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EFFECT OF ROW ARRANGEMENTS ON SORGHUM-COWPEA INTERCROP YIELDS IN THE LOWVELD OF ZIMBABWE

BY

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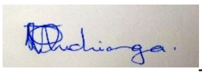
Abstract

In the Lowveld of Zimbabwe, intercropping of cereals with legumes is a predominant feature in the cropping system which is practiced at small scale farms as a means of maximizing the use of limited farm lands as well as attaining food security by subsistence farmers. The usual intercropping system practice is a cereal-legume mixture, where millet and sorghum are widely used as a cereal component of intercropping with crops such as cowpea, groundnut and round nut. However, these interactions would possibly enhance productivity of intercrops if the cropping patterns were in their right proportions. A field trial was conducted during the 2019/2020 cropping season under rain-fed conditions at Chiredzi research station to determine the effect of intercropping on the yield and yield related traits of Sorghum and cowpea and the optimum row arrangement for the mixture of sorghum (SV4) with erect local cowpea (CBC2) for highest yield. The experiment comprised of six treatments; sole sorghum crop, sole cowpea and four spatial/row arrangements of 1:1, 1:2, 2:1 and 2:2 rows of sorghum alternated with cowpea. The treatments were arranged in a randomized complete block design with three replications. Land Equivalent ratio was used to evaluate the productivity. Intercropping sorghum with cowpea at different row arrangements had a highly significant effect on the yield per hectare of sorghum with sole sorghum giving the highest yield of 2455kgs/ha. Treatment 2 with 2rows of sorghum and 2rows of cowpea had the second highest yield of 1871kgs/ha. The intercropping patterns of 1Sorghum: 2Cowpea, 2Sorghum: 2Cowpea, sole cowpea and sole sorghum had LERs of 1.0199, 1.009, 1.000 and 1.000 respectively. The values of the land equivalent ratio (LER), however, indicated that there is no advantage of intercropping over pure stands. From this study, farmers in the Lowveld are advised to intercrop their sorghum and cowpea using the 2:2 row ratio at the onset of the first effective rains for considerable yields. This allows farmers to have a variety of nutrition sources and hence, enhanced food and nutrition security for both humans and livestock compared to mono cropping of sorghum or cowpea.

Key words: Sorghum, cowpea, intercrops, row arrangement, biomass.

Declaration Page

I declare that this dissertation is my original work except where sources have been cited and acknowledged. The work has never been submitted, nor will it ever be submitted to another University for the award of a degree.

Nyasha Tinashe Diana Muchianga  15/02/2021

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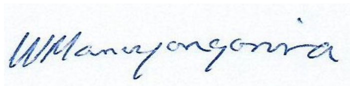
_Walter Manyangarirwa  09/04/21

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Dedication

This project is dedicated to the Almighty God, my son Tinotendaishe Hondo, my late father, Mr. S. Muchianga and my mother, Mrs. S. Muchianga, for they are a source of inspiration and my pillars of strength. Your contribution to my life and your support is of immeasurable value.

List of Acronyms and Abbreviations

AGRITEX	Agricultural, Technical and Extension Services
ANOVA	Analysis of Variance
ARC	Agriculture Research Council of Zimbabwe
BMS	Block Mean Square
BNF	The ability to fix atmospheric nitrogen through biological nitrogen fixation
CV	Coefficient of variation
DMRT	Duncan's Multiple Range Test
DR&SS	Department of Research and Specialist Services
FAO	Food and Agriculture Organization of the United Nations
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
LAI	Leaf area index
LSD	Least Significant Difference
NUE	Nitrogen Use Efficiency
RCBD	Randomized Complete Block Design
RMS	Residual Mean Square
TMS	Treatment Mean Square

Definition of Key Terms

Biomass	The total quantity or weight of organisms in a given area or volume
Effective rains	The difference between total rainfall and actual evapotranspiration
Food Security	The state of having reliable access to a sufficient quantity of affordable, nutritious food.
Intercropping	The growing of two or more crops simultaneously on the same area of land.
Land equivalent ratio	The relative land area under sole crop that would be required to produce the equivalent yield under a mixed or an intercropping system at the same level of management
Resilience	The capacity of an individual, household, population group or system to anticipate, absorb, and recover from shocks and stress, hazards and/or effects of climate change.
Spatial arrangement	The property possessed by an array of things that have space between them.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Intercropping is a potential beneficial system of crop production. It can be defined as the growing of two or more crops simultaneously on the same area of land. Intercropping offers a better utilization of natural resources, labour and safeguards against total failure of single crop, gives greater yield and return per unit area, and minimizes the spread of pests and diseases (Snapp, 2017). In intercropping, the crops are not necessarily sown at the same time and their harvest time may be quite different, but usually they occupy together the same land area for a significant part of the growing season. The crops involved in this system are usually harvested separately and their yields are kept separate (Lithourgidis, Dordas, Damalas & Vlachostergios, 2011). Intercropping practices are extensively used by subsistence farmers in the tropics and subtropics. In the Lowveld of Zimbabwe, intercropping of cereals with legumes is a predominant feature in the cropping system which is practiced at small scale as a means of maximizing the use of limited farm lands as well as attaining food security to the subsistence farmers. The usual intercrop system practice is a cereal-legume mixture, where millet and sorghum are widely used as a cereal component of intercropping with crops such as cowpea, groundnut and round nut (Mukarumbwa & Mushunje, 2010). Therefore, this system is considered to help farmers utilize their limited land and labour resources for attaining yield stability, obtaining higher yields per unit area, and having better control of weeds, pests, and diseases. In addition, it cushions farmers against total crop failure from single cropping during drought. However, the productivity of intercrops could be enhanced if the cropping patterns were done in their right proportions.

Sorghum (*Sorghum bicolor* (L.) Moench.) is a main cereal crop for the communities in the Lowveld of Zimbabwe. Apart from human consumption, it draws its great value as source of grain and straw that is used for animal feed (Mazvimavi, Murendo, Pedzisa & Chivenge, 2017) and in cases where farmers do contract farming, they sell the red sorghum to Delta Corporation. Unfortunately, no proper recommended technologies were undertaken by farmers to address the challenges faced in sorghum production in the Lowveld of Zimbabwe due to frequent cultivation in mono-cropping systems, as well as the inadequate awareness of farmers of the advantages of intercropping and mixed cropping.

Cowpea (*Vigna unguiculata* L. Walp) is famous by the names of black-eye pea, southern pea and locally as “Nyemba”. Cowpea is an important option for intercropping with sorghum due to complimentary resource use (Iqbal, 2016). It is a leguminous crop belonging to genus *Vigna* and family Fabaceae and is known to have its origin somewhere in central Africa (Doring, 2015). It is a heat and drought tolerant crop which is known to have a good potential to thrive well in drier regions. Its advantage to small holder farmers is its ability to fix atmospheric nitrogen although it is not a nitrogen contributor crop (Iqbal, Hamid, Ahmad, Siddiqui, Hussain, Ali & Ahmad, 2019). Cowpea has the ability to thrive well on marginal and poor soils as it can fulfill a greater part of nitrogen requirement through symbiotic nitrogen fixation in the soil. It is also a best choice for intercropping with sorghum, pearl millet or maize due to its shade tolerant characteristics. It is referred to as the ‘poor man’s crop’ because of its seed which contain protein up to 25% and has leaves which are also a rich source of protein for ruminants (Karanja, Kibe, Karogo, & Mwangi, 2017). The productivity of cowpea has been found to be influenced by different planting geometries (Iqbal, 2016), but there is a dire need to optimize spatial arrangements for sorghum-cowpea intercropping systems.

1.2 Background to the Study

The grain yield of sorghum in the Lowveld areas has been dwindling especially during the last decade with farmers getting yields as low as 300 kg/ha due to the poor rains coupled by the infertile soils due to continuous mono-cropping. Cowpea (*Vigan unguiculata* L. Walp.) is one of the important food and cash crops grown by the small scale farmers (Birteeb, Addah, Jakper, & Addo-Kwafo, (2011)). It is usually grown as a sole crop in limited areas. However, some farmers grow it as mixture with sorghum or pearl millet without any particular arrangements. The cowpea crop shows great advantages through its use for human consumption and using the remaining biomass for animal fodder. It provides a good prevention of water run-off and evaporation from the soil surface due to its prostrating growth habit, *Striga hermonthica* plants and other weeds control and increasing soil fertility through the nitrogen fixation. In addition intercropping can spread labour needs and reduce pest problems (Boudreau, 2013). When legumes are grown with cereals, the former can improve the nitrogen economy of the cereal either by contributing nitrogen to the soil or removing less amount of soil nitrogen. Therefore, inclusion of leguminous crops, like cowpea in cropping systems has multiple advantages in improving and sustaining agricultural productivity. There is need therefore, to determine the intercropping pattern/ row arrangement that is most suitable for the Lowveld areas of Zimbabwe where rainfall is insufficient and erratic.

1.3 Statement of the Problem

Sorghum adoption and production is on the rise in the Lowveld of Zimbabwe due to the re-current drought conditions. However, due to continuous land tillage and crop production and very limited soil nutrient replenishment, yields are continuing to decline. There is need to integrate sorghum production with crops that are able to re-cycle soil nutrients, hence the need to intercrop with leguminous plants using the right planting patterns (Mutenje *et al.,* 2010; Hauggaard *et al*., 2016). Integrating leguminous crops such as cowpea into cropping systems could reduce the weed seed bank and improve soil fertility and livelihood of farmers. Competition for space in sorghum-cowpea intercropping, results in increased soil cover and reduced soil erosion (Morel, Braña & Castro-Sowinski, 2012). In addition, it maximises use of limited farmlands, provides food security and improves soil fertility (Lamessa, Sharma & Tessema, 2016). In addition to weed control, intercropping reduces pests and disease incidence (Lopes *et al*., 2016). The problem is centered on farmers having inadequate information on the advantages of intercropping of Sorghum with cowpea and those that are intercropping do not have a specific pattern, hence the need for the most appropriate row arrangement for optimum yield. The inadequate knowledge has led to the continuous poor yields and food insecurity of the farmers. The experiment sought to come up with the most suitable row arrangement for optimal yields and land equivalent ratio.

1.4 Research Objectives

The main objective of this research was to determine the effect of intercropping on the yield and yield related traits of Sorghum and Cowpea, and the optimum row arrangement for the mixture of sorghum with erect local cowpea for highest yield.

1.4.1 Specific Objectives

The specific objectives of the study were to;

a) Determine the effect of intercropping on the yield and yield related traits of Sorghum and Cowpea.
b) Evaluate the effect of cowpea intercropping with sorghum on moisture retention in the soil.
c) Determine the optimum row arrangement for the intercrop of sorghum and cowpea for highest yield.
d) Determine the advantage of intercropping over sole cropping as expressed in-terms of the land equivalent ratio (LER).

1.4.2 Hypotheses

a) There is no significant difference in the growth and yield of Sorghum and Cowpea when intercropped.
b) There is no significant difference in soil moisture retention for sorghum and cowpea grown as intercrops.
c) There is no significant difference in the growth and yield of Sorghum and Cowpea intercropped at different spatial arrangements.
d) Intercropping has no significant difference over sole cropping.

1.6 Significance of the Study

Evaluation of the effect of intercropping Cowpea with Sorghum at different spatial arrangements will help identify the most suitable planting pattern for adoption by farmers in the Lowveld areas of Zimbabwe. This will enable farmers to have optimum to high yields and not have total crop failure in the face of droughts. In addition, it would rebuild soil health and enhance the sustainability of the resource poor agricultural systems of the Lowveld areas. In addition to yields, the soil nutrients will also be re-cycled and apart from harvesting the grain from both Sorghum and the legume for human consumption, they can use both Stover for fodder production and also benefit from the weed control (Monti, Pellicanò, Santonoceto, Preiti & Pristeri, 2016; Mousavi & Eskandari, 2011).

1.7 Delimitations of the Study

The research trial was conducted in Chiredzi at the Chiredzi Research Station of the Department of Research and Specialist Services (DR&SS) which is in Natural Region V, located at a latitude of 21° 01' S, longitude of 31° 33' E and an elevation of 429 meters above sea level. The mean annual rainfall for the past 5 years ranged between 450 – 650 mm per annum. The average annual temperatures for the past 5 years ranged from 28ºC to 42ºC. The soil type is paragneiss or Triangle P series.

1.8 Limitations to the Study

The research trial was conducted at the Chiredzi Research Station under rain fed conditions and mid-season dry spells and/ or drought is one factor that could not be ruled out. During the growing period, the station received a total of 431mm of rainfall, with a minimum of 1mm and a maximum of 76mm. In addition, fall armyworm and African armyworm attacks were experienced. Furthermore, the COVID 19 pandemic also caused disruptions as the whole country was put on total lockdown for 4weeks and indefinite partial lockdown resulting in excessive costs for plot monitoring as well as limited movement to the project site during the trial period.

CHAPTER 2 REVIEW OF RELATED LITERATURE

2.1 Introduction

Irrigation and application of fertilizers in modern agriculture has been set up to solve problems of increased incidences of erratic rains and poor soil fertility in the tropics. These technologies have not yet reached the subsistence and small-scale farmers of Zimbabwe especially in the Lowveld. In order to achieve one of the sustainable development goals, food security, the area under crop production needs to be expanded. In addition the vast dry lands including the marginal areas in Zimbabwe need to be utilized for food production, and this has been exhibited by increased advocacy for use of hardy crops (Poulton & Kanyinga, 2014). Sorghum, although adapted to dry conditions and hardy, despite it being embraced in these dry lands, has continuously produced poor yields (Rao *et al*., 2015). This has been as a result of unpredictable rainfall patterns causing high levels of water deficit to the plant at critical stages of crop development, increased temperatures and high levels of soil infertility due to continuous mono cropping.

Evaluations of climate resilient conservation agriculture systems offers options for betterment of the situation of poor performance of crops, and intercropping is one of them (Otim *et al*., 2016; Himanen *et al*., 2016). In order to meet future food demand and increase resource use efficiencies, sustainable intensification is required in agricultural crops (Mao *et al*., 2012; Yu *et al*., 2015; Bai *et al*., 2016). Thus, the legume cowpea (*Vigna unguiculata* L. Walp) came in handy as it is adapted to dry tropical conditions (Kumar, Choudhary, Solanki & Pratap, 2011). Generally, there have been increasing interests in conservation agriculture with agroforestry scientists stating that it would assist to rebuild soil health and enhance sustainability of resource poor agricultural systems of developing world. Egesa, Njagi & Muui, (2016) it is stated that alternative nitrogen sources for plant growth have been encouraged for reduced environmental pollution, and this could be generated by the legumes-that serve as candidates for intercropping systems. The purpose of this study is to evaluate sorghum-cowpea intercropping patterns, to understand the likelihood of presence of an influence in sorghum growth and yields in the Low Veld area of Zimbabwe where rainfall is insufficient and unpredictable.

2.2 Intercropping

Intercropping is a traditional cropping system and can be defined as the growing of two or more crops simultaneously on the same area of land. The crops are not necessarily sown at exactly the same time and their harvest times may be different, but they are usually simultaneous for a significant part of their growing periods (Crusciol *et al.,* 2012). Intercropping can provide yield advantage compared to sole cropping, such as yield stability, low input, high and better use of growth resources and better control of weeds, pests and disease. When two or more crops are growing together, each must have adequate space to maximize cooperation and minimize competition between the crops (Egesa, Njagi & Muu, 2016), and to accomplish this, four things need to be considered:

1. Spatial arrangement: Intercropping includes four basic spatial arrangements: Row intercropping: growing two or more crops at the same time with at least one crop

planted in rows; Strip intercropping: growing two or more crops together in strips wide enough to permit separate crop production using machines but close enough for the crops to interact; Mixed intercropping: growing two or more crops together in no distinct row arrangement and Relay intercropping: planting a second crop in standing crop at a time when the standing crop is at its reproductive stage but before harvesting.

2. Plant density: to optimize plant density; the seedling rate of each crop in the mixture is adjusted below its optimum rate.

3. Maturity dates: selection of crop or varieties with different maturity dates can reduce the competition between the two crops. It can also assist in harvesting and handling of the grain.

4. Plant architecture: is commonly used strategically to allow one member of the mixture to capture sunlight that would not otherwise be available to the others.

2.3 Types of intercropping (spatial and temporal patterns)

There are several types of intercropping, which vary in the temporal and spatial mixture to some degree. The degree of spatial and temporal overlap in the component crops can vary somewhat, but both requirements must be met for a cropping system to be an intercrop. Thus, there are several different modes of intercropping, ranging from regular arrangements of the component crops to cases where the different component crops are intermingled (Iqbal *et al*, 2017**)**. In mixed intercropping, the plants are totally mixed in the available space without arrangement in distinct rows (Iqbal, Bethune, Iqbal, Abbas, Aslam, Khan& Ahmad, 2019), whereas in alternate-row intercropping, two or more plant species are cultivated in separate alternate rows. Another option is that of within-row intercropping, where the component crops are planted simultaneously within the same row in varying seeding ratios. With strip intercropping, several rows of a plant species are alternated with several rows of another plant species (Iqbal *et al*., 2017).

Intercropping also uses the practice of sowing a fast-growing crop with a slow-growing crop, so that the first crop is harvested before the second crop starts to mature. This practice requires some kind of temporal separation, e.g. different planting dates of the component crops so that the differential influence of weather and in particular temperature on component crop growth can be modified (Iqbal, 2016). Further temporal separation is found in relay intercropping, where the second crop is sown during the growth, often near the onset of reproductive development or fruiting of the first crop, so that the first crop is harvested to make room for the full development of the second crop.

2.4 Advantages of Intercropping Cereals and Grain Legumes

Studies of ecology of intercropping have indicated that numerous indirect and direct advantages of intercropped systems including increased overall productivity, ecological services and economic profitability are common (Lithourgidis *et al.,* 2011). When sorghum is intercropped with cowpea, there would be benefits of increased nitrogen (N) utilization through 'N' fixation. The critical resource would be utilized by the legume in N_2 forms and by the Non-legume in NO_3 forms. Due to fixation, the excess N will increase the supply to neighbouring plants of other species (Cong *et al.,* 2015).

In addition to N fixation, intercropped legumes also increase availability of other nutrients including phosphorous (P) (Xia *et al.,* 2013) and prevent nutrient losses (Cavagnaro *et al.,* 2015). Legumes based intercropping systems improve the absorption of macro and micronutrients from the soil along with nutrient use efficiency (NUE) (Hinsinger *et al.,* 2011). In a study by Borghiet *al.,* 2013, which involved intercropping of sorghum and palisade grass (*Urochloa brizantha* L.), narrow row spacing (0.90 m) yielded a better forage production than wider row spacing, owing to significantly higher NUE. According to Wahbi *et al.,* (2016), the use of legumes as intercrop also increases microbial population in the soil and their services.

Where nutrient requirements and use by the intercropped plants are different, excess forms of a given nutrient are known to be used by the other crop. An increase in the availability of P, K, Ca and Mg in intercropping than in pure stands, for component crops grown in same conditions but separately, has always been attributed to collective resourcing of nutrients by their roots and through the underground interlinks (Cavagnaro *et al.*, 2015.

Cereals lacking strong rhizosphere acidification capacity, when intercropped with legumes could benefit from nutrients solubilized by the legume root exudates (Li *et al*., 2016). Colonization of cowpea roots with arbuscular mycorrhiza, similar to the cases with many mycorrhizal plants has been credited to improved P availability and use efficiency in such plants, improving their growth under limited P conditions (Li *et al.,* 2016). These improvements also occur in mycorrhizal plants intercropped with non-mycorrhizal ones (Taffouo *et al.,* 2014).

Weed suppression rate is usually stronger in intercropping than in the monoculture situation as well as decreased rates of serious pests, (Lopes *et al*., 2016) and disease (Brooker *et al*., 2016) incidences in intercrops. Weeds compete with crop plants for soil (space, nutrients and moisture) and environmental (light and CO_2 for photosynthesis) growth resources and thus reduce the growth and yield of crops (Satheeshkumar *et al*., 2011). Sorghum-legumes intercropping can be a way to reduce the crop-weed competition by reducing weed infestations (Matusso, Mugwe & Mucheru-Muna, 2014). Intercropping reduces weed populations by reducing the uncovered space available to be occupied by weeds. Odhiambo *et al.,* 2011 reported that sorghum intercropping with food legumes suppressed witch-weed (*Striga hermonthica*) density considerably. In a study conducted by Odhiambo *et al*. (2011), growing maize in association with soybean in the field resulted in lower striga incidences, hence better growth and yield of associated maize. Less number of striga per net plot area are observed when sorghum is intercropped with cowpea (Lamessa, Shamma & Tessema, 2016). Productivity of intercrops could be enhanced if the cropping patterns and the planting density were in their right proportions (Hauggaard-Nielsen *et al*., 2016).

According to Himanen *et al.,* (2016), intercropping has the potential to maintain and improve soil quality and fertility. Soil is the most important resource for small scale farmers, thus diverse and prolonged soil cover and shade are important for protecting soil from weather extremes such as heavy rain or prolonged drought (Fan *et al.,* 2016). Evaporation can be lower, and water use efficiency can be higher with intercropping. In intercropping, plants with differing root structures can take up water from varying depths. Adding deep-rooted or drought-resistant crop genotypes can reduce the between-crop competition for scarce water. In sorghum-cowpea intercropping, competition for space results in increased soil cover and reduced soil erosion (Morel *et al*., 2012).

Complementing high caloric cereals such as maize, sorghum, and millet with pulses and other food legumes can give multiple economic benefits and these crop mixtures often provide high cash returns, generally preferred by smallholder farmers relative to cereal monoculture

(Larochelle *et al.,* 2015). The addition of legumes into smallholder farming systems in many cases improves the system's productivity and stability of associated cereals, and thus has the potential to increase income and buffer risk of losses by protecting against total crop failure (Raseduzzaman & Jensen, 2017). Many legumes provide an important source of income as they can be sold for high prices at local or international markets, although this option is not always available, with an example being cowpea processing in West Africa, which is a notable source of agricultural-based income (Otoo *et al.,* 2011).

The advantages of intercropping compared with sole cropping is commonly expressed in terms of land equivalent ratio (LER), which is defined as the relative land area under sole crops that is required to produce the yield achieved in intercrops (Ehsanullah *et al*. 2011). Land equivalent ratio shows the efficiency of intercropping for using the environmental resources compared with mono-cropping with the value of unity to be the critical value (Rathore, 2015). When the land equivalent ratio is greater than one (unity) the intercropping favours the growth and yield of the species, whereas when the land equivalent ratio is lower than one, the intercropping negatively affects the growth and yield of the plants grown in mixtures. When an LER measures 1.0 it means that there is no advantage of intercropping over pure stands (Lithourgidis *et al.,* 2011).

A positive benefit was shown in many experiments that combined legumes with sorghum. In a study by Rathore (2015), where sorghum was intercropped with cowpea, intercropping in 2:2 and 1:1 row ratios resulted in the highest LER. In another study by Oseni (2010), intercropping sorghum and cowpea under different row proportions, a better land equivalent ratio (LER) was obtained from the 2:1 row proportion as compared to other planting patterns. Intercropping resulted in a significantly higher LER when mash (*Vigna mungo* L.) was intercropped with maize in 90 cm spaced double row strips (Ehsanullah *et al.,* 2011).

A field experiment on the interspecific competition and productivity of maize and pea in intercropping mixture, the single and double row combined intercropping mixtures gave the highest land equivalent ratio (1.31 and 1.47 respectively) (Dhar *et al.*, 2013). Maize had strongly higher competition over cow pea in both 1:1 and 1:2 row arrangements. Naim *et al.* (2013) reported highest total LER (2.11) under 1:1 row arrangement. Higher land equivalent ratio was achieved in pearl millet / pigeon pea intercropping system as compared to their sole cropping (Ansari *et al.,* 2014). A study by Workaheyu, (2014) on the effect of legume-based cropping showed higher LER in maize –bean (1:1) of 35 and 22% more than in maize -bean (1:2) respectively.

After conducting a field trial on intercropping of sorghum and cowpea under different row proportions, Tajudeen, (2010) concluded that sorghum-cowpea sown in 2:1 row proportion gave better land equivalent ratio (LER) as compared to other planting patterns. When mash was intercropped with maize in 90 cm spaced double row strips, intercropping resulted in better LER (Ehsanullah *et al*., 2011). Surve *et al*., (2011) intercropped sorghum with cowpea in 1:1, 1:2 and 2:1 row ratios in order to determine the effect of intercropping systems on green forage yield and economic returns, The highest land equivalent ratio (LER) of 1.51 along with the highest net returns were given by sorghum and cowpea sowing in 2:1 row proportion.

2.5 Effect of Intercropping on Vegetative Growth

Intercropping sorghum with cowpea tends to increase sorghum height. In a trial by Egesa *et al*., (2016) intercropping had an effect on plant height and growth rate of sorghum. Cowpea, when intercropped with sorghum enhances the growth rate of sorghum by adding nitrogen in the soil through biological N fixation (Morel *et al*., 2012) and benefits of N fixation have been credited for enhanced sorghum growth under intercropping systems. Results of enhanced growth performance of intercrops has been attributed to a role of the intercropped state, and the effects credited to the optimal moisture conservation and N fixation benefit in the intercropped field (Mucheru *et al*., 2009).

Intercropping of sorghum with cowpea significantly increases total fresh weight yield. In a trial by Naim *et al*., (2013) the arrangement of 1:1 obtained the highest forage yield which could be attributed to the advantage of legume/cereal intercropping and to better utilization of natural resources such as water, light and nutrients. In addition, the enhancement of productivity by mixed legume crop could lead to the increase of crop growth.

In a trial by Egessa *et al.,* (2016), the cowpeas in equal ratio of intercropping were vigorous, developing a dense second canopy cover, shading much of the spaces in between sorghum lines, which was the opposite of the other three patterns 1:0, 2:3 and mixed cropping. The secondary canopy cover by cowpeas is believed to have conferred better moisture conservation to cereals as described by Morel *et al*., (2012). Terao *et al*., (1997) reported that in millet cowpea intercrop the number of branches in intercropped cowpea was 3-4 depending upon varieties, which was only slightly less than that in mono-cropped cowpea, which ranged from 4-6. However, the number of branches of intercropped cowpea planted 3 weeks later decreased to 0.5-2 while the mono-cropped cowpea still had 4-5 branches per plant. Fezan *et al.* (2013) reported that sorghum mono-cropped in 30 cm apart rows produced a maximum plant population of 47 plants per m^2, a plant height of 203.6 cm, number of leaves per plant 11.23, leaf area of 2684.60 cm2, green forage yield of 49.66 t/ha and dry matter yield of sorghum of 20.50 t/ha over other treatments.

When sorghum was intercropped with cowpea in a trial by Refay *et al*., (2013), all growth parameters such as plant height, leaf area index (LAI), dry matter accumulation were increased. However the highest forage yield was recorded when sorghum was intercropped with cowpea in 2:2 row proportions. Cereal-legumes intercropping systems improve water use efficiency. Sani *et al*., (2011) conducted a field trial and reported that cereal-legumes intercropping was effective in increasing the water use efficiency because intercropping systems produced more biomass per unit of the area by using the same quantity of water as compared to their sole cultivation. Depth of roots differs even among cereals and more water can be exploited from different soil horizons in cereal-legumes intercropping systems and resultantly water use efficiency increases significantly. Similar results were reported by Satheeshkumar *et al*., (2011), who reported that intercropping systems have the potential to increase the biomass production per unit area and presented that different crops in intercropping systems can utilize soil moisture and nutrients more efficiently and resultantly robust growth of at least one crop may be witnessed in intercropping systems.

2.6 Effect of Intercropping on Yield and Yield Components

When intercropping legumes with sorghum, spatial arrangement is one of the most important factors which need to be considered because of its effect on compatibility of component crops (Iqbal, 2016). In a field trial by Surve *et al*., (2011) where forage sorghum was intercropped with cowpea in 1:1, 1:2 and 2:1 row ratios in order to determine the effect of intercropping systems on green forage yield and economic returns, sorghum-cowpea intercropping in 2:1 row proportion was the most beneficial intercropping system as it gave the highest biomass as well as dry matter yield. Hence, they suggested that sorghum and cowpea cultivation in 2:1 row proportion has the potential to give significantly higher green forage yield on per hectare basis than their mono cropping.

Higher yields of sorghum in sorghum-cowpea research activities have been previously reported by Musa (2012). In a similar experiment by Egesa *et al*., (2016) intercropping pattern with equal rows of both crops was the best performer in comparison to all the other patterns of sole cropping and mix cropping. Leaf broadness was seen as the top most factor leading to the higher yields. Ceotto *et al*., (2013) reported that other leaf based factors with enhanced efficient capture of solar radiations, such as a high leaf area index, results in increased photosynthesis due to a high canopy cover to interception of photosynthetically active radiations. Although sorghum has the C4 photosynthetic pathway, the lower younger leaves at seedlings stage do exhibit C3 like photosynthesis (Egessa *et al*., 2016). Leaves are the food assimilates powerhouses where minerals are turned into nutrients. The advantages of having larger leaf area was evidenced by the one sorghum to one cowpea intercropping pattern which resulted in higher yields in a trial by Egessa *et al.,* (2016). Extremely narrow leaves in sorghum can be as a result of soil N deficiencies, Mwadalu and Mwangi (2013) whilst broad leaves have high absorbing rate for solar radiation resulting in higher biomas accumulation, and hence, higher grain yield.

In a trial by Dhar *et al.,* (2013) on inter -specific competition, growth and productivity of maize and pea in intercropping, the 1 row maize: 2 cow pea rows arrangement produced maximum seed yield of 7.82 t/ha. This was 47% higher than the yield obtained from 1 maize: 1 cow pea row arrangement of 7.04 t/ha, sole maize of 5.65 t/ha and sole pea of 4.15 t/ha, respectively. Fezan *et al.,* (2013) revealed that sorghum sown in 30 cm apart rows and intercropped with cluster bean in-between the rows produced significantly higher mixed green forage yield of 69.98 t/ha and dry matter yield of 25.37 t/ha. In an experiment on evaluating sorghum and cowpea intercropped at different spatial arrangements, Naim *et al.,* (2013) reported that 1:1 arrangement obtained the highest values of sorghum panicle weight (57 g), grain yield (1079 kg/ha), hay weight (5572 kg/ha) and combined total hay weight (7337 kg/ha) for both sorghum and cowpea. However, Ansari *et al.,* (2014), reported a reduction in yield of 8.3% and 14.9% over the corresponding sole crops of pearl millet and pigeon pea respectively.

2.7 Summary

Intercropping provides a number of advantages over sole cropping including but not limited to yield stability, low inputs, and high and better use of growth resources and better control of weeds, pests and disease. It increases growth parameters such as plant height, leaf area index (LAI), dry matter accumulation. Intercropping results in efficient land use thereby assuring farmers of better yields even on small areas of land.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The trial was conducted in Chiredzi at the Chiredzi Research Station of the Department of Research and Specialist Services (DR&SS) during the 2019/2020 cropping season. The site is in Natural Region V, latitude: 21° 01' S, longitude: 31° 33’ E and elevation of 429 meters above sea level (m.a.s.l.). The mean annual rainfall for the past 5 years ranged between 450 – 650 mm per annum. The average annual temperatures for the past 5years ranged from 25-35 ºC. The soil type is paragneiss or Triangle P series. One variety of each of the crops was used, Sorghum SV4, Cowpeas CBC2 and the seed was bought from Chiredzi Research Station.

3.2 Experimental Design and Crop Establishment

The experiment was laid out in a randomized complete block design with three replications. The plot size was 4.8 m x 5 m (6 rows of 5 m length, 80 cm a part), with six treatments comprising sorghum variety SV4 and cowpea variety CBC2 which is an upright variety, grown in pure stand and in the following sequence of spatial arrangement:

T1. One row of sorghum alternated with one row of cowpea (1:1).

T2. Two rows of sorghum alternated with one row of cowpea (2:1).

T3. One row of sorghum alternated with two rows of cowpea (1:2).

T4. Two rows of sorghum alternated with two rows of cowpea (2:2).

T5. Sole cowpea rows.

T6. Sole sorghum rows.

The land was disc ploughed, levelled and ridged. Sorghum seeds were sown with the onset of the first effective rains, in January 2020, at a seed rate of 4 seeds per hole. Compound D (7.14.7) was applied at a rate of 100-300 kg per ha at planting and top dressing was done 4 weeks after planting at 45 kg ammonium nitrate per hectare. Thinning to one plant per hole was carried out 2 weeks after germination and weeding was done manually three times during the growing season. Monthly temperature, relative humidity and rainfall were recorded during the growing season. Scouting for pests was done twice a week and fall armyworm and African armyworm were controlled using Demise. Midge was controlled using Malathion 85% WP whilst Dimethoate was used to control aphids and tip wilters, Cape mountain riffle beetle which were affecting cowpeas. Armoured cricket was scouted for and handpicked and controlled using Cabaryl by dipping them in cabaryl then leave in the field where they start eating each other as they are cannibalistic. At maturity, 5 plants of the central rows were harvested for grain and stover/haulm yield determination. Harvesting was done by cutting the stem immediately above ground when the plants were partially dried in the field. The dry grain yield was determined by hand shelling the cowpea pods and threshing of sorghum heads after drying to 13- 14% moisture content. Harvesting was done in May 2020.

Table 3.1 Field layout of the different treatments.

Rep 1	**Rep 2**	**Rep 3**
T3	T1	T4
T1	T3	T1
T4	T5	T5
T6	T2	T2
T2	T4	T6
T5	T6	T3

3.3 Data Collection Instruments

Plant height was measured using a 5 m tape measure. A Digi [R] digital scale was used to measure fresh and dry weight as well as weight of grain. Dry weight samples were dried using an oven. Samples for dry weights were cut using a machete. For soil moisture testing, access tubes were inserted into the soil in every plot and soil moisture content testing was done using the PR2 moisture meter. A 100 ml measuring cylinder was used to put grain for weighing. Grain moisture at harvest was measured using the Draminski[R] TwistGrain moisture meter.

3.4 Data Collection Procedure

3.4.1 Growth Attributes

Measurements of vegetative attributes for each crop were based on three random plants taken from the outer two ridges, for the dry weights and inner two ridges in each plot every two weeks for the other attributes, starting one month after sowing and until flowering. Plant height (cm) was measured from a point immediately above the soil surface to the tip of the youngest leaf. Number of leaves per plant and Leaf area were determined by counting all the leaves of the three sampled plants, and then obtaining mean number of leaves/plant for each treatment whilst leaf area was measured once from the point of attachment to the tip of the leaf. For Fresh and dry weight of shoots, the shoots of the three plants were separated, after cleaning mud from the roots, shoots were then weighed to obtain fresh weight, and then oven dried to determine shoot dry weight twice, at 4 weeks after planting and at harvesting. Number of branches/plant was measured for cowpea, and was determined by counting all the branches of the three-sampled sorghum plants. Then mean number of branches/plant was then determined. Days from sowing until 50% of plants in each plot flowered were determined for sorghum.

3.4.2 Yield and Yield Components

The inner two ridges of each plot were used for determining the final yield and yield components for both crops. For Sorghum, seed yield was determined by harvesting the heads of all the plants in each plot. The heads were left to dry in the sun for a day then threshed and weighed. Then grain yield per hectare calculated by multiplying the yield of sorghum per plot by ten thousand square metres then diving by the area of the plot.

For cowpeas, at maturity five cowpea plants were collected randomly from the outer two rows in each plot to determine number of pods per plant. Five pods were randomly selected from each of the above plants and the seeds counted to determine number of seeds/pod. Seeds of the five cowpea plants which were used to determine number of pods per plant, were then weighed to determine weight of seeds/plant. Seed yield was determined by harvesting the pods of five cowpea plants in the central two ridges of each plot and or the centre of the rows of plots with only one row. The pods were air dried and weighed to determine seed yield/hectare.

3.4.3 Land Equivalent Ratio (LER)

Land equivalent ratio is the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level. It is the sum of the fractions of the intercropped yields divided by the sole-crop yields. Relative yield was determined first by dividing intercrop yield of each crop by yield of sole crop. From the sum of relative yields, the land equivalent ratio (LER) was calculated. To calculate LER, the intercrop yields were divided by the pure stand yield for each component crop in the intercrop then, these two figures added together.

3.4.4 Soil Moisture

Access tubes were dug into the soil in every plot and soil moisture content testing was done using the PR2 DELTA T devices moisture meter. The access tubes were inserted into the soil at the centre of each plot and left in the field. Readings were then taken at weekly intervals 8weeks after planting by inserting the PR2 DELTA T devices moisture meter into the access tubes at 10 cm, 20 cm, 30 cm, 40 cm, 60 cm and 100 cm depths. The readings were recorded and data captured into excel.

3.5 Statistical Analysis and Organization of Data

Data was analysed using GenStat 14 and an analysis of variance (ANOVA) appropriate for a randomized complete block design (RCBD) done. Means separation was carried out using Duncan's Multiple Range Test (DMRT) for mean separation and means separated using Fisher's LSD.

MODEL FOR RCBD

Assume μ is the baseline mean, τi is the i^{th} treatment effect, βj is the j^{th} block effect, and ij is the random error of the observation. The statistical model for a RCBD is:

$yij = \mu + \tau i + \beta j + ij$ and $ij \sim IIDN(0, \sigma 2)$, where

- Yij - any observation for which

  i is the treatment factor

  j is the blocking factor

- μ - the mean

- *T*i - the effect for being in treatment *i*
- *B*j is the effect for being in block *j*

ANOVA TABLE

Source	Df	SS	Mean squares	F
Blocks	b-1	Block SS	BMS=BSS/b-1	BMS/ RMS
Treatment	t-1	Treatment SS	TMS=TSS/t-1	TMS/ RMS
Residual	(t-1) (b-1)	Residual SS	RMS=RSS/ (t-1) (b-1)	
Total	tb-1	SS Total		

3.6 Ethical Consideration

The results shared and discussed in this document were taken entirely from the data collected from the field for this trial. Results were handed over to Chiredzi Research Station who will provide advisories to the farmers through AGRITEX.

3.7 Summary

Sorghum SV4 and Cowpea CBC 2 were intercropped in a randomized complete block design with three replications and 6 treatments. Growth attributes, days to flowering and yield and yield components were measured during the growth and at harvesting respectively. Soil moisture was also measured and land equivalent ratio calculated was calculated also to determine the effect of intercropping. Data was analyzed using GenStat 14 and means separation was done using Duncan's Multiple Range Test (DMRT) for mean separation and means separated using Fisher's LSD.

CHAPTER 4 DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1 Introduction

The agronomic parameters that were recorded for sorghum are number of plants per plot, plant height at four weeks after planting and at flowering, days to flowering and leaf area. For cowpea, number of plants per plot and days to flowering were recorded. For yield, the unshelled 10 head weight, shelled 10 head weight, shelling percentage, seed density and grain yield per plot for sorghum was recorded. Number of pods per plant, number of seeds per pod and grain yield per plot of cowpea was also recorded. The combined grain yield per plot for sorghum and cowpea was then calculated to determine the yield per hectare for each treatment. This was calculated by adding the sorghum and cowpea yield per plot. Land equivalent ratio was also calculated by dividing the intercrop yields by the pure stand yield for each component crop in the intercrop then, these two figures added together. Data on moisture was recorded from 10cm to 100cm and only data from 40cm to 100cm is presented and discussed here as data for 10cm to 30cm was non-significant and had very high coefficient of variation.

4.2 Data Presentation and Analysis

4.2.1 Growth Attributes

Cowpea

Cowpea days to flowering

There were no significant differences $p=0.726$ in days to flowering for cowpea (Table 4.1).

Table 4.1 Effect of treatment combinations on growth attributes of Sorghum and Cowpea.

Sorghum: cowpea ratio	Cowpea days flowering (days)	Cowpea number of plants per plot (plants)	Sorghum number of plants per plot (plants)	Sorghum days to flowering (days)	Sorghum plant height 4weeks after planting(cm)	Sorghum plant height at flowering (cm)	Sorghum leaf area (mm)
1:1	60.33	68.67c	77b	71.33	52.67	148.7	501.9
2:1	58.67	50.33cd	87b	71.67	51.67	150.1	426.2
1:2	61.33	91.67b	48.67c	71.67	54.4	149.8	527.5
2:2	58.33	42d	88.33b	71.33	53.71	149.7	500.3
Solecowpeas	57.67	156.33a	n/a	n/a	n/a	n/a	n/a
Solesorghum	n/a	n/a	114a	72	55.33	147.2	479.1
Grand mean	59.27	81.8	83	71.6	53.56a	149.1	487
CV%	6.2	14.5	13.6	1.7	4.5	3.9	11.3
LSD	6.879	22.31	21.27	2.254	4.562	10.92	103.3
SED	2.983	9.67	9.22	0.978	1.978	4.74	44.8
P-value	0.726	0.001	0.001	0.951	0.437	0.97	0.303
Significance	ns	***	***	ns	ns	ns	ns

*** Significance at 0.1% probability level, ** Significance at 0.01% and not significant (ns)

Number of plants per plot for cowpea

Number of plants per plot for cowpeas was highly significant (p<0,001). Plot 5 (sole cowpea) had the highest mean of 156.3 plants (sole crop) and plot 4 (2rows sorghum: 2 rows cowpea) gave the lowest mean of 42plants. Treatment 1 (1row sorghum: 1row cowpea) and Treatment 2 (2rows sorghum: 1row cowpea) were statistically the same in terms of plant population (68.67 and 50.33plants per plot respectively) whilst Treatment 2 (2rows sorghum: 1row cowpea) was also statistically the same as treatment 4 (2rows sorghum: 2rows cowpea). Treatment 3 (1row sorghum: 2rows cowpea) was statistically different from all other treatments, with a mean number of plants per plot of 91.67.

Sorghum

Sorghum number of plants per plot

There were significant differences on the number of plants per plot ($p<0.001$). Treatment 3 (1row sorghum: 2rows cowpea) had the least number of sorghum plants per plot whilst treatment 5 with sole sorghum had the highest number of sorghum plants per plot, 48.7 plants and 114plants per plot respectively. Treatments 1(1row sorghum: 1row cowpea), 2 (2rows sorghum: 1 row cowpea) and 4 (2rows sorghum: 2rows cowpea) were statistically the same with 77, 87 and 88.33 plants per plot respectively. The results for sorghum number of plants per plot are shown in table 4.1.

Plant height of sorghum at four weeks after planting

Intercropping sorghum with cowpea at different row arrangements did not have any significant effect on the plant height of sorghum at 4 weeks after planting $p<0.437$ (Table 4.1). The smallest height of 51.67cm was given by intercropping 2rows sorghum: 1row cowpea) whereas the biggest height of 55.33 cm was given by sole sorghum.

Sorghum plant height at flowering and Sorghum days to flowering

There were no significant differences ($p=0.970$) on the plant heights of sorghum at flowering (Table 4.1).

Sorghum leaf area

There were no significant differences on the leaf area for all the treatments as shown in table 4.1.

4.2.2 Yield and Yield components

Table 4.2 Effect of treatment combinations on the yield and yield components of Cowpea.

Treatment	Number of plants per plot	Number of pods per plant	Number of seeds per pod	Yield (kg/ha)
1	68.67c	18.53	13	420.9c
2	50.33cd	17.67	15.67	291c
3	91.67b	12.6	14	729.2b
4	42d	11.67	14	254.9c
5	156.33a	16.8	15	1060.5a
Grand mean	81.8	15	14.33	551
CV%	14.5	35.5	15.4	23.8
LSD	22.31	10.3	4.154	246.7
SED	9.67	4.5	1.801	107
P-value	<0.001	0.478	0.642	<0.001
Probability	***	ns	ns	***

Means with the same letter are not significantly different from each other in a column

*** Significance at 0.1% probability level, ** Significance at 0.01% and not significant (ns)

Cowpea

Number of pods per plant

There were no significant differences on the number of pods per plant for all the treatments (p=0.478) as shown in table 4.2.

Number of seeds per pod

There were no significant differences on the number of seeds per pod for all the treatments (p=0.642).

Cowpea yield (kg/ha)

Row arrangement had a significant effect on the yield (kg/ha) for cowpea (p<0.001) with a CV% of (table 4.2). The lowest yield was obtained from intercropping 2rows sorghum: 2rows cowpea whilst the highest yield was obtained from sole cowpea, with 255 kgs/ha and 1061kgs/ha respectively. Sole cowpea was significantly different from all row arrangements as well as treatment 3 (1row sorghum: 2rows cowpea) with a mean yield of 729.2 kgs/ha. Treatments 1 (1 row sorghum: 1 row cowpea), 2(2 rows sorghum: 1 row cowpea) and 4(2 rows sorghum: 2 rows cowpea) were statistically the same with 420.9 kgs/ha, 291 kgs/ha and 254.9 kgs/ha respectively. The significant differences in yields can be attributed to the different plant populations per plot as a result of the row arrangements.

Sorghum

Unshelled 10 head weight

The unshelled 10 head weight for sorghum was significant ($p<0.027$) (Table 4.3). The largest weight of 1080.7g was given by treatment 4 (2rows sorghum; 2rows cowpea) whilst the lowest weight of 763.3g was obtained from treatment 5. However, statistically, treatment 4 was the same as treatment 2, which in turn was the same as treatments 1 and 3. Treatment 4 was statistically the same as treatments 1 and 3.

Shelled ten head weight

There were significant differences ($p<0.043$) in the shelled ten head weight for sorghum. Two rows sorghum alternated with 2 rows cowpeas gave the largest weight of 739.3g whilst sorghum sole crop had the smallest weight of 552.7g. Statistically, treatments 1, 3 and 4 were the same as shown in table 4.3. However, treatments 1 and 3 were also the same as treatment 2 and treatment 2 and 3 were the same as treatment 5.

Shelling percentage

There were no significant differences ($p<0.701$) in the shelling percentages across all the treatments. The CV% was 5.6 with treatment 5 having the highest shelling percentage of 72.53 and treatment 4 having the lowest shelling percentage of 68.33. Results for shelling percentage are illustrated in table 4.3.

Seed density

The seed density was significant ($p<0.019$) and the CV% was 1.3 and this is shown in table 4.3. The highest mean seed density was given by treatment 5 whilst the lowest was given by treatment 1. Statistically treatments 3, 4 and 5 were the same whilst treatments 2, 3 and 4 were also the same. Treatments 1 and 2 were also statistically the same.

Yield (kg/ha)

Intercropping sorghum with cowpea at different row arrangements had a highly significant effect on the yield per hectare of sorghum ($p<0.001$) with a CV% of 13.1%. The highest yield of 2455 kgs/ha was obtained from treatment 5 (sole sorghum) whilst treatment 3 (1 row sorghum: 2 rows cowpeas) gave the lowest yield of 824 kgs per hectare (Table 4.3). Treatment 2 with 2 rows of sorghum and 2 rows of cowpea had the second high yield of 1871 kgs/ha and this could be attributed to the addition of soil nutrients by the cowpeas as described by Li *et al*., 2016. Treatments 1 and 2 (1 row sorghum: 1 row cowpea and 2 rows sorghum: 1 row cowpea respectively) were statistically the same with yields of 1172 kgs/ha and 1377 kgs/ha of sorghum respectively. However, statistically, treatment 1 had the same yield as treatment 3 (1172 kgs/ha and 824 kgs/ha respectively).

Table 4.3 Means, Mean Separations, Least Significant Differences (LSD) and Percentage Coefficient of Variance for Sorghum Yield and Yield components

Treatment	Number of plants per plot	Unshelled 10 head weight	Shelled 10 head weight	Shelling %age	Seed density	Yield (kg/ha)
1	77b	1036.7ab	708.7ab	68.64	130c	1172cd
2	87b	858bc	604.7bc	70.57	132bc	1377c
3	48.67c	963.3ab	678abc	70.2	134ab	824d
4	88.33b	1080.7a	739.3a	68.33	135ab	1871b
5	-	-	-	-	-	-
6	114a	763.3c	552.7c	72.53	136a	2455a
Grand mean	83	940	657	70.06	133.4	1540
CV%	13.6	10.8	10	5.6	1.3	13.1
LSD	21.27	191.9	123.6	7.374	3.315	380.2
SED	9.22	83.2	53.6	3.198	1.438	164.9
P-value	0.001	0.027	0.043	0.701	0.019	0.001
Significance	***	**	**	ns	**	***

Means with the same letter are not significantly different from each other in a column

*** Significance at 0.1% probability level, ** Significance at 0.01% and not significant (ns)

4.2.3 General Attributes

Combined grain yield

Row arrangement had a significant effect on grain yield (p<0.001). The lowest mean yield was given by treatment 5 (sole cowpea) (1061 kgs/ha) whilst treatment 6 (sole sorghum) gave the highest mean grain yield (3196 kgs/ha). In terms of yield, treatment 6 (sole sorghum crop) was not statistically different from treatment 4 (2 sorghum rows: 2 cowpea rows) whilst treatments 2 (2 sorghum rows: 1 cowpea row), 1 (1sorghum row: 1cowpea row) and 3 (1 sorghum row: 2 cowpea rows) were not statistically different. Results for combined grain yield are shown in table 4.4.

Land Equivalent Ratio (LER)

There were no significant differences in the LER for all the treatments and the CV % was 15.3% as illustrated in table 4.4. Treatment 3 had the highest LER of 1.0199 and treatment 2 had the lowest LER of 0.8188.

Table 4.4 Means, Mean Separations, Least Significant Differences (LSD) and Percentage Coefficient of Variance for combined grain yield and LER

Sorghum: cowpea ratio	Combined Grain Yield (kg/ha)	L.E.R.
1:1	1960b	0.8784
2:1	2031b	0.8188
1:2	1791b	1.0199
2:2	2686a	1.0009
Sole cowpeas	1061c	1.0000
Sole sorghum	3196a	1.0000
Grand mean	2121	0.953
CV%	13.7	15.3
LSD	527.9	0.265
SED	236.9	0.1189
P-value	0.001	0.474
Significance	***	ns

Soil moisture

Moisture at 40cm

There were significant differences ($p<0.001$) in soil moisture content at 40cm depth when sorghum was intercropped with cowpea at different row arrangements (Table 4.5). Treatment 2 (2 rows sorghum: 1 row cowpea) had the least soil moisture of 4.17mm whilst treatment 1 (1 row sorghum: 1 row cowpea) had the highest soil moisture of 25.17 mm. However, intercropping 1:1 was not significantly different from intercropping1 row sorghum: 2 rows cowpea which had 23.03 mm soil moisture content. Sole cowpea (treatment 5) with a soil moisture content of 19.54 mm, was not significantly different from intercropping 2:1. Sole sorghum - and treatment 2 (2 rows sorghum: 1row cowpea) were not significantly different, with soil moisture content of 14.98 mm and 13.23 mm respectively.

Moisture at 60cm

Soil moisture was significantly different ($p<0.001$) at 60cm depth. The highest soil moisture of 30.34mm was obtained from treatment 1 (1 row sorghum: 1 row cowpea) and it was not significantly different from treatments 5 (sole cowpea) and 4(2 rows sorghum: 2 rows cowpea) with a soil moisture of 29.8 mm and 27.98 mm respectively (Table 4.5). The lowest soil moisture of 22.1 mm was obtained from sole sorghum, which was not significantly different from intercropping 2 rows sorghum: 1 row cowpea with a moisture level of 24.65 mm. Treatments 4 (2 rows sorghum: 2 rows cowpea) and 3 (1 row sorghum: 2 rows cowpea) were not significantly different with soil moisture contents of 27.98 mm and 25.57 mm respectively. However, there were no significant differences between treatments 3(1 row sorghum: 2 rows cowpea) and 2 (2 rows sorghum: 1 row cowpea), with soil moisture content of 25.57 mm and 24.65 mm respectively.

Moisture at 100cm

Intercropping sorghum with cowpea at different row arrangements had significant effect ($p<0.001$) on the soil moisture content at 100cm depth. Treatment 5 with sole cowpea had the highest soil moisture of 35.1 mm whilst treatment 4 (2 rows sorghum: 2 rows cowpea) had the lowest moisture of 25.04 mm and was not significantly different from treatments 2 (2 rows sorghum: 1 row cowpea), 3 (1 row sorghum: 2

rows cowpea) and 6(sole sorghum) with 29.28 mm, 29.16 mm and 27.48 mm respectively. Treatment 1 (1 row sorghum: 1 row cowpea), with a moisture of 29.85 mm had no significant differences in soil moisture from treatments 2, 3 and 6. Results for soil moisture are illustrated in table 4.5.

Table 4.5 Means, Mean Separations, Least Significant Differences (LSD) and Percentage Coefficient of Variance for soil moisture

	Depth		
Sorghum : cowpea ratio	40cm	60cm	100cm
1:1	25.17a	30.34a	29.85b
1:2	4.17d	24.65cd	29.28bc
2:1	23.03ab	25.57bc	29.16bc
2:2	13.23c	27.98ab	25.04c
Sole cowpeas	19.54b	29.8a	35.1a
Sole sorghum	14.98c	22.1d	27.48bc
Grand mean	16.69	26.74	29.32
CV%	30.3	14.3	17.3
LSD	8.298	6.285	8.344
SED	4.122	3.122	4.145
P-value	0.001	0.001	0.001
Significance	***	***	***

Means with the same letter are not significantly different from each other in a column

*** Significance at 0.1% probability level, ** Significance at 0.01% and not significant (ns)

4.3 Discussion and Interpretation

4.3.1 Growth

Plant population at harvest is an important factor which affects final crop yield as less than optimum plant population always cause reduction in economic yield, whilst higher plant populations may result in intense competition which ultimately adversely affects plants' growth and development. The significantly different plant populations at harvest for both cowpea and sorghum show that the different row arrangements had an effect on the plant population and subsequently, on the yield. For sorghum, treatment 5 with sole sorghum (114plants/plot) had the highest yield of 2455 kgs/ha followed by treatment 4 (2 rows sorghum: 2 rows cowpea) with 88.33plants/plot and a yield of 1871 kgs/ha. Of importance to note is that, although treatments 2(2 rows sorghum: 1 row cowpea) and 4(2 rows sorghum: 2 rows cowpea) did not have significant differences in their plant populations, 87plants/plot and 88.33plants/plot respectively, their yields of 1377 kgs/ha and 1871 kgs/ha respectively were significantly different. The relatively higher yield in the 2:2 row ratio could be attributed to the higher amount of cowpea plants which would provide more nutrients by fixing more nitrogen and a higher soil moisture retention at 60cm depth (27.98mm). Sole sorghum was recorded to have comparatively higher plant population at harvest than all other row arrangements. The matter of fact is that plant population of main crop must be maintained in different types of cereal-legumes intercropping systems and intercrops may be added in additive series where there is no compromise of principal crop. Sorghum and cowpea intercropping under different row arrangements reduced the plant population of forage sorghum on per hectare basis, but resulted in an increase in combined yield at 2:2 row arrangement.

Plant height contributes a major share towards green forage yield and may be used to estimate rate of plant growth and development. There was no significant effect of intercropping arrangements on the plant heights of sorghum 4weeks after sowing and at flowering (p=0.437) and (p=0.970) respectively. Plant height is an important agronomic parameter which contributes to green forage yield of cereals including sorghum (Iqbal *et al*., 2016). There was a considerable increase in plant height of sorghum from 4 weeks after planting to flowering in all the treatments and this might be attributed to greater availability of nutrients particularly nitrogen to sorghum at this stage. The reason could be that legumes have the ability to fix atmospheric nitrogen through biological nitrogen fixation (BNF) process and as soon as BNF process becomes fully functional, then legumes can full fill a greater part of their nitrogen requirement on their own and resultantly more soil nitrogen becomes available to cereals (Egessa *et al.,* 2016). As there was comparatively less increase in plant height of sorghum during first 30 days, it showed the dependence of forage sorghum and legume intercrops on soil nitrogen. Similar results were reported by Rathore *et al*. (2012), who found sorghum more competitive than legumes particularly soybean but its plant height was reduced by intercrops particularly at early growth stages. Although there were no significant differences in the plant heights of sorghum, it is interesting to note that at 4weeks after planting, sole sorghum had the mean plant height of 55.33 cm whilst treatment 2 (2 rows sorghum: 1 row cowpea) had 51.67 cm whereas at flowering, treatment 2 had the highest mean plant height of 150.1 cm whilst sole sorghum had the lowest mean plant height of 147.2 cm. This could be due to the competition for nutrients among plants in the sole crop compared to the plants in the 2:1 row arrangement.

Leaves are the most important part of crops as they are the major source of photosynthetic nutrients required for plant growth and subsequently, for yield and contribute greatly to forage/fodder and are highly relished by livestock along with being rich source of protein, fats and other minerals as compared to other plant parts. Leaf area per plant is considered to be a crucial factor because leaves are the natural factories to convert water and carbon dioxide into glucose in the presence of sunlight. Leaves serve as a source for carbohydrates for sinks and play an important role in maintaining source-sink relationship. There were no significant differences on the leaf area for all the treatments. However, treatment 3 (1 row sorghum: 2 rows cowpeas) had the largest leaf area of 527.5 mm and this could have been as a result of little competition between the sorghum plants. This higher leaf area per plant might be due to better water use efficiency as well as complimentary use of nutrients by sorghum and cowpea. Days to flowering of both cowpea and sorghum were non-significant ($p<0.726$ and $p<0.951$ respectively).

4.3.2 Yield and Yield Components

Cowpea

The results of cowpea yield and yields components as affected by intercropping arrangements are shown in table 4.2. Although there were no significant differences in the number of pods per plant, the arrangement of 1:1 obtained a higher number of pods per plant, 18.53 pods per plant. This may be due to considerably high moisture contents in intercropped treatments over pure stand crops, especially at 40 cm and 60 cm depths as well as a minimum competition of one row sorghum plants to the grown cowpea plants as compared to other treatments. The results are the same as the ones obtained by Naim *et al.,* (2013) who found out that for attaining higher total crop yield per unit area of land, the practice of planting one row of sorghum alternated with one row of local cowpea (1:1) is a better mixture over sole cropping. The spatial arrangement had no significant effect on number of seeds per pod. This was mainly due to the absence of sorghum competition. The same findings were reported by Naim *et al.,* (2013) and Surve & Arvadia (2012). However, row arrangement had a significant effect ($p<0.001$) on cowpea seed yield with sole cowpea giving the highest yield (1060.5 kg/ha) followed by treatment 3 (1 row sorghum: 2 rows cowpea) with 729.2 kgs/ha. These observations agree with the earlier results of Muleba & Ezumah,

(1985) who reported that the competitive effect of sorghum on yield of cowpea under the mix cropping system could lead to low yield of cowpea seeds.

Sorghum

The results of sorghum yield and yield components as affected by intercropping arrangement are shown in table 4.3. The unshelled 10 head weight and shelled 10 head weight was significant, $p<0.027$ and $p<0.043$ respectively with the largest 10 head weight (1080.7 g) obtained from the 2:2 arrangement and the lowest (763.3g) obtained from sole cowpea. There were no statistical differences between the 2:2 and 1:1 arrangements. This could be due to absence or reduction of competition from one row cowpea plants to sorghum plants. Moreover, it could be due to the considerable high soil moisture content of intercropped treatments over that of pure stand crops since statistically, the 1:1, 2:1 and 1:2 arrangements were the same. Similar results were reported by Naim *et al*., (2013) and Ma *et al.,* (2004). However, intercropping at different row arrangements did not have an effect on the shelling percentage across the treatments ($p=0.701$).

Intercropping sorghum with cowpea at different row arrangements had a highly significant effect on the yield per hectare of sorghum with sole sorghum giving the highest yield of 2455kgs/ha. Treatment 2 with 2rows of sorghum and 2rows of cowpea had the second highest yield of 1871kgs/ha and this could be attributed to good root nodulation of cowpea (Morel et al., 2012), water conservation by the enhanced canopy cover, and improved mineral resourcing by the colonization of the roots of the plants by mycorrhiza, reduced weed development and the pest repellent effect by the cowpea (Shuaibu, 2015). The poor yield of 824kgs per hectare given by treatment 3 (1row sorghum: 2rows cowpea) could be due to the low plant population compared to the other treatments.

Intercropping at different row arrangements had a highly significant effect on the combined grain yield ($p<0.001$) of sorghum and cowpea. The highest combined grain yield was obtained from sole sorghum (3196 kgs/ha) which was statistically the same as the 2:2 arrangement. This however, was different from results obtained by Naim *et al*., (2013), who obtained a higher yield of 1078.94 kg/ha from the 1:1 arrangement. This could be related to the contribution of cowpea in soil moisture retention and low competition to sorghum plants for nitrogen through its capability of fixing its own nitrogen. This was could be attributed to higher number of panicles/m^2, higher panicle weight and finally to a better and high grain yield for sorghum in the 2:2 arrangement and no competition at all with cowpea in the sole sorghum treatment.

4.3.3 LER

The values of the land equivalent ratio (LER) indicate that there is no advantage of intercropping over pure stands. The intercropping patterns of 1 Sorghum: 2 Cowpea, 2 Sorghum: 2 Cowpea, sole cowpea and sole sorghum had LERs of 1.0199, 1.009, 1.000 and 1.000 respectively. The 1 Sorghum: 1 Cowpea and 2Sorghum: 1 Cowpea arrangements had LERs of 0.8784 and 0.8188 respectively which shows that intercropping at those arrangements have an adverse effect on the crops. These results are different from those obtained by Rathore (2015), where sorghum was intercropped with cowpea, and the 2:2 and 1:1 row ratios resulted in the highest LER. In another study by Oseni (2010), intercropping sorghum and cowpea under different row proportions, a better land equivalent ratio (LER) was obtained from the 2:1 row proportion as compared to other planting patterns. Similar results were obtained by Tajudeen, (2010 and Surve *et al*., (2011). However, the low LER values may be attributed to the very low rainfall received during the season which had an effect on the yield of the crops. The cumulative rainfall received from December to April was 431 mm, with the highest amount of 237.5 mm received in January. For both cowpea and sorghum which took an average of 59 days and 71 days to flower, the rainfall amount received in February was 74.5 mm which was very low and not adequate to sustain flowering, pod formation and grain formation and filling. In April, only 37 mm of rainfall were received. This could have contributed to the relatively low yields and hence, low LER.

CHAPTER 5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter seeks to explain the summary of the study, conclusions that the researcher made and also recommendations to any project related to this. The discussions will be based and limited to the study findings that the researcher analyzed in the previous chapter.

5.2 Discussion

Intercropping sorghum with cowpea at different row arrangements had a highly significant effect on the yield per hectare of sorghum with sole sorghum giving the highest yield of 2455kgs/ha. Treatment 2 with 2rows of sorghum and 2rows of cowpea had the second highest yield of 1871kgs/ha and this could be attributed to good root nodulation of cowpea. The values of the land equivalent ratio (LER) indicate that there is no advantage of intercropping over pure stands. The intercropping patterns of 1Sorghum: 2Cowpea, 2Sorghum: 2Cowpea, sole cowpea and sole sorghum had LERs of 1.0199, 1.009, 1.000 and 1.000 respectively. The 1Sorghum: 1Cowpea and 2Sorghum: 1Cowpea arrangements had LERs of 0.8784 and 0.8188 respectively which shows that intercropping at those arrangements have an adverse effect on the crops. The low LER values could be as a result of the very ineffective rainfall received during the growing season, especially from 4weeks after planting to dough formation. There were significant differences in plant populations at harvest for both cowpea and sorghum and this showed that the different row arrangements had an effect on the plant population and subsequently, on the yield. For sorghum, treatment 5 with sole sorghum (114plants/plot) had the highest yield of 2455kgs/ha compared to the intercropped treatments followed by treatment 4 (2rows sorghum: 2rows cowpea) with 88.33plants/plot and a yield of 1871kgs/ha. Although there were no significant differences in the number of pods per plant, the arrangement of 1:1 obtained a higher number of pods per plant, 18.53pods per plant. This may be due to considerably high moisture contents in intercropped treatments over pure stand crops, especially at 40cm and 60cm depths as well as a minimum competition of one row sorghum plants to the grown cowpea plants as compared to other treatments.

5.3 Conclusion

Although there were no significant differences in the LER obtained from all row arrangements, the practice of planting 2 rows of sorghum to 2 rows of cowpea is the better practice for attaining higher total crop yield per unit area of land. This is also allows for better income through the sales of both crops. In addition, it allows farmers to have a variety of nutrition sources and hence, enhanced food and nutrition security for both humans and livestock compared to mono cropping of sorghum or cowpea alone.

5.4 Implications

The results show that planting of both crops will result in higher combined yields. This results in considerable yield for both crops is noted resulting in improved food security, improved income for the grower from both crops and saves land and space.

5.5 Recommendations

The following are the recommendations the researcher has made: Intercropping sorghum with cowpea at 2:2 row ratio as this will give the farmer considerable yields; There is need to plant with the onset of the first effective rains to maximize water use and To have a better yield, there is need for close monitoring and scouting for pests as well.

5.6 Suggestions for Further Research

There is need for considering intercropping at different row arrangements different varieties of sorghum and cowpea to determine the varieties that better complement each other. In addition, there is need to conduct the trial using different plant population and planting dates over more years. In addition, other row arrangements for sorghum-cowpea intercropping systems such as 1:1, 3:1, 3:2, 3:3 and 2:3 can be evaluated, factoring in row spacing such as 40 or 50 cm spaced rows along with strip intercropping. Sorghum-legumes intermingling of roots and transfer of nitrogen from legumes to sorghum also need to be tested in field conditions. Furthermore, effect of cereal-legumes intercropping on nodule formation and quantity of nitrogen fixed by legumes under varied soil and agro-climatic conditions may be assessed.

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APPENDICES

Appendix 1: List of treatments used

TREATMENT	ROW ARRANGEMENT
T1	One row of sorghum alternated with one row of cowpea (1:1).
T2	Two rows of sorghum alternated with one row of cowpea (2:1).
T3	One row of sorghum alternated with two rows of cowpea (1:2).
T4	Two rows of sorghum alternated with two rows of cowpea (2:2).
T5	Sole cowpea rows.
T6	Sole sorghum rows.

Appendix 2: Analysis of variance table for land equivalent ratio (LER)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.01460	0.00730	0.34	
Reps.*Units* stratum					
treatment	5	0.10431	0.02086	0.98	0.474
Residual	10	0.21220	0.02122		
Total	17	0.33111			

Appendix 3: Analysis of variance table for total grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	11846.	5923.	0.07	
Reps.*Units* stratum					
treatment	5	8227962.	1645592.	19.55	<.001
Residual	10	841892.	84189.		
Total	17	9081700.			

Appendix 4: Analysis of variance table for sorghum grain yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	32193.	16096.	0.39	
Reps.*Units* stratum					
treatment	4	4865342.	1216336.	29.84	<.001

Residual	8	326141.	40768.		
Total	14	5223676.			

Appendix 5: Analysis of variance for sorghum seed density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.200	0.600	0.19	
Reps.*Units* stratum					
treatment	4	69.600	17.400	5.61	0.019
Residual	8	24.800	3.100		
Total	14	95.600			

Appendix 6: Analysis of variance table for sorghum shelling percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	170.65	85.32	5.56	
Reps.*Units* stratum					
treatment	4	34.09	8.52	0.56	0.701
Residual	8	122.71	15.34		
Total	14	327.45			

Appendix 7: Analysis of variance table for sorghum shelled 10 head weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	29876.	14938.	3.47	
Reps.*Units* stratum					
treatment	4	70539.	17635.	4.09	0.043
Residual	8	34455.	4307.		
Total	14	134869.			

Appendix 8: Analysis of variance table for unshelled 10 head weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	4638.	2319.	0.22	
Reps.*Units* stratum					
treatment	4	202831.	50708.	4.88	0.027
Residual	8	83108.	10389.		

Total	14	290578.			

Appendix 9: Analysis of variance table for sorghum number of plants per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	476.4	238.2	1.87	
Reps.*Units* stratum					
treatment	4	6660.7	1665.2	13.05	0.001
Residual	8	1020.9	127.6		
Total	14	8158.0			

Appendix 10: Analysis of variance table for sorghum for leaf area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1371.	685.	0.23	
Reps.*Units* stratum					
treatment	4	17413.	4353.	1.45	0.304
Residual	8	24063.	3008.		
Total	14	42847.			

Appendix 11: Analysis of variance table for sorghum days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.200	0.600	0.42	
Reps.*Units* stratum					
treatment	4	0.933	0.233	0.16	0.951
Residual	8	11.467	1.433		
Total	14	13.600			

Appendix 12: Analysis of variance table for sorghum plant height at flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	378.13	189.07	5.62	
Reps.*Units* stratum					
treatment	4	16.71	4.18	0.12	0.970

Residual	8	269.31	33.66		
Total	14	664.15			

Appendix 13: Analysis of variance table for sorghum plant height 4weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	39.216	19.608	3.34	
Rep.*Units* stratum					
treatment	4	24.789	6.197	1.06	0.437
Residual	8	46.971	5.871		
Total	14	110.976			

Appendix 14: Analysis of variance table for cowpea grain yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	27345.	13672.	0.80	
Reps.*Units* stratum					
treatment	4	1390736.	347684.	20.25	<.001
Residual	8	137340.	17168.		
Total	14	1555421.			

Appendix 15: Analysis of variance table for cowpea number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.733	0.867	0.18	
Reps.*Units* stratum					
treatment	4	12.667	3.167	0.65	0.642
Residual	8	38.933	4.867		
Total	14	53.333			

Appendix 16: Analysis of variance table for cowpea number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.94	0.97	0.03	
Reps.*Units* stratum					
treatment	4	116.04	29.01	0.96	0.478
Residual	8	241.34	30.17		
Total	14	359.32			

Appendix 17: Analysis of variance table for cowpea number of plants per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	571.6	285.8	2.04	
Reps.*Units* stratum					
treatment	4	25197.7	6299.4	44.87	<.001
Residual	8	1123.1	140.4		
Total	14	26892.4			

Appendix 18: Analysis of variance table for cowpea days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	34.53	17.27	1.29	
Reps.*Units* stratum					
treatment	4	27.60	6.90	0.52	0.726
Residual	8	106.80	13.35		
Total	14	168.93			

Appendix 19: Analysis of variance table for soil moisture 400mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	301.91	150.96	5.92	
rep.*Units* stratum					
treat	5	3503.72	700.74	27.49	<.001
Dummy_reps	3	211.93	70.64	2.77	0.052
treat.Dummy_reps	15	23.13	1.54	0.06	1.000
Residual	46	1172.60	25.49		
Total	71	5213.29			

Appendix 20: Analysis of variance table for soil moisture 600mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	544.78	272.39	18.63	
rep.*Units* stratum					
treat	5	613.62	122.72	8.39	<.001
Dummy_reps	3	14.84	4.95	0.34	0.798
treat.Dummy_reps	15	60.27	4.02	0.27	0.996
Residual	46	672.64	14.62		
Total	71	1906.15			

Appendix 21: Analysis of variance table for soil moisture 1000mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	40.08	20.04	0.78	
rep.*Units* stratum					
treat	5	664.73	132.95	5.16	<.001
Dummy_reps	3	58.71	19.57	0.76	0.523
treat.Dummy_reps	15	111.76	7.45	0.29	0.994
Residual	46	1185.59	25.77		
Total	71	2060.87			

Appendix 22: Table of means for moisture at 400mm depth

Grand mean 16.69

treatment	1	2	3	4	5	6
	25.17	4.17	23.03	13.23	19.54	14.98

Dummy_reps	1	2	3	4	day
	18.63	18.04	15.65	14.43	

treatment	Dummy_reps	1	2	3	4	day
1		26.43	26.70	23.77	23.77	
2		7.17	5.63	2.53	1.33	
3		24.27	24.60	21.97	21.30	
4		14.90	14.93	12.67	10.40	
5		22.27	20.70	18.93	16.27	
6		16.73	15.67	14.03	13.50	

Appendix 23: Table of means for moisture at 600mm depth

Grand mean 26.74

treatment	1	2	3	4	5	6
	30.34	24.65	25.57	27.98	29.80	22.10

Dummy_reps	1	2	3	4	day
	27.48	26.52	26.68	26.27	

treatment	Dummy_reps	1	2	3	4	day
1		30.70	30.90	30.10	29.67	
2		25.13	25.70	24.17	23.60	
3		26.80	22.40	26.40	26.67	
4		28.60	28.97	28.07	26.27	
5		30.20	30.13	29.40	29.47	
6		23.47	21.00	21.97	21.97	

Appendix 24: Table of means for moisture at 1000mm depth

Grand mean 29.32

treatment	1	2	3	4	5	6
	29.85	29.28	29.16	25.04	35.10	27.48

Dummy_reps	1	2	3	4	day
	30.12	30.28	28.17	28.71	

treatment	Dummy_reps	1	2	3	4	day
1		28.77	32.00	28.77	29.87	
2		30.30	30.60	28.23	28.00	
3		29.37	30.30	28.60	28.37	
4		25.80	23.30	23.90	27.17	
5		36.30	35.53	33.60	34.97	
6		30.20	29.93	25.90	23.90	