Stern, 1987) because legumes used in crop production have traditionally enabled farmers to reduce soil erosion and replenish soil organic matter and nitrogen into the soil (Scott *et al*., 1987). According to Vandermeer (1992) intercrops have proved to perform better than sole crops by producing higher yields, preserving moisture and sheltering against pest attacks and even regarding the provision of more balanced food supplies for humans and the distribution of labour requirements within the farming enterprise. Research also focused on searching of detailed knowledge on how different species are able to "coexist" productively rather than the benefits of intercropping because crops differ in the way they utilise their environmental resources (Vandemeer, 1989). The basic ideas are based on how different species interact during intercropping. Competition for resources arises from varying time of planting, root growth patterns and different resource demands (Curse *et al*., 1997).

Many developing countries in Asia, Africa and South America are practising cereal-legume intercropping due to its advantage over sole cropping. These advantages are being influenced by factors such as soil fertility, habitat, and moisture level as well as crop varieties and species (Vandermeer, 1992). Though such a system is important, there are very limited sources in the literature concerning the impact of these systems on the physiology of component species and environment. The major disadvantage of intercropping is that it is not well adapted to very dry, poorly drained and heavy clay soils which also imply difficulty in using machinery and harvesting (Prochaska, 2001). Intercropping on large scale using machinery for its operations is generally believed to be impossible as it results in difficulty in mechanisation (for purposes of sowing, fertilising, weeding and harvesting of the crops) although there are examples of cropping systems which use modern machines that exist (Ghaffarzadeh, 1999 and Baumann, 2001).

2.12.1 Effects of intercropping on Water Use Efficiency (WUE)

Availability of water is one of the most important factors determining productivity in legume-cereal cropping systems. Most farmers who rely on rainfed agriculture, in the semi-arid regions of Zimbabwe and the world over usually practise mixed cropping. According to Ofori and Stern (1987), competition for water may not be important in determining intercrop efficiency because cereals and legumes use water equally except under unfavourable environmental conditions. Water can be used more efficiently byan intercrop of two crop species such as legumes and cereals than a monoculture of either species through exploring a larger total soil volume of water especially if the component crops have different rooting pattern and depth (Willey, 1979). Hulugalle and Lal (1986) reported that WUE in a maize-cowpea intercrop was higher than in the sole crops when soil water is not limiting, with the reverse being true under water limiting conditions. Thus WUE in the intercrop can be higher compared to sole maize under water limiting conditions resulting in retarded growth and reduced yield.

2.12.2 Effects of intercropping on Nutrient Use Efficiency (NUE)

More efficient use of nutrients is a possible advantage of intercropping legume with non-legumes. Dalal, (1974) and Masson, Leihner and Vorst (1986) have independently reported that more efficient use of available nutrients and higher total nitrogen uptake may occur in intercropping systems compared to monoculture systems if both species have different rooting and uptake pattern. However, it is unclear if better nutrient uptake is the effect or the cause of higher yield potential (Willey, 1979). Cereal and legume yield were found to be reduced by the maize intercrop at higher nitrogen levels especially under intercropping (Ezumah *et al.*, 1987; Ofori and Stern, 1987). According to Shumba *et al.* (1990) and Siame, Willey and Morse (1998), there was a decrease in maize yield under intercropping compared to sole cropping. The inconsistent performance of cereal-legume intercropping requires critical investigation especially in the areas where the farmers are to benefit from intercropping systems in a specific locality (Mpangane *et al*., 2004). The introduction of legumes as an intercrop came as an effort to improve soil fertility and to minimise the use of external inputs in rotation with other crops.

2.12.3 Effects of intercropping on Radiation Use Efficiency (RUE)

Solar radiation provides energy required for the process of photosynthesis which ultimately sets the potential for production of assimilates hence crop productivity. It also determines water use by the process involved in evaporation and transpiration (Goudriaan, 1982; Keating and Carberry, 1993). Green plants utilise Photosynthetically Active Radiation (PAR) for photosynthesis which conservatively makes up about 50% of global short wave radiation (Szeicz, 1974). Solar radiation is more reliable and used sufficiently by intercrops as they form a complete cover to allow full interception than sole crops unlike high variability that occurs in the supply of water and nutrients to the plant. Solar radiation cannot be stored for later use so it must be intercepted and utilised instantaneously to energise the photosynthesis process. This implies that neighbouring plants compete for solar radiation by direct interception (Keating and Carberry, 1993). Caldwell (1987) noted that studies on crop mixtures for example intercropping and crop/weed interactions have concentrated more on the competition for resources between species and the emphasis in the case of competition for light has been placed on the ability of one species to compete with and shade another. Other factors such as differences between species, developmental pattern, plant density, canopy architecture, plant height, foliage overlap, photosynthetic rate and in the assimilate reserves have resulted in great structural complexity in mixed-species canopies.

The amount of green leaf area per unit of ground area is called Leaf Area Index (LAI) which is a parameter commonly used to describe the probability of light interception in relation to crop canopies (Keating and Carberry, 1993). There is a possibility of great diversity in intercrop canopies as a result of the various combinations in space and time of planting date and spatial distribution, leaf size, shape and orientation as well as plant height. The canopy characteristics of component crops may change due to the presence of other crop species, therefore it does not remain constant (Caldwell, 1987). Crop yield is closely related to assimilate production during the yield development period of crop growth, although it is difficult to relate yield directly to solar radiation because of factors that influence the relative contributions of assimilates produced at pre-anthesis and post-anthesis. According to Evans and Wardlaw (1976), shading and reduced assimilate production will have the least effect on yield if competition occurs during the vegetative growth phase. Reddy and Willey (1981) stated that where the components of an intercrop are in direct competition for light, increased total biomass production by the crop could result in improved yield.

The capturing of radiant energy drives crop evapotranspiration and the pattern of its interception determines the ratio of water use through crop transpiration to that lost through soil evaporation. Probably the single most disadvantage is that legume plants are shaded by the cereal throughout the growing season which results in severe reduction in shoot and root growth and ultimately in low grain and fodder yields. Although cowpea occupy 50% of the land area under intercropping, its grain and fodder yields are 10-20% less than those in sole cropping (Singh, *et al*., 1997; Terao, *et al*., 1997)

2.12.4 Effect of intercropping on weed density

Intercropping reduces weed infestation and is one of the integrated weed management strategies with less effect on the environment than the use of herbicides. The success of intercropping on weed control is much more diverse when different legumes are inter-planted with cereals and both the cereal and the legume are considered as main crops. The legume crop under intercropping supresses weeds through competition for resources (Gliessman, 1983). Weed infestation causes severe yield reductions in field crops and losses of 40-60 % have been reported under sole maize cropping (Ayeni, Duke and Akobundu, 1984) despite that growing crops in a mixture usually reduces weed occurance (Zoufa, Tariah and Isirimah, 1992). According to Olasantan, Lucas and Ezumah (1994), the practice of growing early maturing crops between widely spaced rows of long duration crops and the use of nitrogen fertiliser to enhance early ground cover, improves the supression of weeds. In cereal-legume intercropping, shading supresses weed growth that suggests the superiority of cereal and legume crops over weed growth.

Olasantan, Lucas and Ezumah (1994) found that intercropping maize and cassava (*Manihot esculenta*) with N-fertiliser application gave the highest Leaf Area Index (LAI) and the most effective light interception and hence the best weed control, highest N uptake by the plant, heigher grain yields and LER. Intercropping with no N application made only a slight improvement in LAI, light interception and weed control over the corresponding sole cassava. Weed dry mass was significantly higher under sole-cropped cassava without N application at 4 and 8 weeks after planting and under sole maize with no fertilliser only at 8 weeks after planting, compared to other treatments. Low N fertility, limited moisture content and weed competition have been reported to also affect the LER value. Ayeni *et al.* (1984) reported that weed interference resulted in 1.43 LER while weed free plots resulted in a 1.20 LER value while Weil and McFadden (1991) also found that high fertility levels and weed stress conditions favoured intercropping advantage.

In an investigation of intercropping leek (*Allium porrum*) and cerely [*Apium graveolens* (L.)], Baumann, Bastiaans and Kropff (2003) found it to be an alternative to reduce weed growth and reproductive potential, mainly to maintain productivity. Similar results were obtained using intercropping as an integrated weed management tool particularly for farming systems with low external inputs (Caporali, *et al.*, 1998; Itulya and Aguyoh, 1998; Rana and Pal, 1999; Liebman and Davis, 2000; Schoofs and Entz, 2000). The suppression of weed occurence was also confirmed by Steiner (1984) where maize was intercropped with groundnuts [*Arachis hypogeae* (L.)], mungbean [*Vigna radiata* (L.)] and sweet potato [*Impomoea batatas* (L.)] and in all cases led to the reduction of weed growth, yield loss and required timing of weeding. It was also observed that instead of several weedings required for sole maize, only one weeding was required to accomplish the same yield under intercropping. Maize intercropping with soybeans was also found to reduce weeds by 39% as compared to sole maize. In a study carried out by Ayeni *et al.* (1984), weed growth was not suppressed by intercropping maize and cowpea. It was concluded that weed growth must be controlled initially in order for canopy to develop sufficiently enough for weed suppression in intercropped maize/cowpea systems.

2.12.5 Allelopathic effects of intercropping

According to Rice (1974), allelopathy can be defined as the direct or indirect release of chemical substances into the environment by one plant to harmfully affect another plant. Ferguson and Rathinasabapathi (2003) defined allelopathy as the beneficial or harmful effect that is caused by one plant on another through releasing of chemicals from plant parts byroot exudents, leaching, residue decomposition, volitilisation and other processes in both natural and agricultural systems. Many part of the plant ecology such as plant occurence, plant gowth, plant succession, dominance, productivity, diversity and the structure of the plant communities can be affected by allelopathy. The magnitude of the allelopathic effect depends on the extent of any other stress such as biological factors (insect or disease pressure) or environmental conditions occuring during the growing season.

Allelopathy also plays an important role in supressing the growth of weed species (Reigosa *et al*., 2000; Patil *et al*., 2002; Chung *et al*., 2003; Florentine and Fox, 2003). In a planting mixture, cover crops take advantage of their allelopathic potential to suppress the weeds within its vicinity. The suppression of the weeds through allelopathy has been shown to be species sensitive. Growing of a mixture of different crops helps to control a broader spectrum of weeds each contributing to allelopathic activity towards specific weed species (Creamer and Bennet, 1997). Ferguson and Rathinasabapathi, (2003) reported that there is no physiological target site and common mode of action for all allelochemicals and the effects of allelopathy which are commonly known include reduction in seed germination and seedling growth. Photosynthesis, pollen germination,cell division, mineral uptake and specific enzyme functions are some of the known sites of action for some allelochemicals.

Allelopathic inhibition is a complex process which can involve the interaction of different classes of chemicals like flavinoids, alkanoids, terponoids, phenolic compounds, amino acids and carbohydrates with mixtures of different compounds which sometimes have a greater allelopathic effect than individual compounds alone. Most of these chemicals are of plant residues which are found to the inhibitory of plant processes. They are caused by phytotoxic substances that are actively released from the living plants into the environment through root exudation, volitilisation, leaching and passive liberation through decomposition of plant residues. Allelochemicals do not usually appear to play a role in primary metabolism essential for plant survival and therefore usually considered to be secondary metabolites (Swain, 1977). Putman (1988) identified a number of classes of allalochemicals causing inhibition of germination and growth. Factors such as physiological and environmental stress, pests and diseases, solar radiation, herbicides and less than optimal nutrients, moisture and temperature levels can also affect allelochemical weed suppression. Different plant parts can also have allelopathic activity that varies over a growing season and include flowers, leaves, leaf litter and leaf mulch, stem, bark, root, soil and soil leachates and their derived compounds. Allelochemicals can also persist in the soil, affecting both neighbouring plants as well as those planted in succession (Ferguson and Rathinasabapathi, 2003). Sanford and Hairston (1984) reported that phytotoxic and allelopathic effects of different crop residues could also affect crop yields.

El-Khawas and Shehata (2005) found that seedling emergence was reduced with treatment of *Acacia nilotia* and *Eucalyptus rostrata* on morphological, biological and molecular criteria of maize and kidney pea. Recent yield declines in cropping systems has been attributed to allelopathic effects (El-Khawas and Shehata, 2005). These allelopathy associated problems have been observed both in monocultures and multiple cropping system. Continuous monoculture causes the accumulation of phytotoxins and harmful microbes in the soil that give rise to phytotoxicity and reduced soil fertility. A number of weed species possesses allelopathic properties, which have growth inhibition effects on crops. Allelocompounds inhibiting plant growth affect physiological processes, among others, the effect of iron uptake and hydraulic conductivity (water uptake) are particularly important. Since the root is the first organ to come into contact with the allelochemicals in the rhizosphere, the degree of inhibition depends on their concentration (Blum *et al*., 1999). Some plants are able to escape allelopathic chemical(s) due to their “hypersensitivity”, that is, some plant root tips become strongly affected by allelochemical(s), which can inhibit growth (Chon *et al*., 2002)

2.12.6. Effect of intercropping on pest and disease control

Sorghum is susceptible to many insects such as beetles, caterpillars, weevils, stalk borers, grasshoppers, foliage feeders, chilo borers and the ones that suck plant sap such as leafhoppers and maize aphids (Drinkwater *et al*., 2002). Diseases such as bacterial (stalk rot and leaf streak), viral (dwarf mosaic and streak diseases) and fungal (cob and tassel smuts) are common infectious diseases including maize root knot nematodes (Flett *et al*., 1996). According to Adipala, Omongo and Sabiti (1999) cowpea is normally affected by insect pests such as legume pod borers, foliage beetles, thrips and aphids. It is also affected by diseases such as viral diseases (scab and anthracnose), rusts and bacterial disease such as blight (Edema, 1995)

According to Trenbath (1993) many pests and diseases are attracted when species are grown as sole crops compared to when they are intercropped and show less damage under intercropping than sole cropping systems. This may be related to micro-environment effects of associated crops in intercropping compared to sole cropping (Vandermeer, 1989; Letourneau, 1990). The damage may affect resource capture, resource conversion efficiency or harvest index (HI) depending on the part affected. It can be through damaging of leaves, flowers, flower buds and fruit hence upsetting the source-sink relationship and phenology (Barker and Yusuf, 1976; Crawley, 1989). According to Root (1973) pests find it very difficult to find their hosts in intercrops because of visual disturbance for their search pattern making them to stay for shorter times because of disruptive effect of landing on non-host plants resulting in slow survival. Pest search for hosts can also be similarly affected by the presence of weeds (Altieri *et al*., 1990)

In intercropping, airborne diseases of rapidly evolving specialised fungal diseases such as mildews and rusts have been controlled using breeding of cereal cultivars resistant to the diseases (Wolfe, 1985). Maize leafhopper (*Dalbus maindis*) population was significantly reduced from different maize cultivars under intercropping compared those under sole cropping (Power, 1990). This was the same with fungal spores on leaves, roots parasitic nematodes (eelworms) intercepted by roots of hosts and non-hosts (Trudgill, 1991). Intercropping cowpea cultivar PAN 311 also reduced stalk borer *Chilo partellus* (Swinhoe) infestation significantly in sorghum compared to sole crop (Ayisi and Mposi, 2001). Ogenga-Latigo *et al*. (1992a,b) found that intercropping and aphid attack reduced bean yield. Thus, when yield is reduced due to disease and pests attack LER is also reduced (Kass, 1978).

The variability of insect pest control and yield improvement in intercropping systems relative to sole cropping have been inconsistent over habits, component species, variety, density, row arrangement, soil fertility and moisture (Ayisi and Mposi, 2001) and individual crops may not respond the same (Nwanze and Mueller, 1989). Maize stem borer was found to be more severe under sole cropping than intercropping with lablab [Lablab purpureus (L.)] (Maluleke *et al*., 2005). Higher plant densities were also reported to reduce aphid infestation under intercropping and there was a possibility that low viral diseases under these conditions were due to unfavourable microclimate for the aphids in intercrops (Ogenga-Latigo, *et al*., 1992a,b).

2.13 Adoption of intercropping by farmers worldwide

Adoption of intercropping is generally low mainly in the commercial farming sector as there seems to be a prejudice among these farmers that intercropping is only for peasant farming and has no place in modern agriculture (Lithourgidis, Dordas and Damalas, 2011). This has reduced its adoption by many farmers in many areas of the world with traditional farmers also developing or inheriting complex farming systems (Lithourgidis *et al*., 2011). These complex farming systems are in the form of polycultures which helped them to sustainably manage harsh climatic environments and to meet their sustainable needs without depending on chemical fertilisers, mechanisation, pesticides and other modern agricultural science because they were well adapted to the local environments (Denevan, 1995).

According to Lithourgidis *et al.*, (2011) productivity in terms of harvestable products in multiple cropping by smallholder farmers is generally higher than under sole cropping even with the same management and yield advantages can ranges from 20 to 60 %. This is due to more efficient use of water, nutrients and solar radiation as well as reduction in pest incidence (Clawson, 1985). Mainstream agronomic research has largely focused on monocrop systems despite the multiple advantages and potential of intercropping (Malezieux *et al*., 2009). Intercropping is widespread in many parts of the world and has been traditionally used for thousand years yet still poorly understood from an agronomic perspective. Furthermore, more research has focused on monoculture mainly due to its widespread use in the developed world. Lithourgidis *et al*. (2011) emphasised the need for further research to better understand how intercrops function and to develop intercropping systems that are compatible with current farming systems since the mixture components need to be chosen with care. Thus, some guides on the new combination of crops and varieties should be provided.

2.14 Assessment of intercropping productivity using Land Equivalent Ratio (LER)

Willey (1979) described the Land Equivalent Ratio (LER) as the most frequently used index for comparing the productivity of crop mixtures with that of sole crops and for measuring the advantages of intercropping systems on combined yield of both crops (Mandal and Roy, 1986). It is sometimes called the mixture Relative Yield Total (RYT). This is a method used to determine the effectiveness of intercropping systems. It is the most widely used index. It is defined as the relative land area under sole crops which is required to produce yields achieved in intercropping (Trenbath, 1976). LER is the sum of fractions of intercrop yields divided by the sole crop yield and can be used as an ergonomically sound index for assessing yield advantages derived from intercropping and is calculated as follows;

$$\mathrm{LER} = \frac{\mathrm{I_A}}{\mathrm{S_A}} + \frac{\mathrm{I_B}}{\mathrm{S_B}}$$

Where I_A = intercrop crop A

I_B = intercrop crop B

S_A = sole crop A

S_B = sole crop B

Mead and Willey (1980) reported that LER greater than 1.0 shows that intercropping is more efficient than sole cropping and an LER less than 1.0 shows that sole cropping is more efficient than intercropping. LER value of 1.0 indicates no difference in yield between the intercrop and the collection of monocultures.

CHAPTER THREE

3.0 INTERCROPPING PRACTICES AND FARMERS' PERSPECTIVE ABOUT INTERCROPPING

3.1 Introduction

Matobo District is in Matebeleland South Province of Zimbabwe and falls in a semi-arid region where yields are generally low for most agricultural crops, thus making the district heavily dependent on food aid and famine alleviation programmes (Parliament of Zimbabwe Research Department, 2011). This district lies in Agro-ecological Regions IV and V which are characterized by low and erratic rainfall as well as long dry spells. Aridity in these regions increases year after year owing to the effects of the global phenomenon of climatic change (Ndlovu, 2011). ZimVac (2009) noted that 20-30 % of the households in Matobo district were food insecure with the existing forms of income in the district being wages from labour, remittances from employed relatives, the informal sector, fishing and poaching of wildlife.

The area is a high poverty rural district where the means of livelihood is precariously wedged on unsustainable economic activities which is worsening the food insecurity situation of this highly populated area (Ndlovu, 2011). According to ZIMSTAT (2012) report, Matobo district has a population of 93 991 people and 20 749 households with an average of 4.5 people per household. The study area comprises Ward 15 and Ward 25 of Matobo District. The wards have a population of 5089 and 5 922 respectively with Ward 15 having 1 082 households and an average of 4.7 people per household and Ward 25 having 1 653 households and an average of 3.6 people per household. Within the district, Matopo Research Station is a Centre where crop and livestock based technology is developed.

The Parliament of Zimbabwe Research Department (2011) reported that the area lacked meaningful human development although the general infrastructure of the area was good and called for initiatives which create sustainable livelihood and community economic activities which reduce the vulnerability of households to poverty thereby encouraging sustainable development. These initiatives include capacity building of the local community to participate in the tourism industry through CAMPFIRE projects, conservation of natural resources which in the long run would benefit the community directly (Parliament of Zimbabwe Research Department, 2011) and adoption of sustainable agricultural technologies. These may include growing drought tolerant crops such as sorghum and cowpea and practising intercropping systems at optimal population and row orientation as a plausible technological option for grain food improvement in arid and semi-arid areas. Furthermore, more activities in this district should be directed towards farmers' training and alleviation of poverty so as to improve rural livelihoods through enhanced household activities and food security.

Intercropping seeks to maximize productivity through diversification (Sullivan, 2003), effective use of moisture, nutrient and solar radiation (Hussaini *et al*., 2001), soil and water conservation (Jaranyana *et al*., 2001), weeds, pests and disease control (Liebman and Stover, 2001) and improvement of soil fertility through nitrogen fixation in legume intercrops (Asiwe *et al*., 2009). Therefore, it is necessary to find out whether farmers in these areas have adopted improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security. This research is aimed at assessing perceptions of smallholder farmers in Matobo district about intercropping and establishing their intercropping practices.

3.2 Objectives

i) To establish the extent to which intercropping is practised by smallholder farmers in Matobo district

ii) To establish intercropping practices of smallhoder farmers in Matobo district

iii) To determine smallholder farmers' perspective about intercropping

3.3 Materials and Methods

3.3.1 Study site

The survey was conducted in Wards 15 and 25 of Matobo district. Ward 15 is in Gulathi communal area while Ward 25 is in Woollandale resettlement area. Several factors justify the selection of the research site and these factors include the proximity of the area to Matopo Research Station where the researcher carried out field trials and food insecurity is also the major challenge in this area where farmers lack the knowledge on dry land farming technology (Ndlovu, 2011). Furthermore, resettled farmers face challenges in adapting to the new farming conditions they are introduced to since they are in a new area with different soil types, climate and other conditions and therefore suitable for different agricultural activities. Communal farmers also lack an understanding of intercropping from an agronomic perspective despite it being vital in sustainable agriculture (Lithourgidis *et al.*, 2011). Soils in this area are red Fersialitic soils. Average temperatures are 40 ^{0}C during summer and 13 ^{0}C during winter while rainfall amount ranges from 400 – 650 mm per annum. Farmers in Matobo district commonly grow small grain crops (sorghum, finger millet and pearl millet), legumes (cowpea, sugar beans, groundnuts, bambara nuts and soyabeans) which fix atmospheric nitrogen, water melons, pumpkins, sweet potatoes and part of maize. The recommended cereal crops in Matobo district are sorghum and pearl millet, while cowpea is the major legume crop.

3.3.2 Sampling design

A multistage sampling technique was used to select the sampling units for the interview. Matobo district was purposively selected since it was convenient to carry out the survey close to Matopo Research Station where the researcher was based and would then conduct on-farm trials. The research station is located in Matobo district. Two wards namely Ward 15 and Ward 25 were purposively selected and two villages from each ward were randomly selected. The villages were Mkhokha and Nyumbani in Ward 15 and Foxfarm and Phakama in Ward 25. Questionnaires were administered to 60 randomly selected farmers, 15 farmers per village. Random sampling was used to administer the questionnaires to the farmers to reduce the response bias in survey results. Snowballing approach was then used to identify farmers practising intercropping.

3.3.3 Population and Sample size

The population comprised of the communal and resettlement area farmers in Matobo district Ward 15 and Ward 25. Ward 15 has a population of 5 089 people with 1 082 households and an average of 4.7 people per household and ward 25 has a population of 5 922 people with 1 653 households and an average of 3.6 people per household. Households within 10 km proximity to the research station were considered for the survey. About 30% and 20% of the households in the communal and resettlement areas, respectively, are within the 10 km proximity to the research station making the target population in ward 15 to be 100 households and ward 25 to be 94 households. Questionnaires were administered randomly to 30% of the households within the 10km proximity covering 30 households in each ward. Pre-testing of the questionnaire was undertaken to improve the questionnaire design and enhance quality of responses obtained from the farmers.

3.4 Data analysis

Descriptive statistics were performed on the data. For some of the data inferential tests were performed using Statistical Package for Social Sciences (SPSS) version 21. Graphs were drawn using Microsoft Excel 2013. Chi-squared test was used to determine whether gender, marital status, ward, village, household size and farm area was associated with intercropping.

3.5 Results and Discussion

3.5.1 Proportion of farmers practising intercropping

Results showed that 53.3% (32 farmers) of farmers interviewed were practising intercropping while 46.7% (28 farmers) of them were not practising intercropping. Of the farmers in Ward 15, 40% (12 farmers) were not practising intercropping while 60% (18 farmers) of them were practising intercropping. The percentage of farmers practising intercropping in Ward 25 was lower than that for Ward 15, being 46.7% (Figure 3.2). The rate of adoption of intercropping was high in the communal area (Ward 15) compared to the resettlement area (Ward 25).

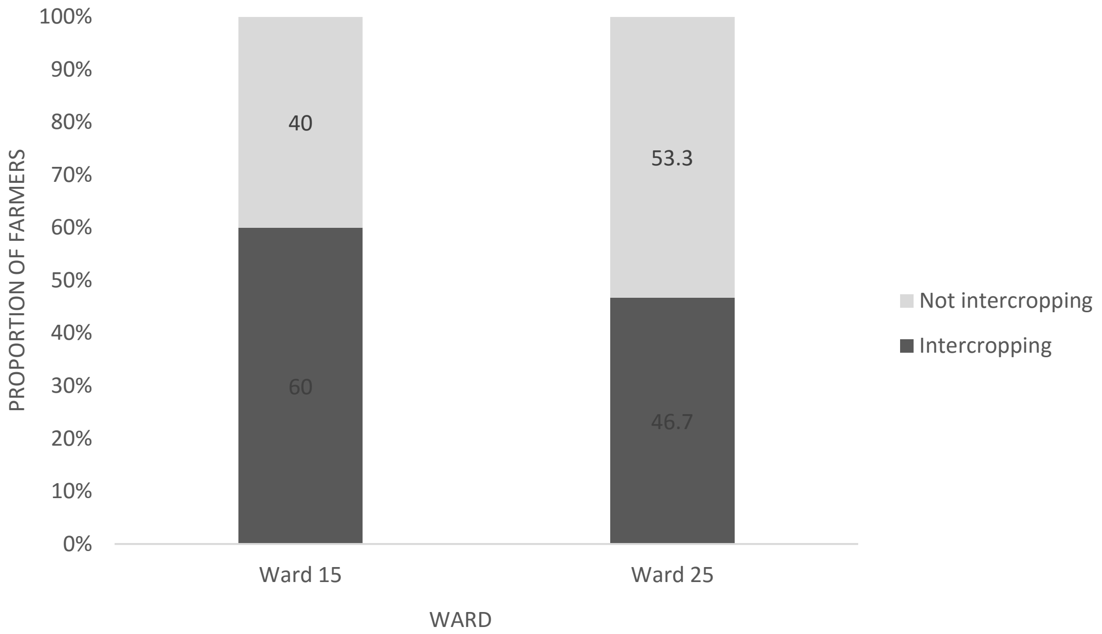


Figure 3.1: The proportions of farmers practising intercropping in wards 15 and 25 of Matobo district during the 2014/15 season

Smallholder farmers in Matobo district were not practicing intercropping due to lack of finances to purchase improved seed on time thereby delaying planting operations. Other factors cited by the farmers include lack of information and knowledge about intercropping practices.

Despite the benefits of cereal-legume intercropping in smallholder agriculture, there are some constrains that needs to be curbed so as to attain progress (Bationo *et al*., 2011; Mapfumo *et al.*, 2011; Mugendi *et al*., 2011; Odendo *et al*., 2011). These include limited availability of phosphorus in acidic soils in some countries (Mapfumo, 2011) making them harmful for BNF process and therefore lessen the N contribution of the legume component to system (Fujita and Ofosu-Budu, 1996; Giller, 2001). This situation is further worsened by low use of mineral fertilisers by smallholder farmers which is associated with accessibility and affordability of appropriate fertilizers (Mapfumo, 2011). Smallholder farmers in Matobo district also lack access to improved seed on time due to financial constraints. Furthermore, there is lack of information and knowledge about intercropping technology because most of the research work that has been done related to cereal legume intercropping system in the past decades had less involvement of the farmers, particularly the resource-constrained farmers (Mugendi *et al*., 2011).

Of the farmers who were practising intercropping in Ward 15, 55.6 % were from Mkhokha village while 44.4 % were from Nyumbani and those who were not practising intercropping were distributed equally within the two villages (Table 3.1). . In Ward 25, 71.4 % of the farmers who were practicing intercropping were from Foxfarm village while 28.6 % were from Phakama village.

Table 3.1: Proportion of farmers practising intercropping within each village during 2014/15 season

Practice	Ward 15						Ward 25					
	Mkhokha		Nyumbani		Total		Foxfarm		Phakama		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Intercropping	10	55.6	8	44.4	18	100.0	10	71.4	4	28.6	14	100.0
Not intercropping	6	50.0	6	50.0	12	100.0	4	25.0	12	75.0	16	100.0

3.5.2 Gender of interviewed farmers

In Ward 15 (communal area), 44.4 % of farmers (8 farmers) practising intercropping were males and 55.6 % of them (10 farmers) were females. The proportion of male and female farmers practising intercropping in the resettlement area (Ward 25) was almost similar to that for the communal area, being 42.9 % and 57.1 % respectively. All the farmers who were not practising intercropping in Ward 15 were females while in Ward 25, 37.5 % and 62.6 % of the farmers were male and female respectively. The largest proportion of the farmers who were practising intercropping were females recording a percentage of 55.6 % and 57.1 % in ward 15 and 25 respectively (Table 3.2).

Table 3.2: Gender of farmer sampled in each ward during 2014/15 season

	Intercropping						Not intercropping					
Ward	Male		Female		Total		Male		Female		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
15	8	44.4	10	55.6	18	100.0	12	100.0	0	0.0	12	100.0
25	6	42.9	8	57.1	14	100.0	6	37.5	10	62.6	16	100.0

The results showed that the largest proportions of female in both wards were practising intercropping because most of the households in the community were being headed by females. This could also be attributed to the fact that crops such as legumes (cowpea, groundnuts, sweet beans etc) which are included in intercropping systems are generally referred to as crops for the women, who were the heads of most families in Matobo District. Katengeza, Kankwamba and Mangisoni (2015) reported that farmers adopt technologies to suit their own circumstances to increase productivity. For example female headed households which are labour constrained tend to adopt technologies such as intercropping that demand less labour as two or more crops can be managed at the same time in the same field. Accelerating technology adoption is fundamental prerequisite to increasing agricultural production for food security, inclusive growth and poverty reduction (Ndiritu *et al*., 2014)

3.5.3 Marital status of interviewed farmers

Approximately 66.7 % (12 farmers) and 85.7% (12 farmers) of the farmers who practiced intercropping in Ward 15 and 25 respectively were married (Table 3.3). In Ward 15, 11.1 % of the farmers were divorced and 22.2 % were widowed while in Ward 25, 14.3 % of the farmers were single.

Table 3.3: Marital status of farmer in ward 15 and 25 during 2014/15

Marital status	Intercropping				Not intercropping			
	Ward 15		Ward 25		Ward 15		Ward 25	
	Freq.	Percentage	Freq.	Percentage	Freq.	Percentage	Freq.	Percentage
Single	0	0.0	2	14.3	0	0.0	2	12.5
Married	12	66.7	12	85.7	10	83.3	8	50.0
Divorced	2	11.1	0	0.0	2	16.7	0	0.0
Widowed	4	22.2	0	0.0	0	0.0	6	37.5
Total	18	100	14	100	12	100	16	100

3.5.4 Responses from farmers who practice intercropping

3.5.4.1 Household size, total farm area and total area under intercropping

The minimum household size for both wards was equal at 3.00 and the maximum, total and mean household size was higher in Ward 15 compared to Ward 25. Ward 15 had the large maximum and total farm area and the small minimum and average farm area compared to Ward 25. The minimum and maximum area under intercropping was similar for both wards, being 0.50 and 3.00ha, respectively. The total area under intercropping was larger in Ward 15 with lower mean compared to Ward 25 (Table 3.4).

Table 3.4: Description of the nature of farmers practising intercropping

Ward		Min	Max	Sum	Mean	Std. Deviation
15	Household size	3.00	13.00	116.00	6.44	2.83
	Farm area (ha)	1.00	10.00	56.00	3.11	2.72
	Total area under intercropping (ha)	0.50	3.00	33.00	1.83	1.08
25	Household size	3.00	8.00	74.00	5.29	2.05
	Farm area (ha)	2.00	5.00	52.00	3.71	1.54
	Total area under intercropping (ha)	0.50	3.00	27.00	1.93	0.70

Household size, total farm area and total area under intercropping were more variable in Ward 15 (communal area) as compared to Ward 25 (resettlement area). This could be attributed to the time of establishment of the areas with the communal area established already and the resettlement area still establishing. The resettlement area comprises of new farmers having a smaller area under cropping.

3.5.4.2 Type of intercropping practised by the farmers

Farmers in Ward 15 were practising mixed and row intercropping while those in Ward 25 were practising mixed, row and strip intercropping. The most practised type of intercropping in both wards was row intercropping with 55.6% and 42.9% of farmers practicing this form of intercropping in Ward 15 and Ward 25, respectively (Table 3.5).

Table 3.5: Types of intercropping practised by smallholder farmers in Ward 15 and 25 during 2014/15 season

Type of intercropping	Ward 15		Ward 25	
	Frequency	Percentage	Frequency	Percentage
Mixed	8	44.4	4	28.6
Row	10	55.6	6	42.9
Strip	0	0.0	4	28.6
Total	18	100.0	14	100.0

The farmers adopted the type of intercropping without any scientific consideration but rather as a common practice in that particular village also because it is a time immemorial practice.

3.5.4.3 Row arrangement, orientation and ratio

Majority of the farmers in both wards were growing the main crop and the intercrop in different rows (77.8 % in ward 15 and 57.1 % in ward 25). On the other hand, 22.2 % of the farmers in Ward 15 and 28.6 % of the farmers in Ward 25 grow the main crop and the intercrop in one row. Approximately 14.4 % of farmers (2 farmers) in ward 25 did not respond to this question.

Table 3.6: Row arrangement in intercropping adopted by smallholders farmers in Ward 15 and 25 of Matobo district during the 2014/15 season

Row arrangement	Ward 15		Ward 25	
	Frequency	Percentage	Frequency	Percentage
None response	0	0.0	2	14.4
One row	4	22.2	4	28.6
Separate rows	14	77.8	8	57.1
Total	18	100.0	14	100.0

In both Wards, there were more farmers who did not consider row orientation important than those who considered it important (Table 3.7).

Table 3.7: Proportion of farmers who considered row orientation important

Row orientation	Ward 15		Ward 25	
	Frequency	Percentage	Frequency	Percentage
Considered	8	44.4	6	42.9
Not considered	10	55.6	8	57.1
Total	18	100.0	14	100.0

Majority of the farmers in both wards do not consider row orientation important though it determines the angle at which the leaves of the plants are arranged hence the amount of Photosynthetically Active Radiation (PAR) being intercepted by the plant. PAR is important in determining the rate of photosynthesis and dry matter being produced by the crops. Farmers thus, compromise on yields by not using the appropriate row-orientation.

In Ward 15, 75.0 % and 25.0 % of the farmers were growing the crops in NS and EW row orientation respectively. Farmers in Ward 25 were growing the crops in NS and EW row orientation. None of the farmers were growing the crops in NW-SE and NE-SW row orientation in both wards (Table 3.8).

Those who considered row orientation important were using row orientation to reduce soil erosion without considering its importance in improving light interception by the plant canopy which is a major contributor to yield. Row orientation also plays an important role in reducing the amount of light being intercepted by the weeds thereby reducing their growth and development.

Table 3.8: Row orientation used in intercropping by farmers in Matobo district during 2014/15 season

Row orientation used	Ward 15		Ward 25	
	Frequency	Percentage	Frequency	Percentage
None response	0	0.0	2	33.3
NS	6	75.0	2	33.3
EW	2	25.0	2	33.3
NW-SE	0	0.0	0	0.0
NE-SW	0	0.0	0	0.0
Total	8	100.0	6	100.0

The number of farmers who practiced row intercropping in wards 15 and 25 were 14 and 8 respectively. Of these, 71.4% (10 farmers) of the farmers in Ward 15 were using 1:1 row ratio, 14.3% were using 1:2 and 14.3% were using 1:3 row ratios (Table 3.9). In ward 25, 75.0% of the farmers were using 1:1 and 25.0 farmers were using1:2 row ratios.

The farmers adopted these row ratios as a common practice in that particular village without any scientific considerations. The major reason why farmers in Matobo District are using these row ratios is because it is a time immemorial practice. Scientifically, row ratio is one of the most important management factor or aspect which determines the plant density and can be used to improve the yield and quality of crop. Dahlmann and von Fragstein (2006) reported that seed rate, techniques and nitrogen supply can influence yield and quality of intercrops. According to Lakhani, (1976) the yield and production efficiency of cereal-legume mixtures is determined by the relative proportions of component crops and the overall mixture density.

In a research by Hong *et al*., (1987) maize and soyabeans were grown as single crops or intercropped in maize:soyabeans row ratio of 1:1, 1:2 and 1:3 and they reported that the stem diameter, length, number of branches and nodes of soyabeans were not significantly affected by sowing arrangements. The largest stalk diameter of maize was obtained in 1:3 row ratios against the lowest in 1:2 row ratios. The highest dry matter yield was recorded in 1:1 row ratio. Sowing of sorghum and soyabean in a 1:1 and 2:1 row ratio increased the fodder nutritive value from 65 g Crude Protein (CP) in pure stands to 105-107 g CP (Malinovskil and Shnurnikova, 1987). Row ratio affects plant density which in turn determines inter- and intra-specific competition between the crop components. This also affects management of the individual crop species.

Table 3.9: Row ratio used by farmers in Matobo district

Row ratio	Ward 15		Ward 25	
	Frequency	Percentage	Frequency	Percentage
1:1	10	71.4	6	75.0
1:2	2	14.3	2	25.0
1:3	2	14.3	0	0.0
Total	14	100.0	8	100.0

3.5.4.4 Crop spacing

The results indicated that most of the farmers in Matobo district were planting sorghum using variable plant populations ranging from 888 889 plants/ha (0.75 m × 0.15 m) to 37 037 plants/ha (0.60 m × 0.45 m) compared to the recommended plant population of 55 555 plants/ha (0.90 m × 0.20 m). Plant populations as low as 37 037 plants /ha result in low plant population leading to lower yields per unit area whereas those as high as 888 889 plants/ha lead to increased competition among the plant species thereby reducing the yield. The seeding rates of crops in the intercrops should be adjusted below its full rate to optimize plant density and to reduce competition. Seran and Brintha, (2010) reported that planting of the intercrops at full rate results in lower yields because of intense overcrowding. According to Tsubo *et al*. (2003) over-population, among other factors is the cause of food insecurity in Africa and developing countries in other continents. According to Van Kessel and Roskoski, (1988), the percentage of total N which is derived from N_2 fixation per individual plant in cowpea was largely independent of spacing. Thus, spacing of the intercrops has no contribution to N-fixation by the legumes in an intercrop.

3.5.4.5 Planting time for main crop and intercrop

Approximately 66.7% and 85.7% of farmers in ward 15 and 25 respectively planted the main crop and the intercrop at the same time (Table 3.10). Approximately 11% of farmers in ward 15 and 14.3 % in Ward 25 planted the main crop and the intercrop separately, with the minor crop planted later.

Table 3.10: Planting time for the main and the intercrop by the farmers in Matobo district during 2014/15 season

Planting time	Ward 15		Ward 25	
	Frequency	Percentage	Frequency	Percentage
None response	4	22.2	0	0.0
Same time	12	66.7	12	85.7
Different times	2	11.1	2	14.3
Total	18	100.0	14	100.0

All the farmers who planted the main crop and the intercrops separately planted the intercrops 1 and 2 weeks after the main crop in Ward 15 and Ward 25, respectively. The results indicate that planting time of the main and intercrop depends on the village the farmer is residing. It also depends on the days to maturity of the crops involved. However, in water stress environments, farmers maximize on the shorter season and low rainfall nature of the season, hence they establish the crops at the same time and with the effective rains.

Planting time has been proven to affect the performance of the component crops under intercrop for instance Mongi, Uriyo, Sudi and Singh (1976) reported that planting maize and cowpea simultaneously (at the same time) gave better yields as compared to separate times. According to Addo-Quaye, Darkwa and Ocloo, (2011) maize planted before or simultaneously with soyabean resulted in significantly higher values of Leaf Area Index (LAI), crop growth rate and net assimilation rate (NAR) compared to the one planted later.

Early planting of intercropped corn and cowpea provides immediate results indicating that cowpea controls weeds to certain extend (Barbosa e Silva *et al*., 2008)

3.5.5 Responses from farmers who did not practice intercropping

3.5.5.1 Description of household size and total farm

The minimum and maximum household size in ward 15 was 2.00 and 6.00 respectively and 1.00 and 5.00 for ward 25. The total and mean number of people in ward 15 was 52.00 and 4.33 respectively and 90.00 and 5.63 in ward. The minimum and maximum farm area for ward 15 was 2.00 and 6.00 respectively and 1.00 and 5.00 respectively for Ward 25. Ward 15 had a total farm area of 42.00 and a mean of 3.50 and ward 25 had a total farm area of 54.00 and a mean of 3.38 (Table 3.11).

Table 3.11: Description of household size and farm area for farmers not practising intercropping during 2014/15 season

Ward		Minimum	Maximum	Sum	Mean	Std Deviation
15	Household size	2.00	6.00	52.00	4.33	1.30
	Farm area	2.00	6.00	42.00	3.50	1.45
25	Household size	1.00	12.00	90.00	5.63	3.90
	Farm area	1.00	5.00	54.00	3.38	1.71

Ward 25 recorded the highest variation on both the household size and farm area compared to Ward 15.

3.5.5.2 Number of farmers who had practised intercropping before and why they had stopped practising it.

Results from the survey showed that 16.7% of farmers in ward 15 were practising intercropping before while 83.3% never practised intercropping and in ward 25, 37.5% of the farmers were practising intercropping before while 62.5% of the farmers never practised intercropping (Table 3.12).

Table 3.12: Percentage of farmers who stopped intercropping

Ward		Frequency	Percentage
15	Intercropping before	2	16.7
	Not intercropped before	10	83.3
	Total	12	100.0
25	Intercropping before	6	37.5
	Not intercropped before	10	62.5
	Total	16	100.0

In ward 15, all the farmers who had practised intercropping before pointed out that they last practised intercropping in the last season while in ward 25, the farmers had last practised intercropping in last season, three seasons ago and more than five seasons ago (Table 3.13).

Table 3.13: Period last practised intercropping by the farmers

Ward		Frequency	Percentage
15	Last season	2	100.0
	Total	2	100.0
25	Last season	2	33.3
	Three seasons ago	2	33.3
	More than five seasons ago	2	33.3
	Total	6	100.0

The reasons which were given by the farmers who stopped intercropping include difficulty in crop management, problems with securing inputs and low rainfall. Farmers in Ward 15 stopped because of poor germination while the farmers in Ward 25 stopped because intercropping had difficulty in use agro-chemicals and harvesting of the crops since the main crops and the intercrop matured at different times. Other challenges which were faced include problems in securing seeds due to the low yield obtained year after year leading to low income generated after selling their produce.

3.5.6 Statistical analysis

Chi-squared test showed that gender, marital status, ward, village and farm area did not significantly influence whether the farmer was intercropping or not. However, there was a relationship between household size and whether the farmer was practising intercropping or not. There is a positive correlation (r = 0.692) between household size and intercropping practice. As the household size increased, the adoption rate of intercropping was also increasing probably to increase the food security situation for the family members through increased production (Figure 3.2).

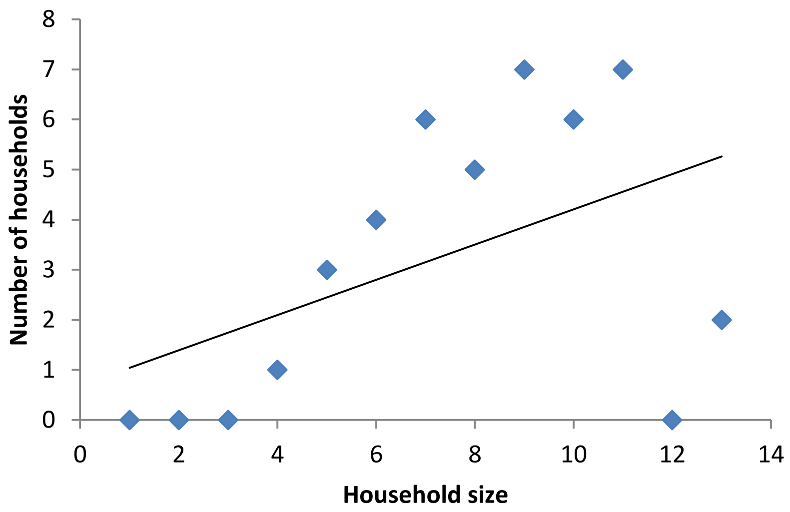


Figure 3.2: Relationship between intercropping and size of household

3.6 Conclusions and Recommendations

The adoption of intercropping by the farmers was low in both wards (60% in Ward 15 and 46.7% in Ward 25). Those who practised intercropping were using the old paradigms such as cereal-cereal intercropping and mixed cropping without following any planting pattern. They also use low or high plant populations which generally results in soil resource exploitation thereby making sustainable land use impossible socially, ecologically and economically. Adoption of intercropping by the smallholder farmers is restricted by financial constraints, lack of knowledge as well as lack of participatory approaches under farm conditions in the research process. Thus, increased adoption rates of intercropping in the agricultural sector can be achieved through better understanding of intercropping systems which can be achieved through on-farm research aimed at equipping the farmers, extension services and other stakeholders' capacity building among the farmers. Farmers should be motivated to use these environmental friendly technologies in sustainable development. Furthermore, scientists need to be aware of their clients; that is the farmer and the practices and constrains faced by the farmers for their research efforts to be most effective.

Some researches on cereal-legume intercropping systems have shown improvement in weed control and crop yield particularly for cereal crop which is the staple crop for smallholder farmers. Furthermore, these researches also focused on intercrop population neglecting row orientation resulting in farmers practising intercropping using variable row orientations. There is also need for proper handling of the issues of accessibility and affordability of improved seeds and appropriate fertilisers to improve the adoption of intercropping systems by smallholder farmers.

CHAPTER FOUR

4.0 EFFECT OF POPULATION DENSITY AND ROW ORIENTATION ON WEED DENSITY AND CROP YIELD UNDER SORGHUM-COWPEA INTERCROPPING SYSTEMS

4.1 Introduction

The production of the main staple foods in Zimbabwe has been declining since the early 1990s which has greatly compromised household food security (Jayde *et al*., 2006). FAO/WFP (2008) reported this food insecurity situation to be due to drastic reduction in food and agricultural production following erratic rainfall and the gross lack of key farming inputs. This is further worsened by poor farming practices and low plant population of the main staple crops. In the case of non-tillering sorghum the recommended plant population in arid and semi-arid areas such as those found in natural region IV in Zimbabwe is 75 000 plants/ha (Food and Agricultural Organisation (FAO), 2006). These low plant densities result in a substantial amount of land being left bare which can be countered by intercropping. It is also believed that intercropping might positively impact on the future food problems for smallholder farmers in the semi-arid regions of developing countries through efficient utilization of solar energy, nutrients, water and other resources (Egbe, 2005).

Intercropping refers to the mixing of crops of different species to ensure maximum exploration of the different layers of the soil profile at different times which may result in less competition between the component crops and attainment of better yields (Lima-Fihlo, 2000). Crop productivity and yield is increased through intercropping in dry areas due to increased plant densities resulting in optimization of land resource use.

In any community, stability of species should be reached to avoid extinction of resources. Ouma and Jethro (2005) reported that stability by a community can be attained when it has reached a high level of diversity. Diverse communities have fewer fluctuations in numbers of a given species making the community more stable as compared to communities which have limited species diversity. Intercropping as well as practices such as enterprise diversification, use of wind breaks, crop rotation and provision of more habitats for microorganisms and integration of crop farming with livestock production promote diversity and stability on the farm (Reddy *et al*., 1992; Reddy and Willey, 1981). Under intercropping the component crops should be adequately spaced to maximize cooperation and reduce competition between them which can be accomplished by factors such as plant density, spatial arrangement, plant architecture and maturity dates of the crops grown (Banik *et al*., 2006) including the appropriate row orientation which increases the interception of solar radiation

Smallholder farmers in semi-arid areas currently face food insecurity and deficit as a result of climate variations which is further worsened by poor knowledge and access of suitable dry land farming technologies such as intercropping. The survey indicated that farmers grow crops like maize, sorghum, beans and cowpea as either sole crop or intercropped at sub or supra optimal plant populations with variable row orientation resulting in low yields. Therefore, this chapter is aimed at determining the effect of cowpea population density and row orientation on weed density and yield of sorghum cowpea intercropping.

4.2 Objectives

i. To determine the effect cowpea population density and row orientation on weed density in sorghum-cowpea intercropping systems.

ii. To determine the effect of cowpea population density and row orientation on sorghum yield (biomass and grain) in sorghum-cowpea intercropping systems.

iii. To determine the effect of cowpea population density and row orientation on yield (biomass and grain) and yield components (number of pods per plant and number of grains per pod) of cowpea in sorghum-cowpea intercropping systems.

iv. To compare the productivity of sorghum-cowpea intercropping with that of sole crops using the Land Equivalent Ratio (LER).

4.3 Hypotheses

i. Cowpea population density and row orientation have an effect on weed density in sorghum-cowpea intercropping systems.

ii. Cowpea population density and row orientation have an effect on sorghum yield (biomass and grain) in sorghum-cowpea intercropping systems.

iii. Cowpea population density and row orientation have an effect cowpea yield (biomass and grain) and yield components (number of pods per plant and number of grains per pod) in sorghum-cowpea intercropping systems.

iv. Intercropping has a yield advantage over sole cropping.

4.4. Materials and Methods

4.4.1 Site Description

The field experiment was conducted at Matopo Research Station during the 2014/15 cropping season. The station is located on latitude $17^{o}42^{1}01\ 64^{11}$ S and longitude $30^{o}56^{1}33\ 24^{11}$ E and an altitude of 1 353 m. The site is in Natural Region IV which receives annual rainfall of 400 - 650 mm. Average annual minimum and maximum temperature of 15 ^{o}C and 27 ^{o}C are experienced, respectively. Average summer temperatures range from 24 ^{o}C to 26 ^{o}C. The site has red Fersiallitic loamy clay soils.

4.4.2 Experimental Design and Treatments

The experiment was laid out in a 2 x 7 factorial arrangement of a Randomised Completely Block Design (RCBD) with three replications. The experiment consisted of 14 treatments (Table 4.1) namely four sole crops, sorghum (S) spaced at 90 x 20 cm (55 556 plants per hectare) and sole cowpea spaced at 45 x 20 cm (C1), 30 x 20 cm (C2) and 22.5 x 20 cm (C3) and three intercrop treatments of sorghum at 55 556 plants per hectare intercropped with cowpea at 111 111 (SC1), 166 667 (SC2) and 222 222 cowpea plants per hectare (SC3) in two row orientations; East-West (E-W) and North-South (N-S).

Table 4.1: Treatment Table

Row orientation	**Intercrop population**						
	S	**C1**	**C2**	**C3**	**SC1**	**SC2**	**SC3**
N-S	T1	T2	T3	T4	T5	T6	T7
E-W	T8	T9	T10	T11	T12	T13	T14

Gross plot dimensions were 71 m by 16 m (1 136 m^2) including 1 m boarders at all the edges of the plot and net plot was measuring 4 m x 4 m (16 m^2). At the edges of each plot, 2 boarder rows of sorghum were planted to avoid boarder effects. Also 1 m field boarders were cleared and kept weed free to avoid the effect of the external environment.

4.4.3 Crop management

The timing of crop management practices was influenced by the start and distribution of rainfall within the season (Appendix 7). The rainfall received during 2014/2015 rainfall season was relatively low though it was well distributed resulting in poor crop. The rainfall recorded from the 4th of October 2014 to 19th of April 2015 was 469.0 mm. The month of December received most of the rainfall, which was 27.0 % of the whole season, and the first three months received 26.1 % of the seasonal rainfall. In October, only 1.5 mm of rain (0.3 % of total seasonal rainfall) was received on the 4th of October 2014 followed by a dry spell until the 3rd of November 2014.

4.4.3.1 Land preparation

The land was deep ploughed to a depth of about 25cm and disced to produce a fine tilth for good seed germination and emergence. Field borders were cleared and kept weed free to counter the effects of weeds, pests and diseases from the external environment.

4.4.3.2 Planting

Planting was done on the 10th of December 2014. The crops were sown simultaneously in the same season according to the treatment for each plot. Five cowpea seeds were planted per planting station and stations were spaced 0.15 m apart. The cowpea seedlings were thinned to one seedling per planting station at 4 weeks after planting (WAP) in all the treatments. Sorghum seeds were broadcasted and thinned at 4 WAP to the required spacing of 90 x 20 cm to achieve a plant population of 55 556 plants per hectare.

4.4.3.3 Fertilizer application

Compound D (8% N:14% P:7% K) was broadcasted during land preparation and incorporated into the soil and nitrogen fertiliser also applied as Ammonium Nitrate (34.5 % N) based on the sorghum recommendation from soil analysis. This was done in all treatments at the same time to reduce variations.

4.4.3.4 Weed control

Weeding was done using hoes once at 3 weeks after crop emergence (WACE) in all the treatments.

4.4.3.5 Pest and disease control

Scouting for insect pests and diseases was done regularly throughout the growing season and remedial action was taken when necessary. Aphids (*Aphis craccivora*) were observed 3WACE of the cowpea plants and they were controlled using Thiodan 35EC (80 ml in 20 l water). Spraying was done after every 2 weeks from 3 WACE to pod formation.

4.4.3.6 Crop harvesting

Crop harvesting was done manually from each plot at physiological maturity (110 days after planting for cowpeas and 150 days after planting for sorghum). Cowpea plants were uprooted and sorghum stalks were cut at the base using a machete from a net plot area of 2 m^2 in the middle of each treatment plot. Cowpea plants were dried and the grains separated from the haulms and sorghum heads were removed from the stalk. The grains were separated from the heads and the grain yield for each plot was measured. The cowpea haulm and sorghum stalks from each plot were oven-dried at 110°C to a constant weight and weighed to obtain the biomass.

4.5 Data collection

4.5.1 Weed density

Quantitative survey of each plot was conducted to determine the weed density and the relative density of each weed species using a quadrat measuring 1m x 1m. Five quadrats were thrown randomly in all the plots. The weed density was determined for each plot. The relative weed density of each weed species was calculated by the following formulae according to Kazi, *et al*. (2007).

$$Relative\ Density\ (\%) = \frac{Mean\ No.of\ individual\ weed\ species\ in\ quadrats}{Mean\ Total\ No.of\ all\ weed\ species\ in\ quadrats}\ x\ 100$$

4.5.2 Cowpea yield and yield components

Number of pods per plant for five plants from each plot and number of grains per pod for five pods from each plot were determined at harvesting. Biomass and grain yield of cowpea were determined and recorded separately for each plot using an electronic scale.

4.5.3 Sorghum yield

Biomass and grain yield of sorghum were measured separately for each plot using an electronic scale.

4.5.4 Land Equivalent Ratio (LER)

The LER was calculated to determine the intercrop advantage. LER is the sum of fractions of intercrop yields divided by the sole crop yield and can be used as an agronomical index for assessing yield advantages derived from intercropping. The index is calculated as follows;

$$\mathrm{LER} = \frac{\mathrm{I_A}}{\mathrm{S_A}} + \frac{\mathrm{I}_B}{\mathrm{S_B}}$$

Where I_A = intercrop yield of crop A

I_B = intercrop yield of crop B

S_A = sole crop A yield

S_B = sole crop B yield

A LER greater than 1.0 shows that intercropping is more efficient than sole cropping and a LER less than 1.0 shows that intercropping is disadvantageous. Willey (1985) indicated that a LER of 1.25 can be interpreted as 25% greater yield for intercropping or as 25% greater area requirement for the monocrop system.

4.6 Data analysis

Analysis of variance ANOVA was done using Genstat version 14th Edition (2013). It was used to test for significant effects of intercrop population and row orientation on weed density, yield components and yield (grain and biomass) for both cowpea and sorghum. Duncan Multiple Range Test was used to analyse the data and where there was significant difference (p-value < 0.05), separation of mean at $\alpha = 5\%$ was done using the Least Significant Difference (LSD). The Land Equivalent Ratio (LER) was used to determine the intercrop advantage.

4.7 Results

4.7.2 Effect of cowpea population density and row orientation on weed density

4.7.2.1. Weed Density

The results revealed that at 3 weeks after crop emergency (3WACE) and prior to first weeding, the interaction of population density and row orientation did not significantly affect the weed density or number of weeds per m^2 (Table 4.2). Effects of individual factors were not significant in determining weed density at 3WACE. The weed species which were more prevalent were *Tagetis minuta, Schkuria pinnata, Cyperus tridens* and *Cyperus rotundus*.

However weed density was significantly affected by the interaction of cowpea population density and row orientation at 6 weeks after crop emergency (6WACE). The weed density was higher in the treatments with combination of sole crops at lower population density and EW row orientation compared to the treatment combination which had intercropped crops at higher population density and NS row orientation (Table 4.2). Mean comparisons showed that the lowest weed density was 10.0 and was obtained by a combination of the highest cowpea intercrop population of 222 222 plants per hectare and NS row orientation (NS-SC3) which produced the best results in supressing weeds. The highest weed density of 48.0 was obtained in the treatment with sole sorghum and EW row orientation (EW-S).

Table 4.2: Weed density m^{-2} at 3 and 6 weeks after crop emergence

Treatment	Weed density	
	3 WACE	6 WACE
NS-SC3	84.0a	10.0a
EW-SC3	92.7a	13.0ab
EW-C3	85.0a	15.0bc
NS-C3	82.0a	15.0bc
NS-SC2	63.0a	17.0cd
NS-C1	79.7a	19.0de
EW-C1	77.0a	20.7de
EW-SC2	74.7a	22.7e
EW-C2	77.7a	29.3fg
NS-C2	59.3a	29.3f
NS-S	98.3a	33.0fh
EW-SC1	71.7a	34.0hi
NS-SC1	89.0a	37.3i
EW-S	86.0a	48.0j
p-value	p=0.810	P<0.001
LSD	37.83	3.65
cv%	28.3	8.9

4.7.2.2 Relative weed density

There was no interaction between cowpea population density and row orientation in determining density of *C. rotundus*. Effects of individual factors were not significant in determining the density of *C. rotundus* and other weeds. The interaction of cowpea population density and row orientation significantly (P<0.05) influenced density of *S. pinnata* and *T .minuta* and *C. tridens* (Figure 4.1). As the cowpea population density increases, the relative density of *S. pinnata* and *T .minuta* and *C. tridens* decreases. The treatment which had sorghum intercropped with cowpea at 222 222 plants/ha showing greatest effect in suppressing these weeds.

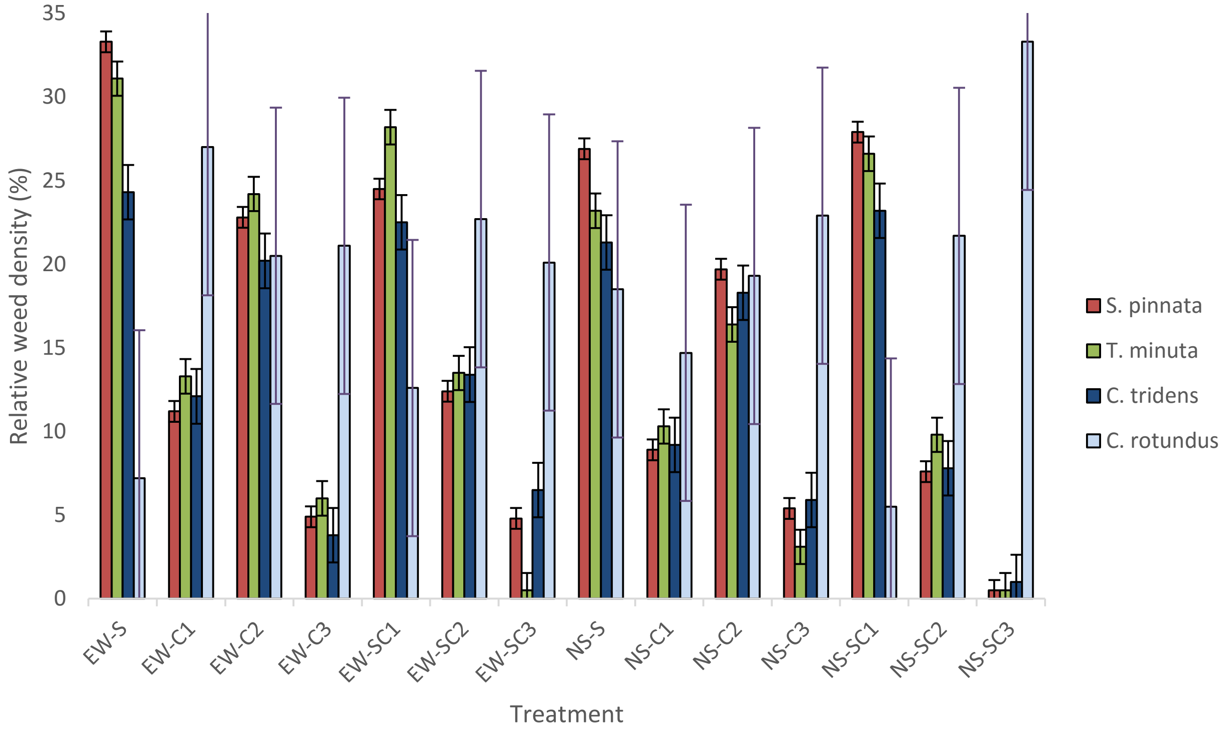


Figure 4.1: Effect of cowpea population density and row orientation on relative weed density in sorghum-cowpea intercropping systems during 2014/2015 growing season at Matopo Research Station

4.7.3 Effect of cowpea population density and row orientation on cowpea yield and yield attributes

4.7.3.1 Effect of cowpea population density and row orientation on cowpea pods per plant

Interaction effects of cowpea population density and row orientation significantly ($P<0.001$) influenced the number of pods per plant. The number of pods per plant ranged from 2.6 (NS-SC3) to 12.6 (EW-C1) with the EW row orientation producing the highest number of pods per plant, ranging from 3.0 to 12.6 as compared to the NS row orientation which produced 2.6 to 5.7 pods per plant (Figure 4.2). Increasing the cowpea population density from 111 111 to 166 667 plants/ha resulted in 7.7 % and 25.0 % increase in the number of pods per plant for EW and NS row orientation, respectively. Further increase of the population of cowpea from 166 667 to 222 222 plants/ha in both sole and intercropped treatments in NS and EW row orientation, reduced the number of pods/plant. In intercropped treatments, the number of pods per plant was reduced by 35.0% and 28.6% in EW and NS row orientation respectively compared to sole cropping; the number of pods per plant were reduced by 68.9% and 21.1% in EW and NS row orientation respectively.

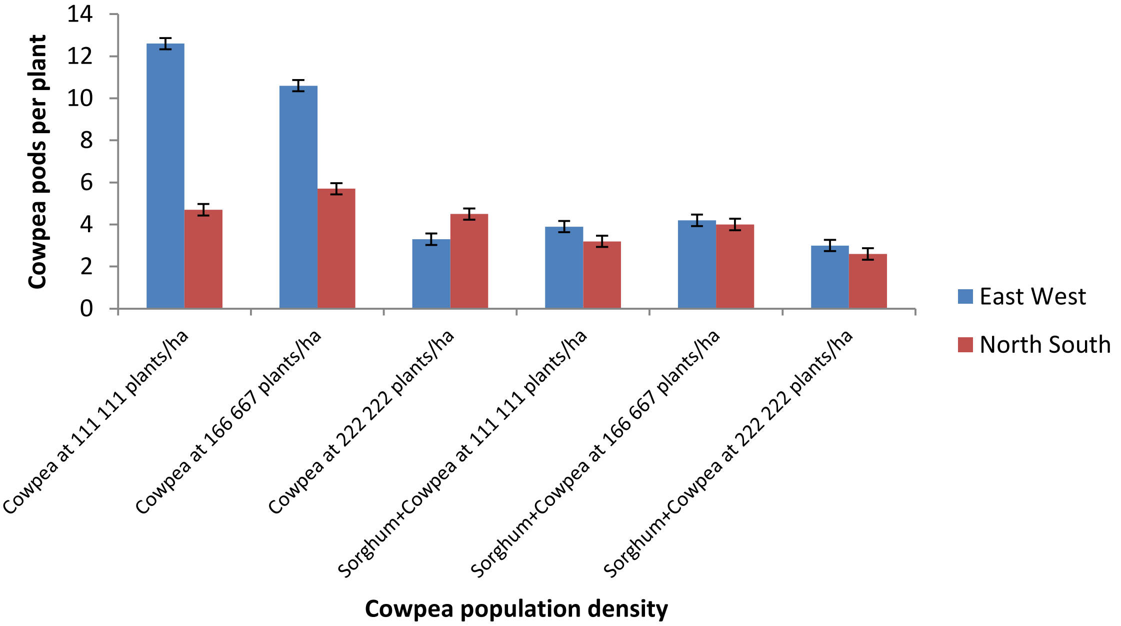


Figure 4.2: Effect of cowpea population density and row orientation on cowpea pods per plant in sorghum-cowpea intercropping systems during 2014/2015 growing season at Matopo Research Station

4.7.3.2 Effect of intercrop population and row orientation on cowpea grains per pod

Interactive effects of cowpea population density and row orientation significantly (P<0.001) influenced cowpea grains per pod (Figure 4.3). The treatment with sorghum intercropped with cowpea at 111 111 plants/ha and EW row orientation (EW-SC1), sole cowpea at 166 667 plants/ha and EW row orientation (EW-C2), sole cowpea at 111 111 plants/ha and NS row orientation (NS-C1) and sole cowpea at 166 667 and NS row orientation (NS-C2) produced the highest number of grains per pod ranging from 13.3 to 13.6 which were not significantly different from each other. The lowest cowpea grain per pod of 6.1 was produced in treatment with the highest cowpea population density and NS row orientation (NS-SC3). The results also show that intercropping gave lower number of grains than sole cropping, with the NS row orientation giving lower yields than EW.

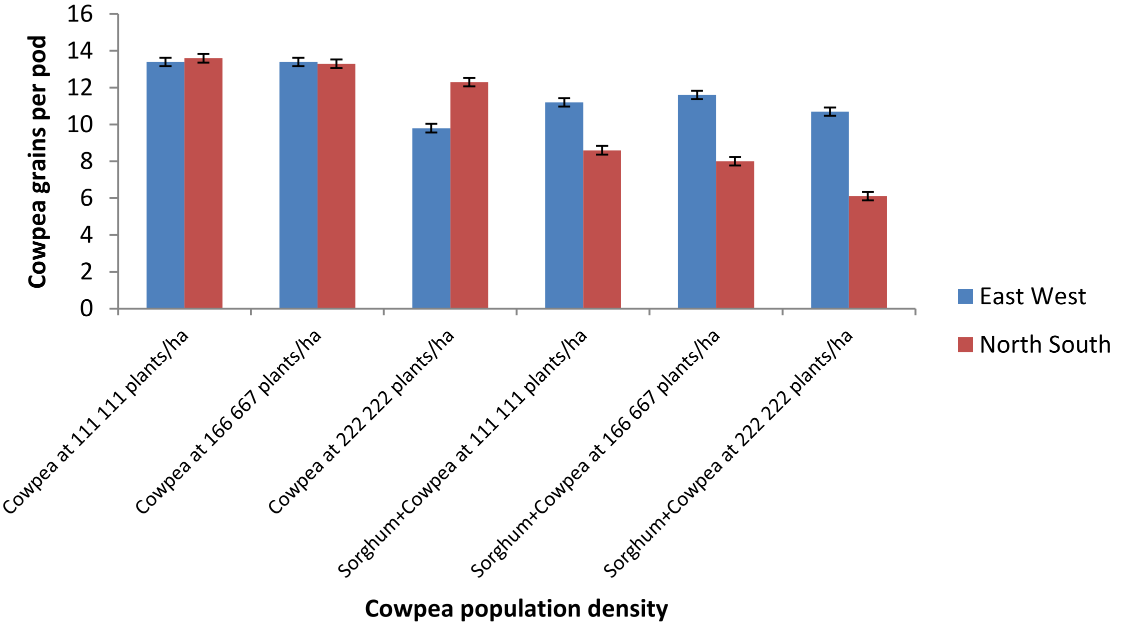


Figure 4.3: Effect of cowpea population density and row orientation on cowpea grains per pod in sorghum-cowpea intercropping systems in 2014/2015 growing season at Matopo Research Station

4.7.3.3 Effect of cowpea population density and row orientation on cowpea biomass

Cowpea biomass yield was significantly ($P<0.001$) influenced by the interaction effects of cowpea population density and row orientation (Figure 4.4). The biomass was generally higher, ranging from 368.5 to 578.5 kg/ha, under sole cowpea cropping in EW row orientation than under intercropping in both EW and NS row orientation which recorded low cowpea biomass ranging from 303.3 to 398.4 kg/ha.

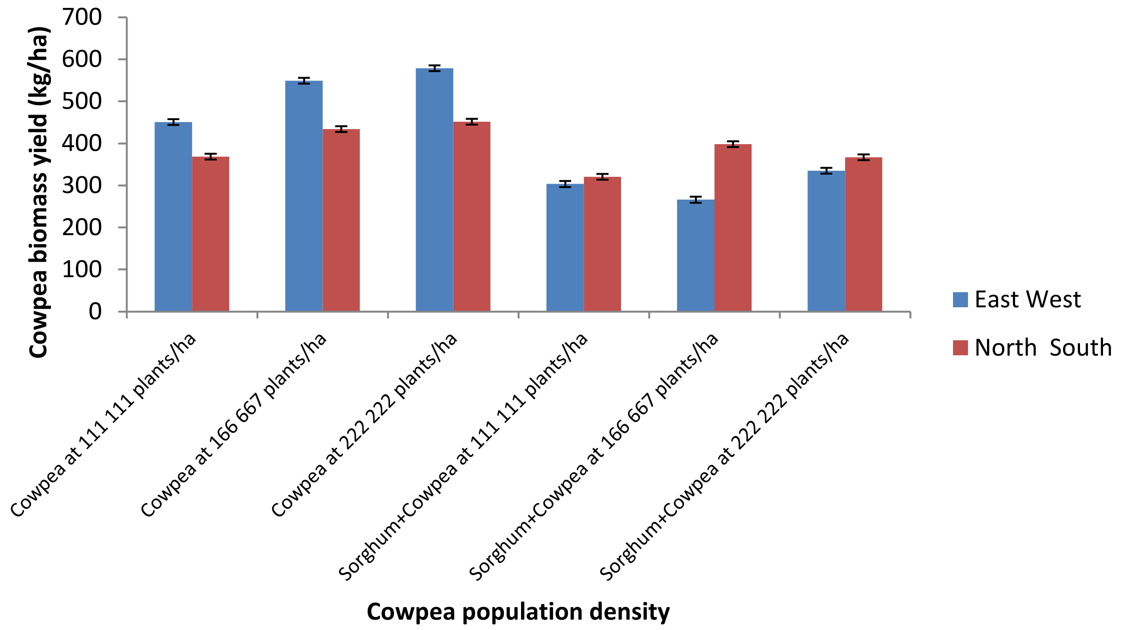


Figure 4.4: Effect of cowpea population density and row orientation on cowpea biomass yield in sorghum-cowpea intercropping systems in 2014/2015 growing season at Matopo Research Station

4.7.3.4. Effect of cowpea population density and row orientation on cowpea grain yield

The grain yield of cowpea was significantly ($P<0.001$) influenced by the interaction of cowpea population density and row orientation (Figure 4.5). The cowpea grain yield was higher in the treatments with sole cowpea in the EW row orientation ranging from 405.0 to 637.2 kg/ha and was lower in the treatments with intercropped cowpea in NS row orientation ranging from 92.4 to 206.3 kg/ha. The least grain yield of 92.4 kg/ha was produced in the treatment with highest cowpea population density in the NS row orientation (NS-SC3) and the highest cowpea grain yield of 637.2 kg/ha was produced in the treatment with sole cowpea in EW row orientation. The lowest cowpea grain yield was 88.5 % lower than the highest cowpea grain yield. The results also indicated that cowpea intercropping with highest population density produced significantly lower grain yield which was 70.9 % and 81.5 % in EW and NS row orientation respectively compared to their corresponding sole crops.

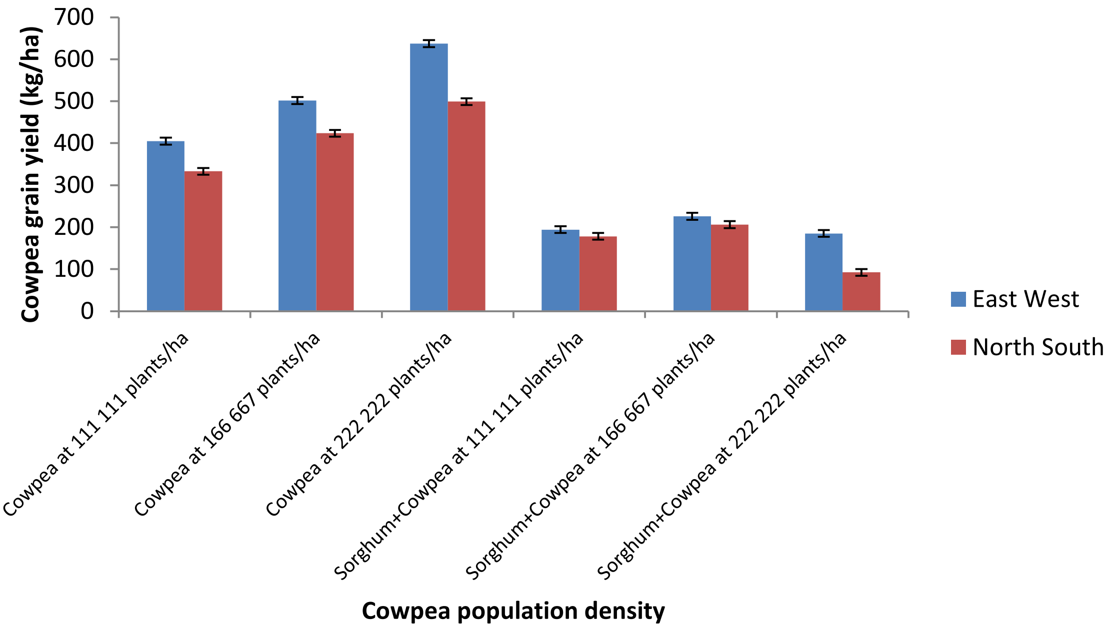


Figure 4.5: Effect of cowpea population density and row orientation on cowpea grain yield in sorghum-cowpea intercropping systems during 2014/2015 growing season at Matopo Research Station.

4.7.4 Effect of cowpea population density and row orientation on sorghum yield

4.7.4.1 Sorghum biomass

Sorghum biomass was significantly influenced by the interaction of row orientation and cowpea population density (Figure 4.6). Sole sorghum in both NS and EW row orientation (NS-S and EW-S) produced biomass which was significantly higher than that under intercropping, with sole sorghum in NS orientation producing significantly higher biomass than EW orientation. The lowest sorghum biomass of 1366.4 kg/ha was produced in the treatment with cowpea intercrop at 111 111 plants/ha planted in EW row orientation, but was not significantly different from all the intercropped treatments. The highest sorghum biomass yield of 2487.4 kg/ha was produced in treatment with sole sorghum in NS row orientation.

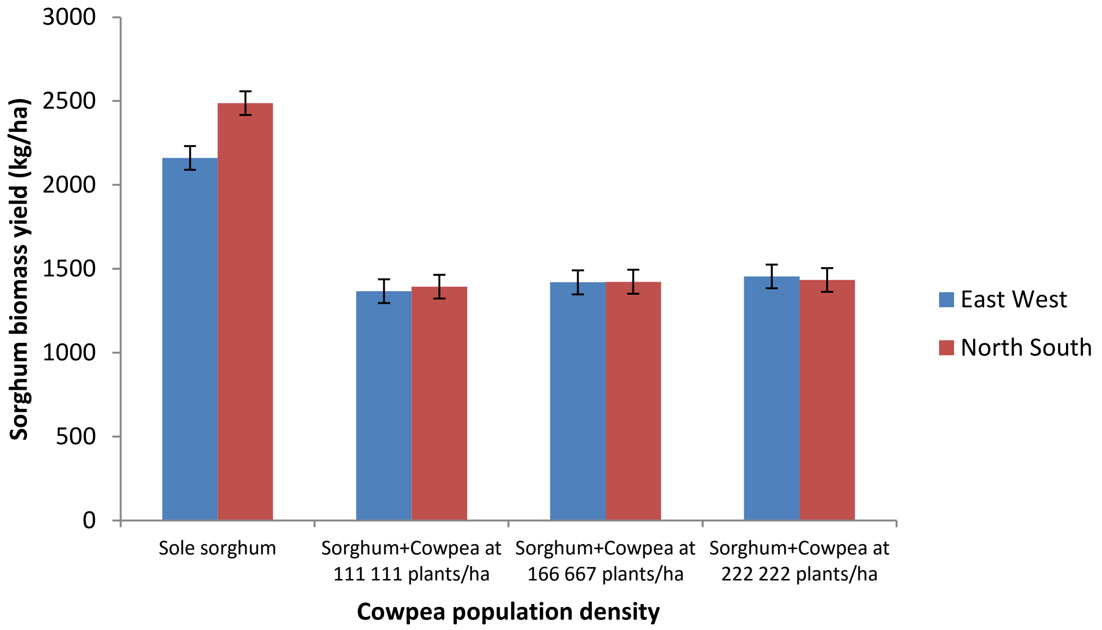


Figure 4.6: Effect of cowpea population density and row orientation on sorghum biomass in sorghum-cowpea intercropping systems in 2014/2015 growing season at Matopo Research Station

4.7.4.2 Sorghum grain yield

Interaction of cowpea population density and row orientation significantly ($P<0.001$) influenced sorghum grain yield (Figure 4.7). Increasing the cowpea population density from 111 111 to 166 667 plants/ha produced significantly higher grain yields which were ranging from 906.4 to 988.5 kg/ha in NS row orientation compared to 491.9 to 831.9 in EW row orientation. The highest grain yield of 1 296 kg/ha was produced in sole sorghum planted in NS row orientation and the lowest sorghum grain yield of 491.9 kg/ha was produced in sorghum intercropped with cowpea at 222 222 plants/ha (highest cowpea population density) and planted in EW orientation. There was higher sorghum yield in sole sorghum in both row orientation which decreased by 29.2% and 30.1% with the introduction of the lowest cowpea population density of 111 111 plants/ha (SC1). As the cowpea population density was increased from 111 111 to 166 667 plants/ha, sorghum yield increased by 21.7% and 9.9% in EW and NS row orientation respectively. Sorghum yield decreased significantly by 40.9%

and 5.6% in EW and NS row orientation respectively when cowpea population density was increased beyond critical of 166 667 (SC2) plants/ha (SC2).

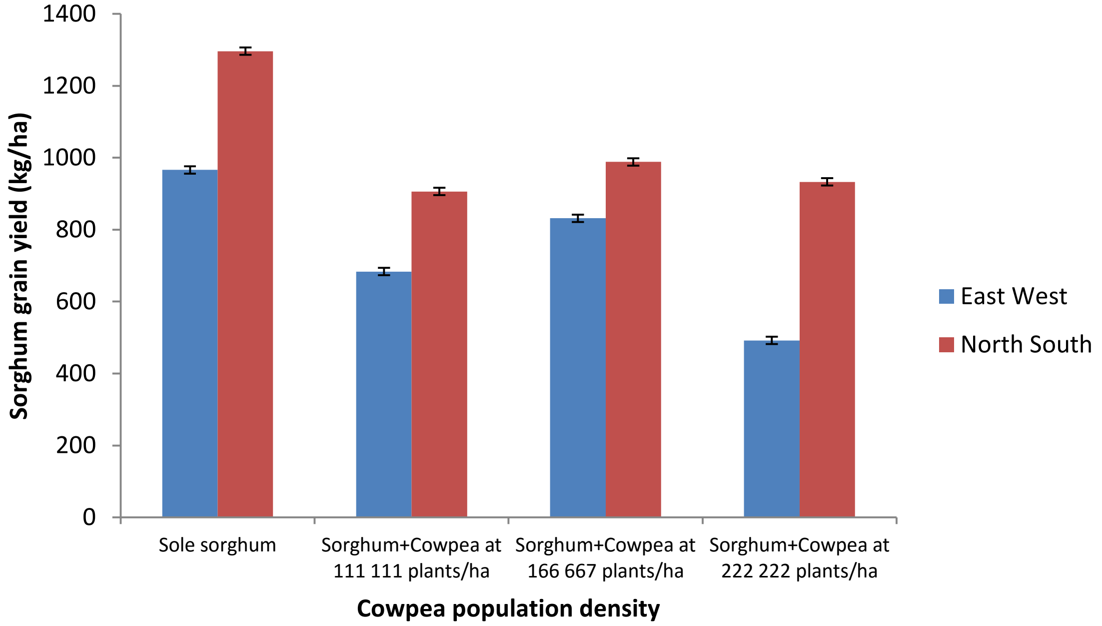


Figure 4.7: Effect of cowpea population density and row orientation on sorghum grain yield in sorghum-cowpea intercropping systems in 2014/2015 growing season at Matopo Research Station

4.7.5 Comparison of the productivity of sorghum-cowpea intercropping with that of sole crops using the Land Equivalent Ratio (LER)

The intercrop performance relative to the sole crop for the 2014/15 season showed that sorghum-cowpea intercropping system performed better than sole crop except for those with highest cowpea population density planted in either EW or NS row orientation which had LERs of 0.800 and 0.905 respectively (Table 4.2). The intercrop system with the highest LER was the one with 166 667 cowpea plants/ha in EW row orientation. Sorghum with cowpea population density of 222 222 plants/ha in EW row orientation had the lowest LER. This indicates that the performance of the intercrop was affected by competition from the cowpea component. When the cowpea population density was increased from 111 111 to 166 667 cowpea plants/ha, the LER increased by 10.4% from 1.188 to 1.312 in EW row orientation and by 1.2% from 1.233 to 1.248 in NS row orientation. The results also indicate that further increase in the cowpea population density from 166 667 to 222 222 plants/ha, reduced the LER by 31.4 and 27.6% in EW and NS row orientation respectively resulting in LERs which are less than a unit.

Table 4.2: LERs for sorghum intercropped with varying population density of cowpea during the 2014/15 cropping season at Matopo Research Station

Treatment	Partial LER		LER
	Sorghum	Cowpea	
EW-Sorghum + cowpea at 111 111 plants/ha	0.480	0.708	1.187
EW- Sorghum + cowpea at 166 667 plants/ha	0.451	0.861	1.312
EW- Sorghum + cowpea at 222 222 plants/ha	0.291	0.509	0.800
NS- Sorghum + cowpea at 111 111 plants/ha	0.536	0.699	1.235
NS- Sorghum + cowpea at 166 667 plants/ha	0.487	0.762	1.249
NS- Sorghum + cowpea at 222 222 plants/ha	0.185	0.720	0.905

4.8 Discussion

4.8.1 Effect of intercrop population density and row orientation on weed density and relative densities of weeds

There was no significant difference in weed density at 3WACE most probably due to the canopy which was not yet fully developed to close the ground and prevent weed germination and growth. The decrease in weed density at 6WACE in the treatment which had high cowpea population density in NS row orientation could be attributed to the ability of the canopy to reduce PAR transmittance to the weeds under the crop canopy (Teasdale, 1995; Tollenaar *et al*., 1994; Begna *et al*., 2001; Tharp and Kells, 2001).

Borger, Hashem and Patham (2010) showed that reducing the crop row spacing or adopting crop row orientation at a near right angle to the sunlight direction (NS row orientation) increases the shading of weeds between the rows. Angiras and Sharma (1996); Sharma and Angiras 1996a,b and Shrestha and Fidelibus (2005) independently reported that the growth of little seed canary grass (*Phalaris minor* Retz.), common vetch (*Vicia sativa* L.), wild oat (*Avena fatua*) and poison rye grass (*Lolium temulentum* L.) in wheat crops and black nightshade (*Solanum nigrum* L.) in vineyards (*Vitis vinifera* L.) were significantly influenced by crop row spacing and orientation. According to Holt (1995) manipulation of crop row spacing and row orientation is one possible way to increase light interception by the crop canopy and to reduce light interception by the weeds.

Furthermore, row orientation affected crop yield or soil moisture relations in apple (*Malus domestica* Borkh) orchards, olive (*Olea Europa* L.) and oats (*Avena sativum* L.) crops (Mohler, 2001; Cannor *et al*., 2009). Increase in the cowpea population density provided more shading leading to smothering of the weeds. This can be attributed to the soil cover of cowpea that created unfavourable conditions for weed germination, growth and development. The canopy cover of the intercrops was also able to reduce the amount of light being intercepted by the weeds resulting in reduced rate of photosynthesis and partitioning of assimilates for the growth and development of the weeds.

However, the interaction between cowpea population density and row orientation in sorghum-cowpea intercropping system was not able to significantly reduce the density of *C. rotundus*. This can be attributed to the fact that growth and development of weeds basically depends on the competitive abilities of the component crops and their respective plant populations (Willey *et al*., 1983). Such differences in the response of different weed species could also be attributed to the inherent genotype capabilities of these weed species and differences in their biology and morphology. *C. rotundus* provides formidable competition for resources with much larger crop plants and ornamentals despite it being relatively small in stature (USDA-NRSS, 2006).

4.8.3 Effect of cowpea population density and row orientation on cowpea yield and yield attributes

The number of pods per plant was higher in the sole cowpea as compared to the intercropped cowpea. This can be attributed to the absence or reduced interspecific competition which led to the production of more branches and probably taller plants with more pod/plant and higher number of grains/pod as compared to the intercropped plants. The reduction in number of pods per plant in intercropped cowpea plants could also, presumably, be attributed to better growth of the more aggressive sorghum plants during the dry spells within the 2014/15 growing season, which might have out-competed the cowpea plants for radiation. More and well-distributed rainfall could have produced taller cowpea plants which would access more solar radiation allowing the crops to produce more pods per plant, number of grains per pod and yield more biomass and grain yield.

Cowpea biomass and grain yield reduction in intercropping might be due to the aggressive effects of sorghum plant on cowpea, similar to the case of reduced number of pods per plant under intercropping. Sorghum which is a C_4 plant probably had the ability to out compete cowpea which is a C_3 plant for resources during the long dry spell experienced during the growing season resulting in lower biomass and grain yield for the cowpea crop. Crops with C_4 photosynthetic pathways have been known to be dominant when intercropped with C_3 crop species like cowpea (Hiebsch *et al*., 1995).

Sorghum possess some drought tolerance mechanisms which allow the plant to maintain metabolic activity during drought and under conditions of reduced plant water potential by osmotic adjustment and antioxidant capacity. In response to water deficit, sorghum plant is known to accumulate glycine, betaine and proline (Buchanan *et al*., 2005). The plant also escapes drought by osmotic adjustments which refers to the lowering of the osmotic potential of the cells by accumulating solutes (Morgan, 1984). Osmotic adjustments enables water uptake to continue under increasing soil water tension in many species and in some cases is associated with maintenance of growth and stable yield under drought (Morgan, 1984). Drought tolerance of many C_4 plants in arid environments is achieved through osmotic adjustment and may enable sorghum to grow when leaf water potential is low.

The yield reduction of intercropped cowpea can also be attributed to the shading of taller sorghum plants as reported by Egbe (2010) who alluded that the photosynthetic rate of the lower growing plants can be reduced by the shading of the taller growing plants in a mixture thereby reducing the final grain yield. Interaction between plant population and row orientation influences solar radiation interception by the plant canopy and soil moisture and nutrient uptake by the crops (Tsubo and Walker, 2003).

This reduction in biomass and grain yield as the cowpea intercrop population is increased can be attributed to severe intra-specific and interspecific competition for growth resources such as soil moisture, solar radiation, nutrients and air between the intercrop components. In addition to these factors, depressive effects like shading of sorghum have also contributed to the decrease in the cowpea grain yield as reported by Egbe (2010). Pal *et al*. (1992) and Muoneke *et al*. (2007) reported similar yield reductions in Benue State, Nigeria in soybeans intercropped with maize and sorghum and associated the yield depression to interspecific competition and the depressive effect of cereals. These results were further explained by Ghosh (2004) in a report where the differences in yield were reported to be due to the differences in canopy height of soyabean and sorghum and added that the two species did not only compete for nutrient and water but also for sunlight.

Row orientation also influences the interception of solar radiation by the plant canopy. Borger, Hashem and Pathan, (2010) found that light influences flowering and fruit set thereby significantly determining number of pods per plant, number of grains per plant and crop productivity. This implies that light is a determinant of both biomass and grain yield. Reducing the crop row spacing or changing the crop row orientation at near right angle to the sunlight direction (NS) increases shading of the intercrop (cowpea) by the main crop (sorghum).

Cowpea yields achieved in this research were far much less than the varietal yield potential of 4 000 kg/ha reported by the Department of Research and Specialist Services (DR and SS) (2015). The differences in yield can be due to differences in soil fertility, the poor rainfall season and possibly management.

4.8.4 Effect of cowpea population density and row orientation on sorghum yield

There was higher biomass and grain yield in sole sorghum than in sorghum-cowpea intercrops probably due to absence of or reduced competition under the former system. Competition for resources such as nutrients, soil moisture, air, solar radiation and space is reduced under sole cropping than under intercropping if same plant population for the main crop is maintained. When cowpea intercrop population was increased from 166 667 to 222 222 plants/ha there was a reduction in both biomass and grain yield and this could be due to the plant density of cowpea which had exceeded the optimum for intercropping. In intercropping, the plant density should be optimised to reduce competition from overcrowding by adjusting the seeding rate of each crop on the mixture below the full rate to allow the crops to yield well in the mixture as reported by Hiesbick, (1980) and Prabhakar, *et al*. (1983). These results are similar to those produced by Kanjara *et al.* (2014). The results are also similar to those produced by Tsubo *et al.* (2003) who reported that maize crops oriented in NS row orientation intercepted more Photosynthetically Active Radiation (PAR), increasing the rate of photosynthesis and thereby increasing the ear length, ear weight and grain yield in maize-beans intercrop experiments in semi-arid conditions of South Africa.

Generally, row orientation produced contrasting results for sorghum and cowpea biomass and grain yields. NS oriented crops produced significantly higher sorghum biomass and grain yield than the EW oriented intercrop crops. On the contrary, EW row oriented crops produced higher cowpea biomass and grain yield than NS oriented crops. This can be attributed to more solar radiation interception by the taller sorghum plants resulting in increased photosynthesis and consequently more dry matter and grain yields production. Cowpea plants in NS row orientation received less solar radiation.

4.8.5 Comparison of the productivity of sorghum-cowpea intercropping with that of sole crops using the Land Equivalent Ratio (LER)

Land Equivalent Ratio (LER) was used to determine yield advantage of intercropping. The results indicated that intercropping had advantages up to a certain cowpea population density as indicated by the LERs which are greater than 1. The LERs which are less than a unity in the treatments with higher cowpea population mean that there was more competitive interference than complementary facilitation. The treatments which resulted in a LER above 1 had yield advantage as compared to sole cropping and the results could stem from low interspecific competition or strong facilitation (Kipkemoi *et al*., 1997)

According to Van der Meer (1989), it is possible to obtain the net result of Land Equivalent Ratio (LER) where the complimentary facilitation is contributing more to the interaction of the crop species intercropped than the competitive interaction since both competition and facilitation take place in many intercropping systems. Thus, a LER < 1 could result from high interspecific competition or weak to no facilitation while a LER > 1 could result from low interspecific competition and strong facilitation among the intercropped crop species.

4.9 Conclusion and Recommendations

4.9.1 Conclusion

Interactive effects of cowpea population density and row orientation did not significantly influence the weed density at 3WACE. The interaction effects of cowpea population density and row orientation were significant at 6WACE when the intercrop canopy had fully covered the ground. The relative densities of *C. tridens*, *S. pinnata* and *T. minuta* were significantly influenced by the interaction of cowpea population density and row orientation. It can be concluded that the highest cowpea population density of 222 222 plants/ha in NS row orientation (SC3-NS) produced the best results in suppressing weeds while the treatment with sole sorghum in EW row orientation (S-EW) was the least effective in suppressing weeds.

The results also revealed that the yield and yield attributes of both the main crop (sorghum) and the intercrop (cowpea) were significantly influenced by the interaction of cowpea population density and row orientation. The treatment which had sole cowpea at 166 667 plants/ha in EW row orientation produced the highest number of pods per plant and the treatment which had sorghum intercropped with cowpea at 222 222 plants/ha in NS row orientation produced the least number of pods per plant. The least cowpea biomass and grain yields were produced in the treatment which had sorghum intercropped with cowpea at 166 667 plants /ha while sole cowpea at 222 222 plants / ha produced the highest cowpea biomass. The highest sorghum biomass and grain yield was produced in the treatment which had sole sorghum in NS row orientation (S-NS) and the least sorghum biomass and grain yield was produced in the treatment which had sorghum with cowpea at 222 222 plants/ha in EW and NS row orientation respectively.

The LER results indicated that sorghum-cowpea intercrop systems performed better than their corresponding sole crops except for the treatments which had the highest cowpea population density of 222 222 plants/ha in both EW and NS row orientation which had LERs of 0.800 and 0.905 respectively.

4.9.2 Recommendations

The results show that high cowpea population density and NS row orientation could be useful cultural weed control measure to restrict the size and activity of the weed seed bank. This is achieved as the canopy formed prevents the germination of weed seeds and addition of more seeds to the seed bank thereby reducing the weeding burden of smallholder farmers in the long term.

Based on the results from this study, farmers in Matobo district should plant cowpea intercrops in sorghum under the ES row orientation at populations of 166 667 plants/ha to produce relatively high yields from cowpea plants as it allows more light penetration and interception by the cowpea canopy and reduces the weed density. This is further supported by an LER which is above unit for the same treatment combinations. This would enhance higher light interception hence higher photosynthesis by cowpea plants and ultimately produce better yields that would vary depending on amount of incident rainfall.

To enhance the yield for sorghum, farmers in Matobo district should plant sorghum-cowpea intercrops in EW row orientation for increased cowpea grain yield but NS row orientation for sole sorghum.

However, to increase validity of the results, there is need to repeat the experiment for at another season.

CHAPTER 5

5.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

The adoption of intercropping by the farmers was low in both wards (60% in Ward 15 and 46.7% in Ward 25). Those who practised intercropping were using the old paradigms such as cereal-cereal intercropping and mixed cropping. Furthermore, the farmers were not following any planting pattern and plant populations which generally results in soil resource exploitation thereby making sustainable land use impossible socially, ecologically and economically. Easy adoption of intercropping by the smallholder farmers is restricted due to lack of participatory approaches under farm conditions.

Thus, increased adoption rates of intercropping in the agricultural sector can be achieved through better understanding of intercropping systems which can be achieved through on-farm research aimed at equipping the farmers, extension services and other stakeholders' capacity building among the farmers. Farmers should be motivated to use these environmental friendly technologies in sustainable development. Furthermore, scientists need to be aware of their clients; that is the farmer and the practices and constrains faced by the farmers for their research efforts to be most effective.

Some studies on cereal-legume intercropping systems have shown improvement in weed control and crop yield particularly for cereal crops which are the staple crops for smallholder farmers. Furthermore, these studies focused on intercrop population neglecting row orientation, hence farmers practise intercropping using variable row orientations. There is also need for proper handling of the issues of accessibility and affordability of improved seeds to improve the adoption of intercropping systems by smallholder farmers.

Results of the field experiment show that at 3WACE, the canopy of the crops was not fully developed to close the ground and suppress the weeds. This is because suppression of weeds in intercropping generally depends on the ability of the canopy to shade the weeds. The treatment which had sorghum intercropped with the highest cowpea population density of 222 222 plants/ha and in NS row orientation showed best results in the suppression of weeds at 6WACE. This could be attributed to ability of the canopy to reduce PAR transmittance to the weeds under the canopy (Teasdale, 1995; Tollenaar *et al*., 1994; Begna *et al*., 2001; Tharp and Kells, 2001).

Borger, Hashem and Patham (2010) showed that crop row orientation at a near right angle to the sunlight direction (NS row orientation) and reducing the crop row spacing increases the shading of weeds between the rows. Manipulation of crop row spacing and row orientation is one possible way to increase light interception by the crop canopy and to reduce light interception by the weeds (Holt, 1995).

The interaction between cowpea population density and row orientation in sorghum-cowpea intercropping system was not able to significantly reduce the density of *C. rotundus*. This can be attributed to the fact that growth and development of weeds basically depends on the competitive abilities of the component crops and their respective plant populations (Willey *et al*., 1983). Such differences in the response of different weed species could also be attributed to the inherent genotype capabilities of these weed species and differences in their biology and morphology. *C. rotundus* provides formidable competition for resources with much larger crop plants and ornamentals despite it being relatively small in stature (USDA-NRSS, 2006).

The number of pods per plant and cowpea yield (biomass and grain) was higher in the sole cowpea as compared to the intercropped cowpea. This can be attributed to the aggressive of sorghum plants on cowpea in the intercropping system and the absence or reduced competition in sole cowpea plants. This led to the production of more branches and probably taller plants with more pod per plant and higher number of grains per pod as compared to the intercropped plants thereby producing higher yields. Better growth of the more aggressive sorghum plants during the dry spells within the 2014/15 growing season, which might have out-competed the cowpea plants for radiation through shading.

Egbe (2010) reported that the photosynthetic rate of the lower growing plants can be reduced by the shading of the taller growing plants in a mixture thereby reducing the final grain yield. More and well-distributed rainfall could have produced taller cowpea plants which would access more solar radiation allowing the crops to produce more pods per plant, number of grains per pod and yield more biomass and grain yield.

The results also showed that row orientation influences the interception of solar radiation by the plant canopy thereby reducing the number of pods pre plant which then reduces yield of the intercrop (cowpea). The results concur with those obtained by Borger, Hashem and Pathan, (2010) who found that light influences flowering and fruit set thereby significantly determining number of pods per plant, number of grains per plant and crop productivity. This implies that light is a determinant of both biomass and grain yield. Reducing the crop row spacing or changing crop row orientation at near right angle to the sunlight direction (NS) increases shading of the intercrop (cowpea) by the main crop (sorghum).

Sorghum biomass and grain yield was higher in sole sorghum than in sorghum-cowpea intercrops due to absence of or reduced competition under the former system. This could be due to increased competition for resources such as nutrients, soil moisture, air, solar radiation and space intercropping than in sole cropping system when same plant population for the main crop is maintained. The plant density should be optimised to reduce competition from overcrowding by adjusting the seeding rate of each crop on the mixture below the full rate to allow the crops to yield well in the mixture as reported by Hiesbick, (1980) and Prabhakar, Shulka and Srinwa, (1983).

Generally, row orientation produced contrasting results for sorghum and cowpea biomass and grain yields. NS oriented crops produced significantly higher sorghum biomass and grain yield than the EW oriented intercrop crops. Contrary, EW row oriented crops produced higher cowpea biomass and grain yield than NS oriented crops. This can be attributed to more solar radiation interception by the taller sorghum plants resulting in increased photosynthesis and consequently more dry matter and grain yields production. Cowpea plants in NS row orientation received less solar radiation.

Land Equivalent Ratio (LER) was used to determine yield advantage of intercropping. The results indicated that intercropping had advantages to a certain cowpea population density as indicated by the LER which are greater than 1. The LER which are less than a unity in the treatments with higher cowpea population means that there was more competitive interference than complementary facilitation. The treatments which resulted in an LER above

1 had yield advantage as compared to sole cropping and the results could stem from low interspecific competition or strong facilitation (Kipkemoi, Wasike and Ooro, 1997).

5.2 General Conclusion and recommendations

The survey has established that the adoption rate of intercropping by the smallholder farmers in Matobo district was generally low with the farmers who were practising intercropping using the old paradigms such as cereal-cereal intercropping and mixed cropping without following any planting pattern and plant populations which generally results in soil resource exploitation thereby making sustainable land use impossible socially, ecologically and economically.

On the other hand, it can be concluded that the highest cowpea population density of 222 222 plants/ha in NS row orientation (SC3-NS) produced the best results in suppressing weed while the treatment with sole sorghum in EW row orientation (S-EW) was the least effective in suppressing weeds. The results show that high cowpea population density and NS row orientation could be useful cultural weed control measure to restrict the size and activity of the weed seed bank. This is achieved as the canopy formed prevents the germination of weed seeds and addition of more seeds to the seed bank thereby reducing the weeding burden of smallholder farmers in the long term.

Farmers in Matobo district should plant cowpea intercrops in sorghum under the ES row orientation at populations ranging of 166 667 plants/ha to produce relatively high yields from cowpea plants as it allows more light penetration and interception by the cowpea canopy and reduces the weed density. This is further supported by an LER which is above unit for the same treatment combinations. This would enhance higher light interception hence higher photosynthesis by cowpea plants and ultimately produce better yields that would vary depending on amount of incident rainfall.

To enhance the yield for sorghum, farmers in Matobo district should plant sorghum-cowpea intercrops in EW row orientation for increased cowpea grain yield but NS row orientation for sole sorghum.

However, to increase validity of the results, there is need to repeat the experiment for at another season.

REFERENCES

Addo-Quaye, A.A., Darkwa, A.A. and Ocloo, G.K., 2011. Yield and Productivity of Component Crops in a Maize-Soyabean Intercropping System as Affecting by Tiome of Planting and Spatial Arrangement. *J. Agric. Biol. Sci.*, pp.6(9): 50-57.

Adipala, E., Omongo, C.A. and Sabiti, A., 1999. Pests and diseases on cowpea in Uganda: Experiences from a dignostic survey. *African Crop Science Journal*, 7(4), pp.465-78.

Agr85, n.d. Agronomy Institute.

Akobundu, O., 1987. *Weed Science in the tropics: Principles and practices*. Chichester: John Willey and sons.

Aliyu, B.S. and Emechebe, A.M., 2003. Efects of intra and inter row mixing of sorghum with two varieties of cowpea on host crop yield. *Agricultural Journal*, pp. Res 1, 24-26.

Allen, J.R. and Obura, R.K., 1983. Yield of corn, cowpea and soyabean under different intercropping systems. *Agron. J.*, 75, pp.1005-09.

Altieri, M.A., Glaser, D.L. and Schmidt, L.L., 1990. *Diversification of agroecolosystems for insect pest regulation: experiments with collards. In:S.R. Gliesman (Editor), Agroecology: Researching the Ecological Basis for Sustainable Agriculture.* Springer-Verlag, New York pp70-82.

Altier, M.A. and Liebman, 1994. Insect,Weed and Plant Disease Management in multiple cropping systems increasing World Food Supplies pp. 171-200. In: R. I. Papendick, P. A. Sanchez and G. B. Tripletts (eds) Multiple Cropping Amer. Soc. Agron. Spec. Public 27.

Alumira, J. and Rusike, J., 2005. The green revolution in Zimbabwe. *Journal of Agricultural Development Economics*, 2(1), pp.50-66.

Andrew, D.J., 1972. Intercropping legumes with sorghum in Nigeria Experimantal Agriculture. pp.8: 139-150.

Andrew, D.J. and Kassam, A.H., 1976. The importance of multiple cropping in increasing world food supply. In: Papendick, R.I., P.A. Sanchez and G.B. Triplett (Eds.). *American Society of Agronomy Publication*, Number 27: 2-7.

Angiras, N. and Sharma, V., 1996. Influence of row orientation, row spacing and weed-control methods on physiological perfomance of irrigated wheat (*Triticum Aestivum*). *Indian J. Agron.*, pp.41: 41-47.

Asiwe, J.A., Belane, N. and Dekora, F.D., 2009. Evaluation of cowpea breeding lines for Nitrogen fixation at ARC Grain crops Potchestroom, South Africa. *16th International congress on biological nitrogen fixation. USA June 2009*.

Ayeni, A.O., Duke, W.B. and Akobundu, I.O., 1984. Weed interference in maize, cowpea and maize/cowpea intercrop in a sub-humid tropical environment. I. Influence of cropping season. *Weed Res.*, 24, pp.269-79.

Ayisi, K.K. and Mposi, M.S., 2001. Grain yield response and Chilo pertellus infestation in diverse sorghum-cowpea intercrop arrangements. *Southern Africa Journal Plant Soil,* 39(1), pp.39-42.

Ballare, C.L. and Casal, J.J., 2000. Light signals perceived by crop and weed plants. *Field Crop Research*, pp.67: 149-60.

Ballare, C.L., Scopel, C.L. and Sanchez, R.A., 1990. Far-red radiation reflected from adjacent leaves; an early signal of competition in plant canopies. *Science*, pp.247: 329-332.

Bamigboye, O.L., 2011. Effect of intercropping and plant population density of jute mallow (*Corchorus olitorius*) on the growth and yield of hot pepper (*Capsicum frutescens*). pp.1-49.

Banik, P., Midya, A., Sarkar, B.K. and Ghose, S.S., 2006. Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. *European J. Agronomy*, 25, pp.202-07.

Bank, T.W., 1989. The costs of soil erosion on Java: A natural resource accounting approach. Policy planning and research staff. *Environment Department Working Paper No. 18. William Magrath and Peter Arens. August 1989*, p.71.

Barbosa e Silva, P.I., Lima e Silva, P.S., de Oliveira, O.F. and de Sousa, R.P., 2008. Planting Times of Cowpea Intercropped with Corn in the Weed Control. *Revista Caatinga (Mossoro Brassil)*, pp.21(1): 113-119.

Barker, E.F.I., 1979. Mixed cropping in northern Nigeria. III. Mixture of cereals. *Expl. Agric.*, pp.15: 41-48.

Barker, E.F.I. and Yusuf, Y., 1976. Research with mixed crops at the Institute for Agricultural Research, Samaru, Nigeria. Samaru conference paper 10, Institute for Agricultural Research. Samaru, Ahmadu Bello University, Nigeria, 1976.

Bationo, A. Kimetu J and Vanlauwe B., 2011. Comparative Analysis of the Current and Potential Role of Legumes in Integrated Soil Fertility Management in West and Central Africa In: A. Bationo *et al*. (eds). In A. Bationo *et al Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management*. pp.978-94.

Baumann, D.T., 2001. Competitive supression of weeds in a leek-celery intercropping system. *PhD dissertation Wageningen University, Wageningen, The Netherlands*.

Baumann, D.T., Bastiaans, L. and Kropff, M., 2003. Intercropping System Optimisation for Yield, Quality and Weed Suppression Combining Mecanic and Sescriptive Model. *Agronomy Journal*, 94, pp.734-42.

Beets, W.C., 1982. Multiple cropping and tropical farming systems. p.156.

Begna, S.H., Hamilton, R.I., Dwyer, L.M., Stewart, D.W., Cloutier, D., Assemat, L., Foroutan-Pout, K. and Smith, D.L. 2001. Weed biomass production response to plant spacing and corn (*Zea mays*) hybrids differing in canopy architecture. *Weed Technol.*, pp.15: 647-653.

Bekunda, M., 1999. Farmers Responses to Soil Fertility Decliner in Banana-based cropping systems in Uganda. Managing Africa's Soil Science No. 4 Russel Publishers No Hingham pp 2.

Bekunda, M.A., Bationo, A. and Ssali, H., 1997. Soil fertility management in Africa: A review paper of selected research trials. 63-79. In: R.J. Buresh et al. (Eds.) Replenishing soil fertility in Africa. *SSSA Spec. Publ. 51.SSSA, Madison, WI.*

Bekunda, M. and Woomer, P.L., 1996. Organic Resources Management in Banana-based cropping systems of the Lake Victoria Basin, Uganda. *Agriculture, Ecosystem and Environment*, 59(3), pp.171-80.

Beltrao, N.E.M., da Nobrega, C.B., de Azevedo, D.M.P. and Vieira, 1984b. Comparacao entre indacadores agroeconomicos de avaliacao de agroecossistemas consorciados e solteiros envolvendo algodao upland e feijao caupi. *Empresa Brasileira de Pesquisa*.

Beltrao, N.E.M., Vieira, D.J., de Azevedo, D.M.P. and da Nobreda, C.B., 1986a. Importancia da configuracao de plantio e da cultivar de sorgo em consorcio com o algodoeira herbaceo. *Persqui. Agropecu. Btras.*, pp.21: 173-185.

Bezerra-Neto, F., Terres-Fihlo, J. and de Holanda J.S., 1991. Efeito do sistema de cultivo e arranjo aspacial no consorcio algodao herbaceo + caupi + sorgo. *Perqui. Agropecu. Bras.*, pp.26: 715-727.

Blawshaw, R.E., O'Donovan, J. and Harker, K., 2006. Reduced herbicide doses in field crops. *Weed Biology and Management*, pp.6: 10-17.

Blum, U., Shafer, R. and Lehmen, M.E., 1999. Evidence for inhibitory allelopathic interactions including phenolic acids in field soils: Concept vs an experiment model. *Crit. Rev. Plant Sci.*, 18, pp.673-93.

Borger, C.P.D., Hashem, A. and Pathan, S., 2010. Manupulating Crop Row Orientation to Suppress Weeds and Increase Crop Yield. *Weed Science Society of America*, pp.58: 174-178.

Buchanan, C., Lim, S. and Salzman R.A., 2005. Sorghum bicolor's transcriptome response to dehydration, high salinity. *Plant Mol. Biol.*, 58, pp.699-720.

Bulson, H.A.J., Snaydon, R.W. and Stopes, C.E., 1997. Effects of Plant Density on Intercropped Wheat and Field beans in an Organic Farming System. *Journal of Agricultural Science, Cambridge (1997)*, pp.128: 59-71.

Caldwell, M.M., 1987. Plant architecture and resource competition. *Ecological Studies*, 61, pp.164-79.

Cannor, D.J., Centeno, A. and Gomez-del-Campo, 2009. Yield determination in olive hedgerow orchards. II. Analysis of radiation and fruiting profiles. *Crop Pasture Sci.*, pp.60: 443-452.

Caporali, F., Campiglia, E., Paolini, R. and Mancinelli, R., 1998. The effect of crop species, nitrogen fertilisation and weeds on winter cereal/pea intercropping. *ITA J. Agronomy*, 2, pp.1-9.

Carter, M.R. and Ivany, J.A., 2006. Weed seed bank composition under long term tillage regimes on fine sand soils loam in Atlanta.

Chivinge, O.A., 1984. The role of herbicide technology on the small scale farm in Zimbabwe.

Chivinge, O.A., 1994. The role of herbicide technology on the small scale farms of Zimbabwe. *Zimbabwe Agricultural Journal*, pp.81: 97-102.

Chon, S.U., Choi, S.K. and Jung, S.A., 2002. Effects of alfalfa leaf extracts and phenolic allelochemicals on early seedling growth and root morphology of alfalfa and barnyard grass. *Crop Protection Journal*, 5, pp.1077-82.

Chung, M., Kim, K.H. and Ahm, S.B., 2003. Comparison of allelopathic potential of rice leaves, straw and hall extracts on barnyard grass. *Agric. Journal*, 95, pp.1063-70.

Clark, E. and Francis, C.A., 1985. Transgressive yielding bean; maize intercrops interference in time and space field crops Res. 11, pp.37-53.

Clawson, D.L., 1985. Harvest security and interspecific diversity in traditiional tropical agriculture. *Econ. Bot.*, pp.39: 56-67.

Crawley, M.L., 1989. Insect herbivores and plant population dynamics. *Ann. Rev. Entomol.*, 34, pp.531-64.

Creamer, N.G. and Bennet, M.A., 1997. Evaluation of cover crop mixtures for use in vegetable production systems. *Horticulture Science*, 32, pp.866-70.

Curse, R.M., Ghaffarzadeh, M. and Prechac, F.G., 1997. Tillage effect on soil water content and corn yield in strip intercropping system. *Agronomy Journal*, 89(6), pp.893-99.

Dahlmann, C. and Von Fragstein, N.P., 2006. Influence of different seed rates, sowing techniquea and N supply on grain yield and quality parameters in intercropping system. Available at http://orgprints.org/secure/00003164/01/Dahlmann Odense paper.doc.

Dalal, R.C., 1974. Effects of intercropping maize with pegeon peas on grain yield and nutrient upptake. *Exp. Agric.*, 10, pp.219-24.

Den Hollander, N.G., Bastiaans, L. and Kropff, N.J., 2007. Clover as a cover crop for weed supression in an intercropping design II. Competitive ability of several clover species. *Europ J. Agron.*, 26, pp.104-12.

Denevan, W.M., 1995. Prehistoric agricultural methods as model for sustainability. *Advanced Plant Pathology*, pp.11: 21-43.

Diallio, S., 2010. Effects of genotypes and nitrogen on grain quality of sorghum. MSc thesis. Department of Agronomy. College of Agriculture. B. S., I.P.R.,Katibougou, University of Mali 1998. pp.1-98.

Donald, C.M., 1963. Competition for light in crop and pasture plants. *Adv. Agron.*, pp.15: 1-118.

DR&SS, 2015. Department of Research and Specialist Services (DR&SS), Harare, Zimbabwe.Available at http://www.drss.gov.zw/index.php?option=com_content&view=article&id=111&Itemid=129.

Drinkwater, T.W., Bate, R., Du Toit, H.A. and Van Den Berg, J., 2002. A field guide for identification of maize pests in South Africa. Potchefstroom, 2002. Agricultural Research Council.

Edema, R., 1995. Investigations into factors affecting disease occurance and farmer control strategies on cowpea in Uganda. *MSc. Thesis, Makerere University, Kampala*, p.100.

Egbe, O.M., 2005. Evaluation of some agronomic potentials of pigeon pea genotypes for intercropping with maize and sorgum in Southern Guinea Savanna.. *PhD Thesis, University of Agriculture, Makurdi, Nigeria*.

Egbe, O.M., 2010. Effects of plant density of intercropped soybeans with tall sorghum on competitive ability of soybeans and economic yield at Otobi, Benue State, Nigeria. *Journal of Cereal and Oilseeds*, 1(1), pp.1-10.

Elemo, K.A., Kumar, V., Olukosi, J.O. and Ogungbile, A.O., 1990. Review of Research Work on Mixed Cropping in the Nigerian Savanna Samaru Miscellaneous Paper No. 127, Institute for Agricultural Research, Samaru, Zaria, Nigeria.

El-Khawas, S.A. and Shehata, M.A., 2005. The Allelopathic Potentials of *Acacia nilotica* and *Eucalyptus rostrata* on monocot (*Zea mays* L.) and dicot (*Phaseolus vulgaris*) Plants. *Biotechnology*, 4(1), pp.23-34.

Ellis-Jones, J., Twomlow, S., Willcocks, T., Riches, C., Dhliwayo, H. and Mudahara, M., 1993. Conservation tillage/weed control systems for communal farming areas in semi-arid Zimbabwe. In *Brighton Crop Protection Conference - Weed 3*.

Evans, L.T. and Wardlaw, I.F., 1976. Aspects of the comparative physiology of grain yield in cereals. *Adv. Agron.*, 28, pp.301-59.

Ezumah, H.C., Nguyen, K.Y.N. and Walker, P., 1987. Maiza-cowpea intercropping as affected by nitrogen fertilisation. *Agronomy Journal*, 79, pp.275-80.

Fanadzo, M., Chiduza, C. and Mnkeni, P.N.S., 2010. Effect of inter-row spacing and plant population on weed dynamics and maize (*Zea mays* L.) yiled at Zanyokwe irrigation scheme, East Cape, South Africa. *African Journal of Agricultural Research*, pp.5(7): 518-523.

FAO/WFP, 2008. Special Report: FAO/WFP Crop and Food Supply Assessment Mission to Bangladesh, 28 August 2008. Food and Agriculture Organisation of the United Nations and World Food Programme, Rome. Available at: ftp://ftp.fao.org/docrep/fao/011/ai472e/ai42e00.pdf. *(Accessed 24 June 2015).*

FAO, 2006. World Agriculture: Towards 2030/2050-Prospects for Food, Nutrition, Agriculture and Major Commodity Groups, Interim Reports. www.fao.org/fileadmin/user_upload/esag/does/Interim_report_AT2050web.pdf.

FAO, 2008. Emergency and Rehabilitation assistance: Consolidated appeals Zimbabwe.

Faria, A.E., Laca-Buendia, J.P.C. and Castrol, E.M., 1980. Consorcio de algadao herbaceo, milho e feijao vigna no norte de Minas. In: Reuniao Nacional de Algodao, I, Condrina P.R., Resumo dos Trabalhos. Londrina IAPAR, 1980. p.61.

Ferguson, J.J. and Rathinasabapathi, B., 2003. *Allelopathy: How plants suppress other plants. University of Florida IFSA Extension. HS944 http://edis.ifsa.ufl.edu. pp1-3.*

Filho, J.M.L., 2000. Physiological responses of maize and cowpea to intercropping. *Pesq. Brasilia*, 35(5), pp.915-21.

Flett, B.C., Bensch, M.L., Smit, E. and Fourie, H., 1996. A field guide for identification of maize diseases in South Africa. Potchefstroom, 1996. Agrivcultural Research Council.

Florentine, S.K. and Fox, J.E.D., 2003. Allelopathic effects of *Eucalyptus* species and grasses. *Allelopathy Journal*, 11, pp.77-78.

Food and Agricultural Organisation (FAO), 2006. *Zimbabwe's natural region and farming systems. FAO Corporate Document Repository*. [Online] Available at: http://www.fao.org/docrep/009/a0395e06.htm [Accessed 4 June 2015].

Fujita, K. and Ofosu-Budu, K.G., 1996. Significance of legumes in intercropping systems. In: Ito O., Katayana K., Johansen C., Kumar Rao J.V.D.K., Adu_Gyamfi J.J. (eds). Roots and nitrogen in cropping systemsof the semi-arid tropics. JIRCAS Int. Agric. Ser. No.3 Japan., pp.19-40.

Fujita, K., Ofosu-Budu, K.G. and Ogata, S., 1992. Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant and Soil*, 141, pp.155-76.

Garget, K.P., Sharma, A.K. and Thakur, B.S., 1970. Manuring cowpea. Studies of the effects of different rates of phosphorus and molybdenum on the growth rate and yield of cowpea fodder and residual effect on wheat. *Indian Journal of Agronomy*, 15, pp.112-17.

Ghaffarzadeh, M., 1999. Strip intercropping. *Agronomy Department, lowa State University, United States*.

Ghersa, C.M., Roush, M.L., Radosevich, S.R. and Cordray, S.M., 1994. Coevolution of agroecosystem and weed management. *Bio. Sci.*, pp.44: 85-94.

Ghosh, P.K., 2004. Growth, yield, competition and economics of groundnut/cereal fodder intercropping in the semi-arid tropics of India. *Field Crops Res.* , 88, pp.227-37.

Giller, K.E., 2001. *Nitrogen fixation in tropical cropping system*. 2nd ed. CABI, Wallingford. 423.

Gliessman, S.R., 1983. Allelopathic interactions in crop/weed mixtures; Applications for weed management. *J. Chem. Ecol.*, pp.9: 991-999.

Goudriaan, J., 1982. Potential production process. In: F. W. T. Penningde Vries and H. H. van Laar (Eds), Simulation of Plant Growth and Crop Production. *Pudoc, Wageningen*, pp.98-113.

Grossman, J. and Quales, W., 1993. Strip intercropping foir biological control. I P M Practitioner 1-11.

Gruhn, P., Goletti, F. and Yudelman, M., 2000. Integrated nutrient management, soil fertility and sustainable agriculture: Current issues and future challanges. *International Food Policy Research Institute, 2033 K Street. N.W. Washington, D.C. 20006 U. S. A. September, 2000*.

Harper, J.L., 1977. Population biology of plants.

Hauggaard-Nielsen, A., Andersen, M.K. and Jensen, E.S., 2006. Density and relative frequency effects on competitive interaction and resource use in pea barley intercrops. *Field crops Journal*, 95, pp.256-67.

Hegstad, J.M., Bollero, G. and Nickel, C.D., 1999. Potential of using plant row yield trials of predicting soyabean yield. *Crop Science*, 39, pp.1671-75.

Hiebsch, C., Tetio-kegho, F. and Chirembo, F.P., 1995. Plant density and soybean maturity in maize soybean intercrop. *Agronomy Journal*, 87, pp.965-70.

Hiesbick, C.K., 1980. Principles of intercropping: Effects of N. Fertilisation, Plant population and crop duration on equivalent ratios in intercrop versus Monoculture. *PhD dissert. North Carolina State University. Raleigh Abstr*, pp.413-4337.

Holt, J.S., 1995. Plant responses to light; a potential tool for weed management. *Weed Science*, pp.43: 474-482.

Hulugalle, N.R. and Lal, R., 1986. Soil water balance in intercropped maize and cowpea grown in a typical hydromophic soil in Western Nigeria. *Agronomy Journal*, 77, pp.86-90.

Hussaini, I.M., Baloch, S. and Sayal, O., 2001. A field study of Sorghum CV. G.263 grown alone or intercropped with cowpeas. *Journal of Agriculture*, pp.15-41, 317-328.

IPA, 1981. Empresa Pernambucana de Pesquisa Agropecuaria. Acao de pesquisa em associacao de culturas 1966-1981 Recife, PE. 292p.

Itulya, F.M. and Aguyoh, J.N., 1998. The effect of intercropping kale with beans on yield and suppression of redroot pigweed under high altitude conditions in Kenya. *Exp Agric.*, 34, pp.171-76.

Jama, B., Palm, C.A. and Buresh, R.J., 2000. Thithonia diversifolia as a green manure for soil fertility improvement in Western Kenya: A review. *Agrofor. syst.*, 49, pp.201-21.

Jarenyama, D.K., Bell, J.C. and Sale, P.W., 2001. Modification of within canopy microclimate in maize intercropping in tropics. *J. Agro Res Tropics*, 2, pp.1020-24.

Javad, H. and Mohsen, S., 2013. Effect of intercropped Barley and Weed Suppression in Chickpea-Barley Intercropping Systems. *International Journal of Agronomy and Plant Production*, 4(5), pp.844-891 VictorQuest Publications.

Jayde, T.S., Chisvo, M., Rukuni, M. and Masanganise, P., 2006. Zimbabwe's Food Security Paradox Hunger Amid Potential. In Rukuni, M. *et al*. *Zimbabwe's Agricultural Revolution Revisited, University of Zimbabwe Publication, Harare, Zimbabwe*.

Jodha, N.S., 1979. Intercropping in traditional farming systems. Proc. Intl. Workshop on intercropping 10-13 Jan 1979 Hyderabad, India pp 318-327.

Kanjara, S.M., Kibe, A.M., Karogo, P.N. and Mwangi, M., 2014. Effects of Intrercropping Population Density and Row Orientation on Growth and Yields of Sorghum-Cowpea Systems in Semi Arid Rongai, Kenya. *Journal of Agricultural Sciences*, 6(5), pp.34-43.

Kaseem, A., 1991. The effect of rates of Phosphorus and Nitrogen on the Growth, Nodulation and Yield of soyabeans. *MSc Thesis Department of Biological Sciences, ABU Zaria*, pp.10-40.

Kass, D.C., 1978. *Polyculture Cropping Systems: A review and Analysis*. Cornell University, Ithaca, NY: Cornell Int. Agric Bull. 32.

Katengeza, S., Kankwamba, H. and Mangisoni, J.H., 2015. Maize and legume technology adoption in Malawi: Gender, social network and SIMLESA effects. Adopting Pathways project discussion paper 7. February 2015.

Kazi, B.R., Buriro, A.H., Kubar, R.A. and Jagirani, A.W., 2007. Weed spectrum frequency and density in wheat (*Triticum aestivum*) under Tandojam conditions. *Pak J. Weed Sci. Res.*, 13(3-4), pp.241-246, 2007.

Keating, B.A. and Carberry, P.S., 1993. Resource capture and use in intercropping: solar radiation. *Field Crop Res.*, 34, pp.273-301.

Kipkemoi, P.L., Wasike, V.W. and Ooro, P.A., 1997. Effects of intercropping pattern on soyabean and maize yield in Central Rift Valley of Kenya.

Kondap, S.M., 1981. Effect of different cropping systems and weeding intervals on weed infestations and grain yield of sorghum. In *Presented at the Annual Conference of Indian Society of Weed Science, 1981. Department of Agronomy, A.P. Agricultural University, Hyderabad A.P., India*., 1981.

Kumar, V., Ogunlela, V.B. and Yadav, R.C., 1987. Productivity of maize and associated intercrops in relation to bed configuration and planting pattern. *Samaru J. Agric. Res.*, pp.51(1-2): 97-108.

Labrada, R., Caseley, J.C. and Parker, C., 1994. Weed management for developing countries. In: Eds R. Labdrada, J.C. Caseley and C. Parker. Rome: Fao.

Lakhani, D.A., 1976. A crop physiological study of mixtures of sunflower and fodder radish. PhD Thesis, Reading University, England (cited by Rao, MR and Willey, RW paper presented at the 2nd INPUTS review meeting at East-West Centre, Hawaii 8-17 May 1978).

Landers, J.N., 2007. Tropical crop-livestock systems in conservation agriculture: The Brazilian experience. *Integrated Crop Management*, 5-2007 FAO. Rome, Itally.

Letourneau, D.K., 1990. Two examples of natiral enermy augmentation: consequence of crop diversification. In: S.R. Gliessman (Editor), Agroecology: Researching the ecological Basis for sustainable Agriculture. Springer-Verlag, New York, pp11-29.

Liebman, M. and Davis, A.S., 2000. Integration of soil, crop and weed management in low-external-input farming systems. *Weed Res*, 40, pp.27-47.

Liebman, M. and Davis, A.S., 2001. Integration of soil, crop and weed management in low input farming systems. *Weed Res*, 40, pp.27-47.

Liebman, M. and Gallandt, E.R., 1997. Many little hammers; ecological management of crop-weed interactions. New York Academic doi:10.1016/B978-012378260-1/50010-5.

Lima-Fihlo, J., 2000. Physiological Response of Maize and Cowpea to intercropping. *Agropec. Brasillia*, pp.35: 915-921.

Lithourgidis, A.S., Dordas, C.A., Damalas, C.A. and Vlachostergios, D.N., 2011. Annual intercrops: an alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, 5(4), pp.396-410.

Mabasa, S. and Rambakudzidga, 1993. Periodicity of weed seedling emergence and the effect of weeding frequency on maize and sorghum.

Magaguda, G.T., Haque, I., Godfrey, W., Fenda, I. and Masina, G.T., 1979. Intercropping studies in Swaziland. Present status and future projections. Proc. Intl. Workshop on intercropping 10-30 Jan., 1979, Hyderabad, India pp. 98-104., 1979.

Makuvaro, V., 2014. Impact of climatic change on smallholder farming in Zimbabwe, using a modelling approach. In *A thesis submitted in fulfillment of a PhD degree in Agricultural Meteology, Department of Soil, Crop and Climatic Sciences. Faculty of Natural and Agricultural Sciences, University of the Free State. Bloemfontein. South Africa*., 2014.

Makuvaro, V., Walker, S., Munodawafa, A., Masere, T.P., Murerwi, C. and Chagonda, I., 2014. An overview of current agronomic practices of smallholder farmers in semi-arid Central and Western Zimbabwe. *African Journal of Agricultural*, 9(35), pp.2710-20.

Malezieux, E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine, H., Rapidel, B., de Tourdonnet, S. and Valantin-Morison, M., 2009. Mixing plant species in cropping systems: concepts, tools and models. A review. *Agron Sustain Dev*, pp.29: 43-62.

Malinovskil, B.N. and Shnurnikova, 1987. Increasing protein contents in fodder of mixed stands grain soyabean with grain legumes. *Doklady vesoyuznoi ordena Linina I ordena Trudovogo Krasnogce znameni Akademii Sel's Skokozyistvennkh Nauk imenl V.I. Lenina 8: 11-12 [Herbage Absts., 58: 747-1988]*.

Maluleke, M.H., Addo-Bediako, A. and Ayisi, K.K., 2005. Influence of Maize/Lablab Intercropping on Lepidopterous Stem Borer Infestation in Maize. *J. Econ. Entomol.*, 92(2), pp.384-88.

Mandal, B.K. and Roy, P.K., 1986. Yield of wheat, mustard and chick pea grown as sole and intercrop with four moisture regimes. *India J. Agron. Scie.*, 56, pp.577-83.

Mandumbu, R., 2008. Weed seedbank dynamics under different tillage practices and mulch retention levels in semi-arid South Western Zimbabwe. A thesis in partial fulfillment of the requirements of the degree of MSc Crop Protection. Crop Science Department, UZ.

Mandumbu, R., Jowah, P., Karavina, C. and Handisen, T., 2011. Integrated Weed Management in Zimbabwe's Smallholder Sector, Where Are We? : A Review. *Modern Applied Science*, 5(5), pp.111-17.

Mandumbu, R., Jowah, P., Karavina, C. and Tibugari, H., 2011. Intergrated Weed Management in Zimbabwe's Smallholder Sector. Where are we? A Review. *Mod. Appl. Sci.*, pp.5(5): 111-117.
Mapfumo, P., 2011. Comparative Analysis of the Current and Potential Role of Legumes in Integrated Soil Fertility Management in southern Africa. In (eds), A.B.e.a. *Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management*. pp.175-200.

Mariga, I.K., 1990. Effect of cowpea planting date and density on the perfomance of maize-cowpea intercrop. *Zimbabwe Journal of Agricultural Research*, pp.28: 125-132.

Mashingaidze, A.B. and Chivinge, O.A., 1995. Weed control using reduced herbicide dosages: A theoretical Framework. Transaction of Zimbabwe Scientific Association., 1995.

Mashingaidze, A.B. and Chivinge, O.A., 1998. Preventative and cultural control. In weed ecology and management. Nectar Natura module for MSc in sustainable Crop Protection pp 1-13.

Mashingaidze, N., Madakadze, C. and Twomlow, S., 2012. Crop yiled and weed growth under conservation agriculture in semi-arid Zimbabwe. *Soil Till. Res.*, pp.124: 102-110.

Mashingaidze, A.B., Nyakanda, C., Chivinge, O.A., Mwashaireni, A. and Dube, K.Y., 2000. Influence of live mulch on weed dynamics. *African Plant Protection Journal*, pp.6(1): 57-63.

Masson, S.C., Leihner, D.E. and Vorst, J.J., 1986. Cassava-cowpea and cassava-peanut intercropping. III. Nutrient concentration and removal. *Agronomy Guide AY-136. Purdue University Cooperative Extension service*.

Matusso, J.M.M., Mugwe, J.N. and Mucheru-Muna, M., 2014. Potential role of cereal-lugume intercropping systems in integrated soil fertility management in smallhollder farming systems of Sub-Saharan Africa. *Research Journal of Agriculture and Environmental Management*, pp.3(3) 162-174.

Mbanje, E., Twomlow, S.J. and O'Nell, D.H., 2001. Evaluation of animal weeders for smallholder maize production in Zimbabwe. In *Proceedings of the BCPC Conference, 12-15 November 2001*. Brighton, UK, 2001.

McCoy, S., Vyn, T. and Kline, A., 2001. Management considerations for relay intercropping: II. Soybean. *Agronomy Guide. AY-136. Purdue University Cooperation Extension service*.

Mead, R. and Willey, R.W., 1980. The concept of "Land Equivalent Ratio" and advantages in yields from intercropping. *Expl. Agric.*, 16, pp.217-28.

Mohler, C.L., 2001. Enhancing the competitive ability of crops pages 269-321 In M. Liebman, C. L. Mohler and C. P. Staver, eds Ecological Management of Agricultural Weeds. Cambridge, UK: Cambridge University Press.

Mohler, C.C., 2001. Enhancing the competitive ability of crops pgs 269-321. In M. Liebman, C.L. Mohler and C.P. Staver, eds Ecological management of weeds. Cambridge, UK: Cambridge University Press.

Mohta, N.K. and De, R., 1980. Intercropping maize and sorghum with soyabeans. *J. Agric. Sci.*, pp.117-22.

Mongi, H.O., Uriyo, A.P., Sudi, Y.A. and Singh, B.R., 1976. An appraisal of some intercropping methods in terms of yield, response to applied phosphorus and monetary returns from maize and cowpea. *East Africa Agriculture For. Journal*, pp.42: 66-70.

Moody, K. and Shetty, S.V.R., 1981. Weed management in intercropping system. In *in Proceedings of the International Workshop on Intercropping, 10-13 January 1979, International Crop Research Institute for the Semi-Arid Tropics*. Patancheru, A.P., India, 1981.

Morgado, L.B. and Rao, M.R., 1985. Consorciacao com a cultura do algodao no Nordeste do Brasil; resultados atuais e pespectivas parafuturas pesquisas. Petrolina, PE, EMBRABA-CPATSA (Documentos, 33).

Morgado, L.B. and Willey, R.W., 2003. Effect of plant population and nitrogen fertiliser on yield and efficiency of maize-bean intercropping. *Persquisa Agropecuaria Brasileiva*, pp.38: 1257-1264.

Morgan, J.M., 1984. Osmoregulation and drought stress in higher plants. *Annu. Rev. Plant Physiol.*, 35, pp.299-319.

Mpangane, P.N.Z., Ayisi, K.K., Mishiyi, M.G. and Whitebread, A., 2004. Grain yield of maize grown in sole and binary cultures with cowpea and lablab in the Limpopo Province of South Africa. Tropical legumes for sustainable farming systems in Southern Africa and Australia., 2004. Edited by Whitebread, A. M. and Pengelly, B. C. ACIAR Proceedings No.115.

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mungwe, J., Merckx, R. and Vanlauwe, B., 2010. Staggered maize-legume intercrop management robustly increases crop yield and economic returns in the highlands of Central Kenya. *Field Crop Research*, 115, pp.132-39.

Mugabe, F.T., Hachigonta, S., Sibanda, L.M. and Thomas, T.S., 2012. Southern African Agriculture and Climate Change: A COMPREHENSIVE ANALYSIS — ZIMBAMBWE. *Food, Agriculture and Natural Resources Policy Analysis Network*.

Mugabe, N.R., Singh, M.E. and Sibuga, K.P., 1982. A study of crop/weed competition in intercropping. in intercropping. In *Proc. of the second symposium on intercropping in semi-arid area, Morogoro, Tanzania, Ottawa, Canada, Intl. Dev. Research Centre (1982).*, 1982.

Mugendi, D.N., 1997. Tree biomass decomposition, nitrogen dynamics and maize growth under agroforestry conditions in the sub-humid highlands of Kenya. PhD Thesis, University of Florida, Grainesville, Florida, USA.

Mugendi, D.N., Waswa, B.S., Mucheru-Muna, M.W. and Kimetu, J.M., 2011. Strategies to Adapt, Disseminate and Scale Out Legume Based Technologues. In (eds)., A.B.e.a. *Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management*. pp.85-116.

Mullen, C., 1999. *Summer legume forage crops: cowpeas, lablab, soyabeans*. Second Edition ed. Agfact P4.2.16.

Munguri, W.M., Mariga, I.K. and Chivinge, O.A., 1995. Optimising cattle munure utilisation in Chinyika Resettlement Area, Zimbabwe. In *Proceedings of the International Crop Science Conference for East and Southern Africa. Blantyre, Malawi. 19-24 February 1995*., 1995.

Mungwe, J., Mugendi, D. and Mucheru-Muna, M., 2009. Determinants of the decision to adopt intergrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. *Expl Agric*, 45, pp.61-75.

Muoneke, C.O., Ogwuche, M.A.O. and Kalu, B.A., 2007. Effect of maize planting density on the perfomance of maize/soybean intercropping system in a Guinea savanna agroecosystem. *Afr. J. Agric. Res.*, 2, pp.667-77.

Mutsaers, H.J.W., 1978. Mixed cropping experiments with maize and groundnuts. *Neth. J. Agric Sci.*, pp.26: 3444-353.

Mutsaers, H.J.W., 1980. The effect of row orientation, date and latitude on light absoption by row crops. *Journal of Agricultural Sciences (Cambridge)*, pp.95: 381-6.

Ndiritu, S.W., Kassie, M. and Shiferaw, B., 2014. Are there systematic gender differences in adopting of sustainable agricultural intensification practices? Evidence from Kenya. Available at Science Direct. *Food Policy*, pp.49: 117-127.

Ndlovu, E., 2011. An investigation into the impact of prolonged food aid programme on vulnerable populations in Zimbabwe. A case study of food aid programming in wards 9 and 10 of Matobo district in South Western Zimbabwe. Masters thesis., 2011.

Nkongulo, K.K., 2003. Genetic characterisation of Malawi cowpea landraces, diversity and Gene flow among accessions. *Euphytica, 129(2)*, pp.219-28.

Nwanze, K.F. and Mueller, R.A.E., 1989. Management options for sorghum stem borer for farmers in the semi-arid tropics. In international workshop for sorghum stem borer, 17-20 November 1987. ICRISAT. Pacheru. India, pp105-113., 1989.

Nyamangara, J., Mashingaidze, N. and Masvaya, E.N., 2013. Weed growth and labour demand under hand-hoe based reduced tillage in smallholder farmers' fields in Zimbabwe. *Agriculture, Ecosystems and Environment*, pp.1-9.

Nyamudeza, P., 1998. Rainfed Cropping and Water Conservation on Vertisols in the South Eastern Lowveld of Zimbabwe. *Proceedings of a Workshop on Vertisols Management in Africa, Harare*.

Obilana, A.T., 2005. Economic Importance ofSorghum, Lagos State Polytechnic, Public Lecture Series. 2, pp.1-27.

Odendo, M., Bationo, A. and Kimani, S., 2011. Socio-Economic Contribution of Legumes to Livelihoods in Sub-Saharan Africa. In (eds), A.B.e.a. *Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management*. pp.1536-38.

Ofari, F. and Stern, W.R., 1987. Cereal-legume intercropping systems. *Adv.agron.*, 41, pp.41-90.

Ogenga-Latigo, M.W., Ampofo, J.K.O. and Baliddawa, C.W., 1992a. Influence of maize row spacing on infestation and damage of intercropped beans by the bean aphid (*Aphis fabae* Scop.). 1. Incidence of aphids. *Field crop Res.*, 30, pp.111-22.

Ogenga-Latigo, M.W., Ampofo, J.K.O. and Baliddawa, C.W., 1992b. Influence of maize row spacing on infestation and damage of intercropped beans by bean aphid (*Aphis fabae* Scop.). II. Reduction in bean yields. *Field Crop Res.*, 30, pp.123-30.

Oladeji, S.A., 2014. Economic analysis of sorghum-based cropping systems in Garko local government area of Kano State of Nigeria. Msc thesis, Facult of Asgriculture, Ahmadu Bello University, Zaria, Nigeria.

Olasantan, F.O.E., Lucas, E.O. and Ezumah, H.C., 1994. Effects of intercropping and fertiliser application on weed control and perfomence of cassava and maize. *Field Crop Res*, 39, pp.63-69.

Onwueme, I.C. and Sinha, T.D., 1991. Field Crop Production in Tropical Africa: Principles and Practice Technical, Centre for Agricultural and Rural Cooperation.

Oseni, T.O., 2010. Evaluation of sorghum-cowpea intercrop productivity in savanna agro-acology using competition indices. *Journal of Agricultural Science*, pp.2(3): 229-233. www.ccsenet.org/jas.

Osman, A.N., Raebild, A., Christiansen, J.L. and Bayala, J., 2011. Performance of cowpea (*Vigna unguiculata*) and Pearl Millet (*Pennisetum glaucum*) Intercropped under Parkia biglobosa in an Agroforestry System in Burkina Faso. *African Journal of Agricultural Research*, 6(4), pp.882-91.

Ouma, G. and Jeurto, P., 2010. Sustainable horticultural crop production through intercropping: The case of fruits and vegetable crops: A review. *Agriculture and Biology Journal of North America*, pp.1098-105.

Owuor, C., Tenywa, J.S., Muwanga, S., Woomer, P.L. and Esele, P., 2002. Perfomance of a sorghum-legume intercrops in response to row level on nitrogen. Program and extended abstracts. FORUM Working Document. No. 5. The Forum on Agriculture Resource Husbandry, Nairobi, pp. 542-544.

Pal, U.R., Oseni, T.O. and Norman, J.C., 1992. Effect of component densities on productivityof soybean/maize soybean/sorghum intercrop. *J. Agronomy Crop Sci.*, 170, pp.66-70.

Parliament of Zimbabwe Research Department, 2011. Matobo North Constituency Profile., 2011.

Patil, R.H., Hunshal, C.S. and Itnal, C.S., 2002. Influence of Bund Planted *Eucolyptus* Trees Row on Winter Wheat. *Allelopathy Journal*, 10, pp.21-28.

Patterson, D.T., 1982. Shading responses of purple yellow nutsedges (*Cyperus rotundus* and *C. esculentus*). *Weed Science*, pp.30: 25-29.

Plucknett, D.L., Evenson, J.P. and Sanford, W.G., 1970. Ratoon Cropping. *Adv. Agron.*, pp.22: 285-330.

Power, A.G., 1990. Leafhopper response to genetically diverse maize stands. *Entomol. Exp. Appl.*, 49, pp.213-19.

Prabhakar, B.S., Shulka, V. and Srinwa, K., 1983. Nutritional potential of vegetable intercropping system. *Indian J. Hort. Vol. 2 No. 3*, pp.258-68.

Prasad, R.B. and Brook, R.M., 2005. Effect of Varying Maize Densities on Intercropped Maize and Soyabeans in Nepal. *Exp. Agric.*, pp.41: 365-382.

Prochaska, S.C., 2001. *Evaluation of USDA soybean innoculate in a modified relay intercropping system*. Rzewnicki, P. (Ed.) Agonomic Crops Teams On-Farm Research Projects, 2000. Special Circular 179. Wooster: Ohio Agricultural Research and Development Centre. The Ohio State University.

Putman, A.R., 1988. Allelochemicals from plants as herbicides. *Weed Technology*, 2, pp.510-18.

Rachie, K.O., 1985. Introduction in Cowpea Research Production and Utilisation. Edited by S.R. Singh and K.O. Rachie IITA, Ibadan Nigeria. *John Willey Sons Ltd*, pp.xxi-xxvi.

Rana, K.S. and Pal, M., 1999. Effect of intercropping systems and weed control on crpo-weed competition and grain yield of pegionpea. *Crop Res*, 17, pp.179-82.

Rao, M.R. and Shetty, S.V.R., 1976. Some biological aspects of intercropping systems on crop-weed balance. *Indian J. Weed Sci.*, pp.8(1): 32-43.

Reddy, K.C., Vissel, P. and Buckner, 1992. Pearl/millet and cowpea yields in sole and intercrop systems and their after effects on soil and crop productivity. *Field Crop Res.*, pp.4: 13-124.

Reddy, M.S. and Willey, R.W., 1981. Growth and resource use studies in an intercrop of pearl millet/groundnut. *Field Crop Res.*, 4, pp.13-24.

Rees, D.J., 1986a. Crop growth, development and yield in semi-arid conditions in Botswana.II. The effects of intercropping *Sorghum bicolor* with *Vigna unguiculata*. *Experimental Agriculture*, 22, pp.169-77.

Rees, D.J., 1986b. The effects of population density and intercropping with cowpea on the water use and growth of sorghum in semi-arid conditions in Botswana. *Agriculture and Forest Meteorology,* 37, pp.293-308.

Reigosa, M.A., Gonzalezy, L., Souto, X.C. and Pastoriza, J.E., 2000. Alleloparthy in forest ecosystem. Alleloparthy in ecological agriculture and forestry. Proceeding III. Dwawad, India. 18-21 August, 1998, 2000, 183-193, 2000. Cong. Allel. Eco. Agr. Forestry.

Rice, E.L., 1974. *Allelopathy*. New York. NY: Academic.

Rohrbach, D., 1991. The impact of new sorghum and millet technologies in the evolving grain market of Southern Africa, pages 51-60. Proceedings of the international Sorghum and Millet Conference, 8-12 July 1991. Corpus Christi, Texas, USA, 1991.

Root, R.B., 1973. Organisation of plant-anthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). *Ecol. Monogr.*, 43, pp.94-125.

Rousseaux, M.C., Hall, A.J. and Sanchez, R.A., 1996. Far-red enrichment and photosynthetically active radiation level influence leaf senescence in field-grown sunflower. *Physiol. Plant.*, pp.96: 217-224.

Rupende, E., Chivinge, O.A. and Mariga, I.K., 1995. The effect of curing cattle manure on survival of weed seeds and nutrient release. In *Proceedings of the biennial weed science conference of East Africa*. Morogoro, Tanzania. 18-22 September 1995, 1995.

Saidi, M., Ngouajio, M. and Ituya, F.M., 2007. Leaf harvesting initiation time and frequency effect biomass partitioning and yield of cowpea. *Crop Science 47*, pp.1159-66.

Salasya, B., Obendo, M. and Ondeya, J., 1996. Adoption of improved sorghum and other production technologies in Busia, Kenya. In *Proceedings of 5th KARI scientific conference. 14th-16th October 1996*. KARI Nairobi, Kenya, 1996.

Sanchez, P.A., 1976. *Properties of Management of Soils in the Tropics*. London: John Willey.

Sanford, J.O. and Hairston, J.E., 1984. Effects of N fertilisation on yield, growth and extraction of water by wheat following soyabeans and grain sorghum. *Agronomy Journal*, 76, pp.623-27.

Sanginga, N. and Woomer, P.L., 2009. Integrated soil fertility management in Africa: Principles, Practices and Development Process. (Eds.). *Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture. Nairobi*, p.263.

Sanyal, D., Bhowmik, P.C., Anderson, L. and Shrestha, A., 2008. Revisiting the pespective and progress of Intergrated Weed Management. *Weed Science*, pp.56: 161-167.

Schoofs, A. and Entz, M.H., 2000. Influence of annual forages on weed dynamics in a cropping system. *Can. J. Plant Sci*, 80, pp.187-98.

Scott, T.W., Pleasant, J., Burt, R.F. and Otis, D.J., 1987. Contributions of groungcover, dry matter and nitrogen from intercrops and cover crops in a polyculture system. *Agron. Journal*, 79, pp.792-98.

Seran, T.H. and Brintha, I., 2010. Review on maize based intercropping. *Journal of Agronomy*, pp.9 (3): 135-145.

Sharma, V. and Angiras, N.N., 1996a. Effect of row orientations, row spacing and weed-control methods on light interception, canopy temperature and productivity of wheat (*Triticum aestivum*). *India J. Agron.*, pp.41: 390-396.

Sharma, V. and Angiras, N.N., 1996b. Light interception, weed growth and productivity of irrigated wheat as influenced by crop geometry and weed control methods. *India J. Plant Physiol.*, pp.1: 157-162.

Shetty, S.V.R., Ntare, B.R., Bationo, A. and Renard, C., 1995. Millet and cowpea in mixed farming of Sahel. A review of strategies for increased productivity and sustainability. Pages 293-304 in Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Addis Ababa, Ethiopia, 1995. Edited by J. M. Powell, S. Fernandez Revira, T. O. Williams and C. Renard. Proceedings International Conference, ILCA.

Shetty, S.V.R. and Rao, A.N., 1981. Weed management in sorghum/pigeonpea and pearl millet/groundnut intercropping system; some observations. Tropics Patancheru, A.P., India, 1981.

Shrestha, A. and Fidelibus, M., 2005. Grapevine row orientation affects light environment, growth and development of black nightshade (*Solanum nigrum*). *Weed Science*, pp.53: 802-12.

Shumba, E.M., Dhilwayo, H.H. and Mukoko, O.Z., 1990. The potential of maize-cowpea intercropping in low rainfall areas of Zimbabwe. *Zim J. Agric. Res.*, 28, pp.33-38.

Siame, J., Willey, R.W. and Morse, S., 1998. The response of maize/Phaseolus intercropping to applied nitrogen on Oxisol in northern Zambia. *Field Crops Res.*, 55, pp.73-81.

Sibuga, K.P., 1999. The role of woman and children in weed management i smallholder farming systems. In *Proceedings of the 17th East Africa Bi-annual Weed Science Conference, Harare, 27-29 September 85-90.*, 1999.

Singh, B., 2003. Improving the production and utilisation of cowpea as food and fodder. *Field Crop Research*, 84, pp.149-69.

Singh, B.B., Chambliss, O.L. and Sharma, B., 1997. Recent advances in cowpea breeding. Pages 39-40 in Advances in cowpea research, edited by B. B. Singh, D. R. Mohan Raj, K. Dashiell and L. E. N. Jackai.. *Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Centre for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria*.

Steiner, K.G., 1982. Intercropping in tropical smallholder agriculture with special reference to West Africa. *Schriftenreihe der GT2, N. 37, Eischborn, Germany*.

Steiner, K.G., 1984. *Intercropping in Tropical Smallholder Agriculture with Special Reference to West Africa*. Second Edition ed. Eschborm, Germany: Deutsche Gesellschaft fur Technische Zusammenarbeit.

Sullivan, P., 2003. Intercropping principles and practices. *Agronomy systems guide science*, 188, pp.212-18.

Swain, J., 1977. Secondary compound as protective agents. *Annual Review of Plant Physiology*, 28, pp.479-501.

Szeicz, G., 1974. Solar radiation for plant growth. *Journal of Applied Ecology*, 11, pp.617-36.

Tatterfield, J.R. and Cronin, C.H., 1958. Weed control in maize in Southern Rhodesia with Special Reference to Use of Herbicides. In *Victoria Falls, paper presented at the African Weed Control Conference*., 1958.

Taylor, T.R.N., 2008. Overview importance of sorghum in Africa.

Teasdale, J.R., 1995. Influence of narrow row high plant population corn (*Zea mays* L.) on weed control and light transmittance. *Weed technol.*, pp.9: 113-118.

Terao, T.I., Watanabe, R., Matsunagas, H. and Singh, B.B., 1997. Agrophysiological constraints in intercrop cowpea: an analysis. Pages 129-140 in Advances in cowpea research, edited by B. B. Singh, D. R. Mohan Raj, K. Dashiell and L. E. N. Jackai. *Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Centre for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria*.

Tharp, B.E. and Kells, J.J., 2001. Effect of glufosinate resistant corn (*Zea mays*) population and row spacing on light interception, corn yield and common lambsquarters (*Chenopodium album*) growth. *Weed technol.*, pp.15: 413-418.

Thembani, P., 2002. Effect of intercropping, leaf stripping, detasselling and weeding regime on radiant environment, weed dynamics and productivity. In *A thesis submitted in partial fulfillment of the requirements of the degree of MSc Crop Protection, Crop Science Dept., UZ.*, 2002.

Tollenaar, M., Nissanka, S.P., Anguilera, A., Weise, S.F. and Swanton, C.J., 1994. Effect of weed interference and soil-nitrogen on 4 maize hybrids. *Agron. J.*, pp.86: 596-601.

Trenbath, B.R., 1976. Plant interactions in mixed crop communities pp 129-169. In R.I. Papendick, P.A. Sanchez and G.B. Triplett (eds.). Multiple cropping. *Amer. Soc. Agron. Spec. Public. No. 22*.

Trenbath, B.R., 1993. Intercropping for the management of pests and diseases. *Field Crop Research*, 84, pp.381-405.

Trudgill, D.L., 1991. Resistance to and tolerance of plant parasitic nematodes in plants. *Annu. Rev. Phytopathol.*, 29, pp.167-92.

Tsubo, M., Mukhala, E., Ogindo, H.O. and Walker, S., 2003. Productivity of maize-beans intercropping in a semi-arid region of South Africa. *Department of Soil, Crop and Climate Science, University of Free State, P.O. Box 339, Bloemfontein 9300, South Africa*, pp.381-87.

Tsubo, M. and Walker, S., 2003. Shade effect on *Phaseolus vulgaris* L. intercropped with *Zea mays* L. under well-watered conditions. *J. Agronomy and Crop Science*, 190, pp.168-76.

Turker, U., 2005. Determination of Spartial Weed Variability for Precision Spraying. *Gelis Tarihi*, p.24.11. 2005.

USDA-NRSS, 2006. Purple Nutsedge (*Cyperus rotundus* L.).

Van Kessel, C. and Roskoski, J.P., 1988. Row spacing effects on N-fixation, N-yield and soil N uptake of intercropped cowpea and maize. *Plant and Soil Science Jourmal*, pp.111: 17-23.

Vandermeer, J., 1989. *"The Ecology of Intercropping"*. Cambridge: University of Cambridge.

Vandermeer, J., 1992. *"The Ecology of Intercropping"*. Reprinted Edition ed. Cambridge: University of Cambridge.

Viljoen, J. and Allemann, J., 1996. Cowpea and maize intercropping. Pages 16-24 in: Training course. Cowpeas, Vegetables and Ornamental Plant Institute. *Agricultural Research Council, Roodeplaat*.

Vincent, V. and Thomas, R.G., 1960. An agricultural survey of Southern Rhodesia: Part I: agro-ecological survey. Government Printer, Salisbury.

Waddington, S.R. and Kangwindi, J., 1996. Grain yield of maize populations and commercial hybrids after competition from weeds early in crop development. *Zimbabwe Journal of Agricultural Research*, pp.45-54.

Waghmare, A.B., Krishnan, T.K. and Singh, S.P., 1982. Crop compatibility and spartial arrangement in sorghum-based intercropping systems. *J. Agric. Sci.*, pp.99: 621-629.

Weil, R.W. and McFadden, M.E., 1991. Fertility and weed stress on perfomance of maize/soybean intercrop. *Agronomy Journal*, 83, pp.717-21.

Westerman, P.R., Liebman, M., Monalled, F.D., Heggenstaller, A.H., Hatzler, R.G. and Dixon, P.M., 2005. Are many little hammers effective? Velvetleaf population dynamics in two-and four-year crop rotation systems. *Weed Science*, pp.53: 382-392.

Willey, R.W., 1979a. Intercropping its importance and research needs. Part I. Competition and yield advantages. *Fld. Crop. Abstr.*, 32(1): 1-10.

Willey, R.W., 1979b. Intercropping its importance and research needs. Part II. Competition and yield advantages. *Field Crop Abstract*, 32, 73-85.

Willey, R.W., 1985. Evaluation and presentation of intercropping advantages. *Experimental Agriculture*, pp.21:119-133.

Willey, R.W., Natarajan, M., Ready, M.S., Rao, M.R., Nambiar, P.T.C., Kammainan, J. and Bhatanagar, V.S., 1983. *Intercropping Studies with Annual Crops. In: Better Crops for Food. Nugent. J. and M. O'Connor (eds). Pitman Co. London*.

Willey, R.W. and Osiru, D.S.O., 1972. Studies on mixtures of maize and bean (*Phaseolus vulgaris*) with particular reference to plant population. *Journal of Agricultural Sciences (Camb.)*, pp.77: 513-540.

Wolfe, M.S., 1985. The current status and prospects of multilane cultivars and variety mixture for disease resistance. *Annu. Rev. Phytopathol.*, 23, pp.251-273. www.csun.edu/%7Ehcbio027/biotechnology/lec10/lindemann.html.

WRI, 2005. The wealth of the poor: Managing ecosystem to fight poverty. *World Research Institute, Washington DC*.

Zimbabwe Vulnerability Assessment Commitee (ZimVac, 2009). ZimVac Rural Household livelihood Survey Report No. 11, October 2009, Harare., 2009.

ZIMSTAT, 2012. Preliminary report on Census 2012., 2012.

Zoufa, K., Tariah, N.M. and Isirimah, M.O., 1992. Effects of groundnut, cowpea and melon on weed control and yields of intercropped cassava and maize. *Field Crop Res*, 28, pp.309-14.

APPENDICES

Appendix 1: Questionnaire for a survey to assess farmers' perception about intercropping

FARMER INTERCROPPING PRACTICES IN SEMI-ARID ZIMBABWE: SURVEY IN MATOBO DISTRICT

FEBRUARY 2015

OBJECTIVES

1. To find out if farmers in semi-arid Zimbabwe practice intercropping
2. To find out if the farmers consider population density and row orientation in their planting
3. To find out if the farmers have realised any benefits from intercropping and the challenges they have faced

GUIDANCE TO THE ENUMERATOR

1. **Brief introduction of self**
2. **Purpose of interview**
   - To find out if farmers in semi-arid Zimbabwe practice intercropping
   - To find out if the farmers consider population density and row orientation in their planting
   - To find out if the farmers have realised any profits from their intercropping and the challenges they have faced
3. **Reasons for selection**
   The information collected is confidential and is going to be used for strictly for research purposes only.
4. **May you please spent some time to complete the questioner with me**

Name of enumerator
……………………………………………………………………………………………

Name of farmer
………………………………………………………………………………………………

Gender of the farmer ☐ **Male** ☐ **Female**

Size of household ☐

Marital status

☐ **Single** ☐ **Married** ☐ **Divorced** ☐ **Widowed**

Ward………………………………………. **Village …………………………………**

SECTION A

A1 How big is the farm area?		………....ha
A2 Which crops do you grow?	Sorghum = 1, pearl millet = 2, maize = 3, cowpea = 4, sugar beans=5, others (specify) ………………………………………………………………………………………………… …………………………………………………………………………………………………	
A3 Do you practice intercropping?	Yes =1, no = 2	

*(If **YES**, proceed to **Section B**, if **NO** proceed to **Section B**)*

SECTION B

B1 Total area under intercropping?		………....ha
B2 Which type of intercropping do you practice?	1= mixed, 2 = row, 3 = row, 4 = other (specify)…………………………… …………………………………………………………………………………………………	
B3 If row intercropping, are the component crops in one row or separate rows?	1 = one row, 2 = separate rows	
B4 If row orientation, what are the row ratios of cereal: legume?	1 = 1:1, 2 = 1:2, 3 = 1:3, 4 = 2:1, 5 = 3:1, 6 = others (specify)…….............	
B5 Are the component crops planted at the same time?	1 = Yes, 2 = No	
B6 If not, how many weeks after the main crop is planted do you plant the minor crop?	1 = 1 week, 2 = 2 weeks, 3 = 3 weeks, 4 = others (specify)…………………………………….	

B7 Do you consider the spacing of the crops (plant population)?	Yes = 1, No = 2		

B8 Do you consider row orientation?	Yes = 1, No = 2		

B9 If so, which row orientation do you use?	North-South = 1, West-East = 2, North West-South East = 3, North East-South West = 4	

B10 Benefits from intercropping	1 = Flexibility, 2 = Profit maximisation, 3 = Risk minimisation against crop failure, 4 = soil conservation and maintenance, 5 = better weed control, 6 = balanced nutrition, 7 = increased profitability, 8 = better utilisation of time, labour, management and machinery, 9 = higher yields than sole crop, 10 = greater yield stability, 11 = more efficient use of environmental resources, 12 = improved quality by variety, 13 = preservation of moisture, 14 = shelter against pest attacks, 15 = others (specify)……………………………………………………….. …………………………………………………………………………………………………….	

B11 Challenges faced when intercropping	1 = Difficulty in harvesting, 2 = difficulty in using machinery (mechanisation), 3 = Difficulty in the use of chemicals (herbicides, pesticides etc), 4 = others specify)…………………………………………....... ………………………………………………………………………………………………………..	

SECTION C

C1 Did you practise intercropping before?	1 = Yes, 2 = No	
C2 If you have practised it before, when did you last practice it?	1 = Last season, 2 = Two seasons ago, 3 = Three seasons ago, 4 = four seasons ago, 5 = Five seasons ago, 6 = More than five seasons ago	
C3 Is there any reason why you are no longer practising intercropping?	1 = Yes, 2 = No	

C4 If so, list the reasons below

Reason 1 ………
Reason 2 ……………………………………………………………………………………………...……………………………….
Reason 3 …………………………………………………………...…………………………………………………………………….
Reason 4 ………………...……….
Reason 5…….
Reason 6
…….

C6 Any other comment
……..
…………………………...………
……..
………
……………………………………..………………………………………………………………………………………………
……..

Appendix 2: ANOVA showing the relationship between gender of farmer and intercropping practise

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.530[a]	1	0.112
N of Valid Cases	60		

Appendix 3: ANOVA showing the relationship between marital status and intercropping practise

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square N of Valid Cases	3.941[a] 60	3	0.268

Appendix 4: ANOVA showing the relationship between ward and intercropping practise

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square N of Valid Cases	1.071[a] 60	1	0.301

Appendix 5: ANOVA showing the relationship between village and intercropping practise

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square N of Valid Cases	7.624[a] 60	3	0.054

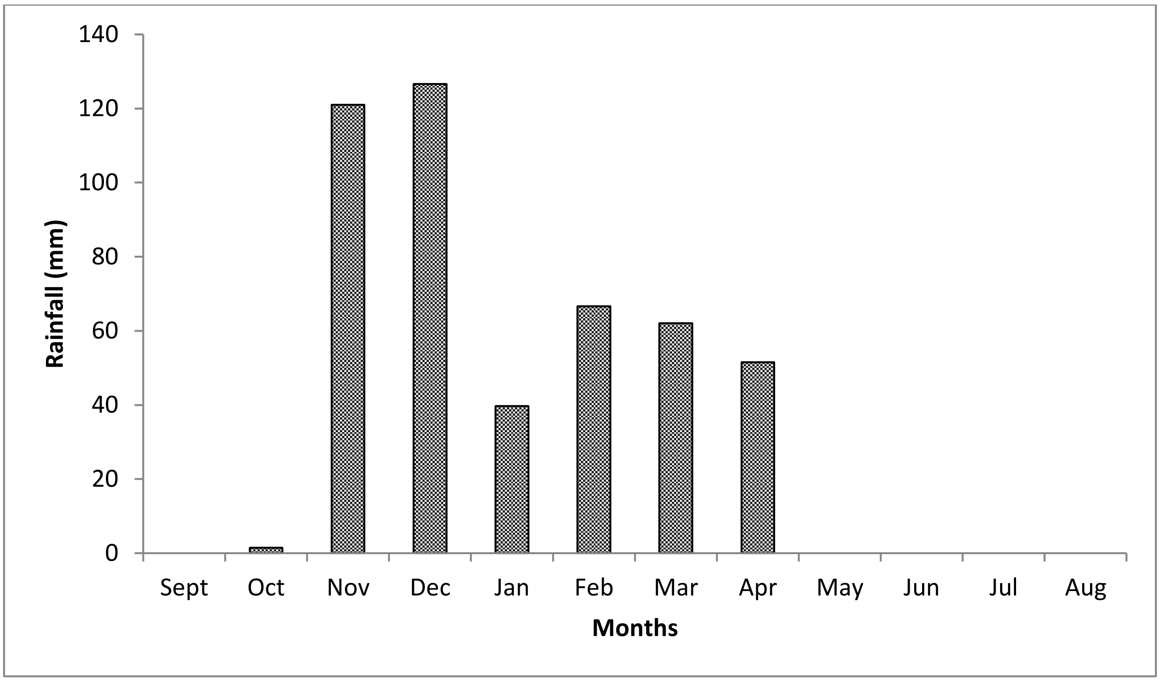
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.53.

Appendix 6: ANOVA showing the relationship between size of household and intercropping practise

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square N of Valid Cases	25.045[a] 60	10	0.005

a. 19 cells (86.4%) have expected count less than 5. The minimum expected count is .93.

Appendix 7: Rainfall pattern during the 2014/15 rain season at Matopo Research Station



Appendix 8: ANOVA showing the effect of cowpea intercrop population and row orientation on weed density at 3 weeks after crop emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	2937.3	489.6	0.96	0.472
Row	1	18.7	18.7	0.04	0.850
InPpln.Row	6	1505.3	250.9	0.49	0.810
Residual	28	14324.7	511.6		
Total	41	18786.0			

Appendix 9: ANOVA showing the effect of cowpea intercrop population and row orientation on weed density at 6 weeks after crop emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	4241.143	706.857	148.44	<.001
Row	1	103.714	103.714	21.78	<.001
InPpln.Row	6	316.286	52.714	11.07	<.001
Residual	28	133.333	4.762		
Total	41	4794.476			

Appendix 10: ANOVA showing the effect of cowpea intercrop population and row orientation on relative density of Dwarf marigold (*Schkuria pinnata*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	4153.9590	692.3265	1206.04	<.001
Row	1	62.6593	62.6593	109.15	<.001
InPpln.Row	6	101.9724	16.9954	29.61	<.001
Residual	28	16.0733	0.5740		
Total	41	4334.6640			

Appendix 11: ANOVA showing the effect of cowpea intercrop population and row orientation on relative density of Mexican marigold (*Tagetis manuta*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	4011.339	668.557	424.22	<.001
Row	1	153.909	153.909	97.66	<.001
Row.InPpln	6	80.565	13.427	8.52	<.001
Residual	28	44.127	1.576		
Total	41	4289.939			

Appendix 12: ANOVA showing the effect of cowpea intercrop population and row orientation on relative density of Wild jute (*Cochorus tridens*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	2355.577	392.596	98.35	<.001
Row	1	55.086	55.086	13.80	<.001
InPpln.Row	6	75.889	12.648	3.17	<.001
Residual	28	111.767	3.992		
Total	41	2598.318			

Appendix 13: ANOVA showing the effect of cowpea intercrop population and row orientation on relative density of Nutsedge (*Cyperus rotundus*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	1320.2	220.0	1.87	<.001
Row	1	4.7	4.7	0.04	<.001
InPpln.Row	6	759.7	126.6	1.08	<.001
Residual	28	3295.5	117.7		
Total	41	5380.1			

Appendix 14: ANOVA showing the effect of cowpea intercrop population and row orientation on relative density of other weeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	6	20630.1	3438.4	32.32	<.001
Row	1	654.5	654.5	6.15	0.019
InPpln.Row	6	715.6	119.3	1.12	0.376
Residual	28	2978.9	106.4		
Total	41	24979.2			

Appendix 15: ANOVA showing the effect of cowpea intercrop population and row orientation on cowpea number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	5	191.56889	38.31378	456.58	<.001
Row	1	42.68444	42.68444	508.67	<.001
InPpln.Row	5	92.36556	18.47311	220.14	<.001
Residual	22	1.84611	0.08391		
Total	35	329.33889			

Appendix 16: ANOVA showing the effect of cowpea intercrop population and row orientation on number of grains per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	5	129.32472	25.86494	453.01	<.001
Row	1	16.67361	16.67361	292.03	<.001
InPpln.Row	5	53.83806	10.76761	188.59	<.001
Residual	22	1.25611	0.05710		
Total	35	201.80972			

Appendix 17: ANOVA showing the effect of cowpea intercrop population and row orientation on cowpea biomass yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	5	218716.40	43743.28	773.25	<.001
Row	1	5043.37	5043.37	89.15	<.001
InPpln.Row	5	77172.75	15434.55	272.84	<.001
Residual	22	1244.56	56.57		
Total	35	302651.68			

Appendix 18: ANOVA showing the effect of cowpea intercrop population and row orientation on cowpea grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	5	874480.12	174896.02	2686.18	<.001
Row	1	43465.30	43465.30	667.57	<.001
InPpln.Row	5	16014.02	3202.80	49.19	<.001
Residual	22	1432.41	65.11		
Total	35	936375.80			

Appendix 19: ANOVA showing the effect of cowpea intercrop population and row orientation on sorghum biomass yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	3	3732679.	1244226.	208.49	<.001
Row	1	42260.	42260.	7.08	0.019
InPpln.Row	3	119328.	39776.	6.67	0.005
Residual	14	83547.	5968.		
Total	23	4014528.			

Appendix 20: ANOVA showing the effect of cowpea intercrop population and row orientation on sorghum grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
InPpln	3	595139.6	198379.9	1903.60	<.001
Row	1	496541.4	496541.4	4764.67	<.001
InPpln.Row	3	70083.1	23361.0	224.17	<.001
Residual	14	1459.0	104.2		
Total	23	1164274.4			