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GROWTH AND YIELD RESPONSE OF COWPEA (*Vigna unguiculata* L. Walp.) TO DIFFERENT ROW SPACINGS AND FREQUENCY OF WEEDING IN NYAKOMBA, NYANGA NORTH

BY

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Abstract

Cowpea (*Vigna unguiculata* (L) Walp) is an important legume grown in the semi-arid areas of sub-Saharan Africa. It is a deep rooted hardy crop with good drought tolerance and fixes atmospheric nitrogen through symbiosis with nodule bacteria thereby improving soil fertility. In Zimbabwe, cowpea it is the most commonly grown pulse in communal areas. The major problem encountered by farmers in Zimbabwe is the interference of weeds within the crop, due to the fact that planting is done in wide spacing and cowpea has an initial slow growth. During the rainy season weeds come in two to three flushes and compete with cowpeas for nutrients, space, and light. There is inadequate information on the critical time of weed removal in cowpeas hence the need to address this problem in Nyanga north. The major objective of the research was to evaluate the effects of row spacing and frequency of weeding on cowpeas growth and yields under rain fed conditions at Nyakomba in Nyanga. The specific objectives were to; (i) determine the effects of weeds on growth of cowpea as influenced by row spacing, and (ii) determine the effects of weeds on yield of cowpea as influenced by frequency of weeding and spacing. Two experiments were conducted at Nyakomba Irrigation scheme. Both experiments were laid in a Randomized Complete Block Design (RCBD). Some 200kg/ha compound D basal fertiliser was applied at planting. The semi-determinate Cowpea variety CBC 2 was used at a seed rate of 30kg/ha. Experiment one comprised of 9 treatments with three spacings used namely; 75cm*15cm, 60cm*15cm and 45cm*15cm. Experiment 2 comprised of 8 treatments namely; one hand weeding and hoeing at 2WAE, one hand weeding and hoeing at 3WAE, One hand weeding and hoeing at 4WAE, two hand weeding and hoeing at 2 and 5WAE, weed-free check and weedy check. The insecticide Acetamiprid was used to control aphids. Data collected included plant height, number of leaves per plant, number of branches per plant, days to 50% flowering, days to 90% maturity, number of pods per plant, number of seeds per pod, 100 seed weight, aboveground dry biomass yield, harvest index, grain yield for both experiments. From experiment one it was concluded that row spacing of 45cm*15cm had greater mean number of leaves (81.067), mean aboveground dry biomass yield (6785.2 kg/ha) and mean grain weight (2.8000t/ha). From Experiment two, it was concluded that two hand weedings and hoeing at 2 and 5 WAE had a great mean aboveground biomass yield (6440.0 kg/ha) mean yield (2.440 t/ha) and yield loss of 12.920%. It can be recommended that spacing of 45cm *15cm and weeding at 2 and 5 WAE should be adopted by farmers in Nyanga north.

Key words: cowpea, row spacing, weeding frequency

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.

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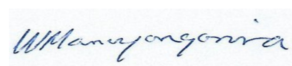
Walter Manyangarirwa	 09/03/21
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Dedication

This dissertation is dedicated to my family, wife Gladys and daughter Caroline for the immense support financially, love, prayers and encouragement they gave me during the course of this study.

List of Acronyms and Abbreviations

ANOVA	Analysis of variance
AUREC	Africa University Research Ethics Committee
BNF	Biological Nitrogen Fixation
DAE	Days after emergence
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organisation Corporate Statistical Database
HI	Harvest Index
IITA	International Institute of Tropical Agriculture
NASA	National Aeronautical and Space Administration
RCBD	Randomized Complete Block design
RWD	Relative Weed Density
SADC	Southern African Development Community
WAE	Weeks after emergence

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is an important leguminous crop grown predominantly in the tropics and is suited to semi-arid areas of sub-Saharan Africa where other food legumes are not well suited (Sankie, Addo-Bediako, & Ayodele, 2012). It is a deep rooted hardy crop (Dadson, Hashem, Javaid, Joshi & Allen, 2003). Adaptation mechanisms such as turning of leaves upwards to reduce heat stress and closing of stomata help to give it drought tolerance (Sankie *et al*., 2012). These characteristics have made cowpea an important component of subsistence agriculture in the semi-arid tropics of Africa, Latin America, and Southeast Asia.

Cowpea is an annual herbaceous summer crop that exists in a variety of forms. It can be upright or spreading. The upright type can take three months to whilst the spreading types can take up to five months to mature. Cowpeas form an important human diet especially among poor families who cannot afford animal protein (Mbwaga, Hella, Mligo, Kabambe & Bokos, 2010). Its importance is largely based on its use as a short season protein rich grain crop for human and livestock consumption. It has the ability to fix atmospheric nitrogen through symbiosis with nodule forming bacteria thereby improving soil fertility (Shiringani & Shimeles, 2011).Cowpeas is referred to as the "hungry-season crop" given that it is the first crop to be harvested before cereal crops are ready (Madamba, 2000). Cowpea leaves can be harvested for direct use as needed during times of food scarcity while the end of season collection of above ground biomass after harvest provides valuable livestock feedstock as fodder either for direct use or as a transportable commodity for sale or barter (Singh & Tarawali, 1997). Most farmers in

Africa grow cowpea intercropped with sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), maize (*Zea mays*), cassava (*Manihot esculenta*) or cotton (*Gossypium* spp.) (Madamba, 2000).

1.2 Background to the Study

Cowpea has the ability to fix atmospheric nitrogen through symbiosis with nodule bacteria thereby improving soil fertility (Shiringani & Shimeles, 2011). In Africa, yields are estimated at about 250 to 300kg/ha. In Asia and Latin America, yields are 400 to 500kg/ha and in the USA, yields are 600 to 800kg/ha (IITA, 1989). The total area under cowpea in the small holder communal in Zimbabwe was estimated to be at 3137 ha in 2002 and it is most commonly grown pulse in the communal areas (Greenberg, 2000).

The major problem encountered by farmers in Zimbabwe is the interference of weeds with the crop, due to the fact that planting is done in wide spacing and cowpea has an initial slow growth. The problem is more serious during the rainy season because weeds come in 2-3 flushes and growth is very fast competing for nutrients, space, and light. Weeds also harbor pests and diseases and intercept pesticides reducing their effectiveness. Weeds contaminate harvested produce thus reducing quality. Yield losses caused by weeds alone in cowpea production can range from 25% to 76% depending on the cultivar and environment (Gupta, Gupta and Rani, 2016). Similarly, (Freitas, Medeiros, Grangeiro, Silva, Nascimento & Nunes, 2009) also reported that weed interference in cowpea not only reduced the final stand but also the number of pods per plant, and grain yield by 90%.

The critical period of weed competition in cowpea has been identified as 20-30 Days After Sowing (DAS) and the presence of weeds beyond this period causes severe reduction in yields (Gupta *et al*., 2016, Akobundu, 2005). In this regard, weed control needs to be undertaken during the initial period of crop growth. The types of weeds, weed density, their persistence, the environment, stage of crop growth, duration of crop exposure to weeds and crop management determine the magnitude of yield loss (Osipitan, Adigun & Kolawole, 2016). Weeds compete with the crop right from germination to harvest, affecting the crop yield adversely (Yadev, Joon & Singh, 1998). Apart from direct effect on yield and quality reduction, common weed species such as *Portulaca oleraceae*, *Solanum nigrum* (L) and *Amaranthus spinosus* (L) have been reported to serve as reservoir hosts for various pests and diseases (Alegbejo, 1987). Weeds cause a lot of problems in cowpea production and these include reduction in crop yield, less efficient land use, higher cost of production as a result of insects and plant disease control, reduction in crop quality, water management problems, and less efficient utilisation of labour (Mekonnen, Sharma, Lisanework & Tamado, 2015). Hand weeding is the most widely used physical weed control method in cowpea. Reports have shown that two timely hand weeding within first 30 to 40 Days After Emergence (DAE) are necessary to minimize weed competition in cowpea (Osipitan, Adigun, Lagoke & Afolami, 2013). (Fadayomi, (1979) also showed that hand weeding for three times within 42 days of crop growth gave yield similar to plots that are kept weed-free. Thus, weeds can be controlled by using appropriate planting pattern and frequency of weeding.

There are numerous constraints on the production of cowpea and one of them can be cited as row spacing recommendations. Poor yields are obtained due to inter-and intra - specific competition. As plant density increases competition between plants becomes severe. Masa, Tana & Ahmed, (2017) postulated that one way of increasing yield is through maintaining appropriate plant population through different planting patterns. Planting pattern (row spacing) has a significant impact on radiation interception and utilization of moisture from the soil (Ihsanulla, Hayat, Habib, Abdul & Noor, 2002). Matthews Armstrong, Lisle, Menz & Shephard (2008) reported that plant density has an effect on early ground cover, competitive ability of crops with weeds, soil surface evaporation, light interception, lodging and development of an optimum number of fruiting sites in a crop canopy. Plant density also has a significant effect on canopy development, plant architecture and distribution of pods. Selecting optimal row spacing is important to improve crop productivity as plants growing in rows that are too wide may not efficiently utilize light, water, and nutrient resources. Hussain, Mehmood, Khan, Farooq & Lee (2012) noted that crops grown in too narrow rows may result in severe inter-row competition and row spacing also modifies plant architecture, photosynthetic competence of leaves, and dry matter partitioning in several field crops. One of the widely researched cultural methods that could potentially provide weed suppression and increase cowpea yield is row spacing. Grain legumes planted with narrow spacing generally have quicker ground cover that provides shade for weed suppression (Mekonnen Negatu, Sharma & Tana, 2017). Variation in within intra-row-spacing has been shown to have less influence on grain yield of cowpea than differences in inter-row spacing (Adigun, 2002; Chattha, Jumai & Mahmood, 2007). Thus the current study was carried out to evaluate the effect of row spacing and frequency of weeding on the growth and yield of cowpea.

1.3 Statement of the problem

Smallholder farmers in Zimbabwe produce crops in diverse ecosystems but continue to register low yields even below the genetic potential of crops and they continue to experience persistent poverty and food insecurity (Athanase, Tenywa, Makooma, Okiror, Leonidas, Mupenzi & Augustine, 2013). Cowpea has multiple roles for humans, the environment and livestock. To humans it provides food security, nutrition and livelihoods. Farmers are faced with several problems with regard to increasing the yield of cowpeas because they have limited knowledge on how to solve is a problem. Smallholder farmers also lack an understanding of how best to tackle constraints to productivity. Smallholder farmers lack relevant knowledge, information, proper training and access to research findings which can enhance their farming activities. Their failure to realize the impacts of weeds on their farm lands poses constraints in attaining good yields.

Failure by farmers to address cultural practices in cowpea production particularly weed management and row spacing has led to reduced cash income and malnutrition among rural communities. There are several crop production constraints and among them is poor plant spacing and weed management that substantially lowers grain yield. Improper plant spacing leads to crops suffering from insufficient light, space, water and nutrition hence aerial and underground growth is severely affected leading to low yields. Failure to effectively control weeds which cause invisible damage to crops unlike pests and diseases has continued to add weed seeds to the weed seed bank posing great dangers to crop productivity. Weeds compete with crops for light, space, water, carbon dioxide and competition starts at germination of the crop and continues until maturity. There is inadequate information on the critical time of weed removal and proper row spacing in cowpea among farmers in Nyanga north hence the need to address this problem.

1.4 Research objectives

1.4.1 Main objective

The major objective of the study was to evaluate the effects of weeds on growth and yield as influenced by row spacing and frequency of weeding in cowpeas under rain fed conditions during the 2019/20 season at Nyakomba Irrigation Scheme (17.791035 S, 32.976 160 E) in Nyanga north .

1.4.2 Specific objectives

The specific objectives of the study were to;

(i) determine the row spacing on cowpea yield.

(ii) determine the weeding frequency on cowpea yield.

1.5 Research Questions

The study was guided by the following research questions;

(i) What is the effect of row spacing on weed density and subsequent growth and yield of cowpea ?.

(ii) What is the effect of different frequencies of weeding on the growth and yield of cowpea?.

1.6 Hypotheses tested

The study was guided by the following hypotheses:

(i) Growth and yield of cowpeas is influenced by row spacing .

(ii) Frequency of weeding in cowpeas has an effect on the growth and yield of cowpeas.

1.7 Significance of the study

The research findings sought to improve the yields of cowpeas in rural areas through proper row spacing and weed control. Ghadiri & Bayat (2004) reported that the ability of plants to reduce weed dry weight was further enhanced in medium (60 cm) and narrow (45 cm) inter-row spicing compared to wide rows (75 cm) in Pinto bean (*Phaseolus vulgaris* L.). This experiment sought to generate more information and knowledge on the best row spacing and weeding frequencies. The information is also important in other crops which are closely related to cowpeas like dry beans, and soya beans. Farmers will benefit from appropriate knowledge that will be essential in ensuring food security in this period of climate change. Farmers will improve their livelihoods by selling the surplus to generate more income.

1.8 Delimitation of the Study

The research was conducted at Nyakomba Irrigation scheme (17.791035 S, 32.976 160 E) in Nyanga North. Data collection was limited to the period from December 2019 to March 2020.

1.9 Limitations of the Study

The study was slightly affected by a mid-season dry spell that was encountered at Nyakomba Irrigation scheme during the month of January 2020.

CHAPTER 2 REVIEW OF LITERATURE

2.1 Introduction

Cowpea is a legume that originated in Africa and is grown widely worldwide with the highest production in Nigeria, Sudan, and Asia. It is an annual summer crop that is drought tolerant, due to its extensive root system, and grows on a wide range of soils but prefers sandy soils and survives on low nutrition. Both people and livestock benefit from cowpea. Green leaves, pods, grain and pounded grain are consumed by people whilst the crop residue can be fed to livestock. The crop supplies appreciable amounts of protein, minerals and vitamins. Weeds compete for nutrients, space, light and water with cowpeas and can lead to yield loss of more than 70%. Weeds in cowpea can be controlled with physical and cultural among the majority of smallholder farmers in Zimbabwe. Spacing and weeds have significant effects on growth and yield of cowpea (Madamba, 2000).

2.2 Cowpea Taxonomy

Cowpea belongs to the class *Dicotyledonae,* order *Fabales,* family *Fabaceae,* sub-family *Papilionoideae,* tribe *Phaseoleae*, sub tribe *Phaseolinae* and genus *Vigna,* section *Catiang* and species *unguiculuta* (Padulosi & Ng, 1997). Cowpea is one of the common names in English. Other common cowpea names are Bachapin bean, Black-eyed pea, Black eye bean Crowder pea, China pea and Cowgram and Southern pea. It is also known internationally as Lubia, or frijolcaupi, feljao caupi. Cowpeas are classified into five cultivar groups namely: *biflora, melanophthalmus*, *sesquipedalis*, *textilis* and *unguiculata*.

2.3 Origin and distribution of cowpea

The cowpea was first domesticated in Africa between 1500 to 1700. (Singh, 2014), and all cultivated varieties grown in the world today originated from West and East Africa (Xiong, 2016). The exact origin of cultivated cowpea has been a controversy for many years as other scholars believe that Asia and Africa could be independent centres of origins for the crop. Early observations showed that cowpeas present in Asia are very diverse and morphologically different from those growing in Africa (Timko & Singh, 2008). Other literature indicates that although domestication occurred in West Africa, Southern Africa is the center of origin, also the distribution of diverse wild cowpea from Ethiopia to South Africa lead to the proposition that East and Southern Africa are primary centers of diversity, also West and Central Africa are secondary centers of diversity (Padulosi & Ng, 1997). Other scientist believe that its origin can be traced to Ethiopia because both wild and cultivated species are abound in this region (Fatokun, Tarawali, Singh, Kormawa & Tamo, 2002). Cowpea is grown in more than two-thirds of the third world countries as a relay crop with major cereals (Tarawali, Singh, Peters & Blade, 1997). The greatest genetic diversity in wild relatives of cowpea has been found in southern Africa in a region encompassing Namibia from the west, across Botswana, Zambia, Zimbabwe and Mozambique to the east, and South Africa and Swaziland to the south (Padulosi & Ng, 1977). This genetic diversity includes many primitive traits that were lost in domestication such as perennially, hairiness, small size of seeds and pods, hard seeds, pod shattering and outbreeding. The South African Transvaal may have been the centre of speciation of *Vigna unguiculata* due to the presence of the most primitive subspecies (Padulosi & Ng, 1997).

2.4 Geographical distribution

Cowpea is cultivated predominantly in Africa and is grown for food, fodder and green manure. Production has expanded the world over the past decades and in 2017, over 87% of the crop was produced in Africa. In South America, Brazil showed a recent increase in cowpea cultivation placing the country in third place in terms of global area and production (FAOSTAT, 2019). The top ten performers in 2017 were Nigeria, Niger, Brazil, Burkina Faso, Tanzania, Cameroon, Myanmar, Kenya and Sudan (FAOSTAT, 2019). The majority of the world's cowpea production takes place in Sub-Saharan Africa with about 12.5 million hectares under cultivation worldwide in 2014 (Singh, Khajuria, Gill & Lal, 2002). Sub-Saharan Africa dominates in cowpea production with 96% area share, producing about 4.9 million tons per year. The largest producer of cowpea is Nigeria that holds 3.1 million ha of land under cowpea, producing 2.5 million tons in 2008–10. Niger follows behind in production although it holds a higher share of land area than Nigeria due to a low yield level of 267 kg/ha (FAOSTAT, 2014).

2.5 Crop Description

Cowpea is a warm season, annual, herbaceous legume. Growth forms maybe erect, trailing, climbing or bushy or indeterminate under favorable conditions. It follows an epigeal emergence pattern which makes it prone to seedling injury especially when the seed bed is not firm (Shiringani, 2007). Early or late planting may lead to the crop having elongated internodes, more vegetative growth and lower yield than those planted at optimum time (Davis, Oelke, Oplinger, Doll, Hanson & Putnam, 1991). Leaves are alternate and trifoliate with a smooth surface, dull to shiny and usually dark green. Cowpea has a vigorous growth and can reach height of 48-61 cm for determinate varieties and 2m for climbing cultivars. Stems are striate, smooth or slightly hairy, sometimes tinged with purple (Aveling, 1999)

It is an annual herb with a strong tap root and extensive lateral roots in surface soil. The long taproot, can reach a maximum effective rooting depth of about 2.4 m within eight weeks after planting, especially if drought conditions prevail. The root system has large nodules which are more extensive than those of soya bean. The root nodules are smooth and spherical, about 5mm in diameter, and are numerous on the tap root and its main branches, but sparse on the smaller roots (Madamba, 2000).

Flowers are self-pollinating and may be white, dirty yellow, pink, pale blue or purple in colour. They are arranged in raceme or intermediate inflorescences in alternate pairs. Flowers open in the early day and close at approximately midday and after blooming they wilt and collapse. Pollinating insect activities are beneficial in increasing the number of pods set, the number of seeds per pod or both. However, there are no recommendations for the use of pollinating insects on cowpeas (McGregor, 1976). Under short day photoperiod flowering takes place from 33 to 90 days after planting. However, the pod filling period is relatively short, ranging from 17 to 24 days after fertilization.

Fruits, are pods that vary in size, shape, colour and texture. Pods occur in pairs forming a V shape. They may be erect, crescent shaped or coiled. They are cylindrical, 6 to 20 cm long and 3-12 mm broad, usually yellow when ripe, but may also be brown or purple in colour. Initially, the seed develops into a kidney shape; when the pod is not restrictive. The seed maintains that shape until maturity (Gomez, 2004). But the pod has the tendency of restricting seed shape to a more globular shape. There are usually 8-20 seeds per pod. Seeds vary considerably in size, shape and colour. They are relatively large, 2-12 mm long and weigh 5-30 g/100 seeds. Seed shape could be reniform or globular. The testa - the coat covering the grain - may be smooth or wrinkled; white, green, red, brown, black, speckled, blotched, eyed (the hilum - central line - is white surrounded by a dark ring) or mottled in colour (Aveling, 1999). What is considered essential part of the plant in cowpea would be determined by the intended end use of the plant. A number of the plant parts could be important, that is seed, young leaves or seed and pod.

2.6 Environmental requirements for cowpea

2.6.1Temperature requirements for cowpea

Cowpea grows best in summer. Germination requires 8.5°C and 20 °C for leaf growth. It is a drought tolerant crop. Optimum temperature for growth and development is 30°C. Day length differs among varieties, some flower within 30days after sowing when grown at a temperature around 30 °C. The optimum sowing times are December to January. Early-sown crops tend to have elongated internodes, are less erect, more vegetative and have a lower yield than those sown at the optimum time

2.6.2 Water Requirements for cowpea

The crop is more drought tolerant compared to many other crops like groundnuts, soya beans and sunflower and can tolerate moderate amounts of shade. Cowpea requires sufficient water for good yield and quality of the product. The crop can produce from one to five tons of hay per hectare. The crop does not tolerate water-logging conditions which impedes nodulation and reduce yields significantly. Rainfall is important during flowering and podding stage. The crop can adapt to moisture stress by limiting leaf growth and reducing leaf area by changing leaf orientation and closing the stomata that give it drought tolerance. Flower and pod abscission occur when there is moisture stress. Drought reduces BNF. The crop needs adequate water for about 55 days (65%) of its life.

2.6.3 Soil Requirements for cowpea

Cowpea can grow on a wide range of soils but prefers sandy soils which do not limit root growth (Daffs, 2011). Cowpea tolerates infertile and acid soils compared to many crops. Cowpeas thrive in well-drained soil and less on heavy soils. It requires a soil pH of between 5.6 and 6.0 (Daffs, 2011).

2.6.4 Cultivation and Management

Cowpea is grown from seeds, broadcasted under mixed cropping or in rows 2,5cm deep and good seed soil contact is important. Seed rates when broadcasted is 50-60 kg/ha and 30-40 kg/ha when grown in pure stands. Cowpea will respond to manure or low rates of inorganic fertiliser of about 100-200kg/ha compound D. As a legume, cowpea fixes its own nitrogen, and does not need nitrogen fertiliser. The seed should be inoculated with the appropriate *Bradyrhizobium* spp. for optimum nitrogen fixation. Legumes have a high propensity for phosphorus which is essential for nodule development and optimum plant growth. In cases where the soil nitrogen is too low, a limited amount of nitrogen (starter nitrogen) should be applied to support the initial stages of crop and nodule development for N fixation. Excess nitrogen (N) should be avoided because it promotes lush vegetative growth, delays maturity, may reduce seed yield, may suppress nitrogen fixation and may make the plants more susceptible to pests and disease attacks.

2.7 Socio-economic Importance of Cowpea

In Zimbabwe cowpeas are grown for their many uses. They have a great flexibility in use (Dube & Fanadzo, 2013). Cowpeas is referred to as the "poor man's diet" or the "hungry season crop". In addition, consumption of legumes has been related to many beneficial physiological effects in stabilizing various metabolic diseases such as coronary heart disease and colon cancer (Bazzano, He, Ogden, Loria, Vupputuri, Myers & Whelton, 2001). Cowpea grains complement the grains of cereals as foods for people by enhancing the quantities and qualities of proteins and vitamins. For example, cowpea grains have substantial levels of folic acid, which is a critical vitamin for all people and especially pregnant women since it prevents the occurrence of neural tube defects such as spina bifida in infants.

Cowpea provides nutrition and livelihoods to millions of people in sub –Saharan Africa. It is consumed in many forms. Young leaves, green pods and immature seeds are used as vegetables and the dry seed is used in several forms of food preparation. Women in rural and urban centres trade fresh produce and processed cowpea products thus earning income.

2.7.1 Uses of leaves

Cowpea is the most popular leafy vegetable throughout SADC. The leaves can be boiled or fried or dried as a method of preservation. In some African countries the leaves are boiled and dried then ground into powder and stored for use in the dry season when the crop is not available. Leaves are eaten as a nutrition supplement and extension of that is supplied by the grain. Smith & Eyzaguirre (2007) listed cowpea leaves among the top indigenous leafy vegetables that are eaten on the entire African continent and they postulated that the amount of leaves eaten will increase due to rising population. Matikiti *et al.,* (2012) says that there is a high demand of cowpea leaves from Zimbabwe through Tanzania up to Nigeria. Among low income earners cowpea leaves are vital since they cannot afford animal protein (Matikiti, Chikwambi, Nyakanda & Mashingaidze, 2012). Cowpea leaves are more valuable than the seed since their protein content and protein productivity surpasses that of the seed in a dry weight basis and protein concentrations of 29-43% have been reported for cowpea leaves against 21-33% in seed (Nielsen, Ohler & Mitchell, 1997). Leaves are vital as they supply other dietary components more than seeds, 20% more thiamine, twice the amount of riboflavin and equal amounts of niacin (Bubenheim, Mitchell & Nielsen, 1990). Leaves also provide large amounts of essential amino acids, methionine and cysteine (Nielsen *et al*., 1997).

Cowpea is efficacious in treating worms in the stomach when boiled and eaten whereas an extract from the seed can be taken to treat amenorrhea (Chopra, Nayar & Chopra, 1986). The powdered roots can be added to porridge and taken to relieve menstrual pains and treat epilepsy pain in chest (Lim, 2012). The leaves can be mashed and applied on burns and the dry leaves as snuff to cure headaches (Lim, 2012). The cowpea leaves can also be used to induce vomiting in fever patients as well (Hutchings and Booth*.,* 1996). Cowpea leaves are also used by herbalists in the treatment of bilharzia (Kritzinger, Barrientos & Rossouw, 2004).

2.7.2 Importance of grain

Cowpea plays a very important subsistence role in diets of many households in Africa both urban and rural dwellers (Dube & Fanadzo 2013). The crop is grown for its edible beans despite the fact that leaves, fresh pea pod and fresh pea pods can be eaten. Cowpea grain which is highly valued for its nutritive value and short cooking time serves as a major source of proteins in the daily diets of the rural and urban poor in Africa. The crop is vital as it is a rich source of protein, calories, minerals and vitamins. The seed contains 25% protein, 50-67% starch, fat is 1.3%, fibre 1.8% and 8-9% water (Thomas, 2009). It provides nutrients that are deficient in cereal crops, such as iron, calcium and zinc. It has been reported that folic acid, a vitamin B necessary during pregnancy to prevent birth defect in the brain and spine content is found in higher quantity in cowpea compared to other plants (Timko & Singh, 2008). Singh, Chambliss & Sharma, (1997) revealed that the grain is considered nutritious as 100g dry weight of it contains 23.5mg proteins, 1.3mg fat, 60.0 mg carbohydrate, 10.6mg fibre, 110mg Ca, Mg 184mg, 424mg P, 8.3mg Fe, 3.4mg Zn, 50 IU vitamin A, 0.85mg thiamin, 0.23 riboflavin, 2.1mg niacin, 0.36 mg vitamin B6, 633 µg folate and 1.5mg ascorbic acid.

The seeds contain proteins that are rich in amino acids, lysine, leusine, arguinine and tryptophan, but they lack methionine and cysteine when compared with animal protein. However cowpea are low in the sulphur amino acids (methionine and cysteine) compared to cereals and animal products and thus for a balanced diet cowpea needs to be supplemented with cereals or vegetables, meat and or dairy products (Iqbal, Khalil, Ateeq & Beauchat, 2006). The protein in grain legumes like cowpea has been shown to reduce low-density lipoproteins that are implicated in heart diseases (Phillips, Mcwatters, Chinna, Hung, Beauchat, Sefadeh, Sakyi-Dawson, Ngoddy, Nnanyelugo & Enwere, 2003). Also the grain legume starch is digested more slowly than the starch from cereals and tubers; it produces fewer abrupt changes in blood glucose levels following consumption (Phillips *et al*., 2003). Protein isolates from cowpea grains have good functional properties, including solubility emulsifying and foaming activities (Rangel, Saraiva, Schwengber, Narciso, Domont, Ferreira & Pedrosa,, 2004) and could be a substitute for soy proteins isolates for persons (especially infants) with soy proteins allergies.

Cowpea seed is therefore, valued as a nutritional supplement to cereals. Combining cowpea with a cereal crop, e.g. rice or maize meal, one can make food with a near-complete or a balanced set of nutrients. In Zimbabwe seeds can be boiled together with dried maize (mutakura) and consumed or can be ground into powder and cooked into porridge (rupiza) and used as relish (Matikiti *et al.,* 2012). Because of its superior nutritional attributes, versatility, adaptability and productivity, cowpea was chosen by NASA in the USA, as one of the few crops worthy of study for cultivation in space stations (Bubenheim *et al*., 1990). Cowpea contains some anti-nutritional factors that includes oligosaccharides, phytic acid, polyphenols, protease inhibitors and lectins. For some humans, flatulence is a constraint to the consumption of cowpeas. Dehulling, soaking, germination and cooking can reduce oligosaccharide content (Singh, 2014).

2.7.3 Green fresh pods

The immature pods of cowpeas can be harvested, boiled and eaten. Some people prefer them chopped into small pieces and mixed with some relish. The pods can be boiled when then the seed is mature but not dry and then the seed is consumed from the pod. Green immature pods can yield up to 18t/ha in 3-4 pickings from 45 days after planting. Kedebe & Sembene, (2011) report that in Senegal people harvest the immature green pods of the early traditional varieties at the end of the wet season and this provides them with food during the greater times of the year when food becomes extremely scarce.

2.7.4 Fodder

Cowpeas can be used as food for livestock (Fatokun *et al*.,2002). The forage (vines and leaves) of fodder can be made into hay or silage and used as fodder for livestock. The haulms contain about 45-65% stems and 35-50% leaves and sometimes roots are an important by-product in Sub-Saharan Africa (Singh, Nag, Kundu & Maity, 2010). Cowpea pod husks which are a residue after threshing are also used to feed livestock. The sole crop can produce a yield of 1-2.5t/ha fresh fodder and an intercrop can give 0.35-1 t/ha fresh fodder.

2.7.5 Biological nitrogen fixation

Cowpeas can be included in a rotation to increase soil nitrogen and it is helpful in soils that have depleted in terms of soil fertility from over cropping (Giller, McDonagh & Cadisch, 1994). Cowpea can fix up to 240kg of nitrogen per hectare from atmospheric nitrogen and makes available about 60-70kg of nitrogen for the succeeding crop in rotation with it (Aikins & Afuakwa, 2008), although (Rusinamhodzi, Murwira & Nyamangara, 2006) have estimated that cowpea can fix up to 200kg/ha and can leave a positive nitrogen balance of up to 92kg/ha. Cowpea can be used as a cover crop which is incorporated into the soil when sufficient green material is available and usually done at peak flowering (Cameroon, 2003). The foliage has a relatively low C:N ratio and the N is quickly mineralized. Cowpea fixes nearly 70-240kg nitrogen/ha per year (Berner & Williams, 1988) and the residue of fixed nitrogen deposit of 60-70kg nitrogen/ha can be left to the successive crop. Due to this, cowpea is grown in rotation or mixed with many cereals and tuber crops. Cowpea can be grown and used for green manuring and provides biologically fixed N for subsequent crops. The crop has a direct agricultural product by maintaining and restoring soil fertility through fixing a large proportion of its nitrogen (Matikiti *et al*., 2012).

2.7.6 Soil erosion control, weeds and pests suppression

The crop has deep a root system and is best adapted to marginalized sandy soils, and is more tolerant to drought than soya beans. In areas with low rainfall at least cowpea provides soil cover that protects against erosion (Dadson *et al.,* 2003). Singh *et al.,* (1997) reported that cowpeas has the ability to cause suicidal germination of *Striga* species at higher plant densities. Roberts, Kitch, Murdock, Boukar, Phillips & McWatters, (2005) reported that when cowpea is used as a cover crop it showed that it can suppress nematodes in tomato production.

2.8.1 Cowpea growth traits

The growth traits of cowpea include number of branches, plant height, node number, stem diameter, number of leaves, leaf area and root length (Singh *et al*., 1997). Number of branches formed during the vegetative stage determines the plant skeleton, limits the number of leaves that are the source and number of pods that become the sink.

2.8.2 Yield and yield components of cowpea

The grain yield of cowpea depends on other components traits like number of pods per plant, pod length, number of seeds per pod and seed weight (Nakawuka & Adipala, 1999). Each yield component contributes to the total yield hence effects on any component affect yield. Yield is a function of the number of pods per plant, number of seed per plant, pod length and 1seed weight (Bapna, Joshi & Kabaria, 1972). In Uganda, Nakawuka & Adipala, (1999) reported that branch number, pod number and seeds per pod significantly contributed to grain yield. In another study conducted by (Asio, 2004), pods per plant, pod length and seeds per pod significantly contributed to yield and were considered during selection of high yielding cowpea genotypes.

2.9. Effect of row spacing on growth and yield of cowpea

2.9.1 Plant height

In an experiment to study the influence of various inter-row spacings on some varieties of mung bean in Pakistan. (Rasul, Cheema, Sattar, Saleem & Wahid, (2012) found out that plant height was affected immensely by inter-row spacing and maximum plant height were observed at a plant spacing of 45cm which produced plants that were 50.83cm in height while the mean plant height at maturity of 30 and 60cm inter-row spacing were 49.36cm and 47.72cm respectively. Kabir & Sarkar, (2008) conducted an experiment in Bangladesh and the tallest plant were observed at a spacing of 40cm*30cm since there was enough space for growth. The shortest plant were observed at spacing of 20cm*20cm.In contrast, (Bitew, Asargew & Beshir, 2014) found the tallest plants were from closer row spacing in cowpea. In field pea, (Derya, 2013) indicated that denser plant population increased plant height due to competition among plants. This might be due to close row spacing, the space for plant spreading was less and hence plant height increased significantly. On the other hand, in chickpea, (Yousaf, Ahsanui, Tahir & Ahmed, 1999) also observed reduction in plant height under closer row spacing. Mohammed & Getnet (2019) found that the effects of inter-row spacing was highly significant on plant height, and plant height ranged from 30.34cm in 40cm *10cm to 49.87 cm in 70cm *10cm spacing. This variation can be attributed to less interspecific competition for available resources in wider spacing thus facilitating plants to have more resources for growth. Mengesha, Sharma, Tana & Nigatu (2015) found out that plant height was not significantly affected by plant spacing of common bean and this is in agreement with (Blackshaw, Molnar, Muendel, Saindon & Li 2000) did not observe any effect of row spacing on plant height of common bean. In contrast to these results, however, increased plant density increased plant height of field pea (Yayeh, Fekremariam & Oumer, 2014). Orchado (2013) on an experiment on green pepper found out that the narrow spacing (30×40 cm) elicited the tallest plants (7.48 cm) as compared to shorter plants of 6.70 cm and 6.82 cm in the 40×40 cm and 50×40 cm treatments respectively.

2.9.2 Number of branches per plant.

Rasul *et al*., (2012) carried out a field experiment to observe the influence of spacing of various inter-row spacing on different varieties of mung bean and observed that the inter-row spacing of 30cm made plants to produce more number of fruit bearing branches (6.24) and was statistically at par with that of inter-row spacing of 45cm that produced 6.20 numbers of fruit bearing branches. Lakew, Ayalew & Assefa (2018) on an experiment carried in Ethiopia on sesame observed that more number of branches per plant (2.86) and (3.35) was recorded in 60cm inter-row spacing respectively. Likewise the highest mean number of branches per plant (4.46) was recorded for plants grown at 60cm whereas, the lowest number of branches per plant (1.33) was obtained from plants grown at 40cm inter-row spacing.

2.9.3 Number of leaves per plant

In an experiment carried out on sesame in Ethiopia by (Lakew *et al*., 2018) concluded that inter-row spacing of 60cm produced the highest number of leaves (41.36) whilst the lowest number of leaves (31.40) was recorded at 40cm inter-row spacing. This can be attributed to the fact that as row spacing decreased competition between plants for limited resources increased, and there is less vegetative growth and low number of branches per plant leading to low number of leaves.

2.9.4 Days to 50% flowering

Ahmad, Mahmood, Saleem & Ahmad (2002) reported that sesame row spacing had significant effect on number of days to flower and maximum days (56) were taken to flower at 60 cm row spacing, while the crop that was sown at 30cm rows took minimum days (52) to flowering and this can be attributed to more nutritional area available in wider spacing leading to vegetative growth. Mengesha *et al*., (2015) reported that days to flowering in common bean were not affected by plant spacing. Mohammed & Getnet (2019) found out that the effect of plant spacing was significant on days to 50% flowering of groundnuts. The result revealed that crops flowered earlier (31.88 days) when planted at narrow inter-row spacing (40*10cm) and flowered late (44.17days) when planted at wider spacing (70cm *10cm). The differences observed among the groundnut may be due to increased resource utilization efficiency in higher plant population densities and weed competition.

2.9.5 Days to 90% maturity

Lakew *et al*., (2018) whilst conducting an experiment on sesame in Ethiopia observed that the longer date of physiological maturity (107.56) were recorded at inter-row spacing of 60cm while inter-row spacing of 40cm exhibited the shortest days (81.66) to physiological maturity. This current result is in line with the observation of (Blackshaw *et al*., 2000) who stated that maturity of dry bean was not affected by row spacing.

2.10. Effect of row spacing on yield of cowpea

2.10.1 Number of pods per plant

In an experiment on groundnuts, El Naim, Eldouma, Ibrahim & Zaied, (2011) found out that there was an increase in number of pods per plant with increasing plant spacing. They reported that closer spacing reduced the number of pods per plant. These results may be attributed to the competition between plants and between the different parts of the individual plant under high planting population. In the same experiment they found out that decreasing plant spacing decreased seed yield per plant during the two seasons. Mekonnen, Negatu, Sharma &Tana (2017) whilst carrying out a research on effect of planting pattern and weeding frequency on weed infestation, yield components and yield of cowpea in Ethiopia found out that there was a reduced number of pods per plant at closer spacing and the increase in the number of pods per plant in wider row spacing might be due to vigorous plants in wider spacing, since vigorous plants produced more branches leading to high number of pods per plant. In closer row spacing plant growth was decreased resulting in less number of pods per plant.

Bitew *et al*., (2014) found similar results in field pea where they found the highest number of pods per plant in wider row spacing as compared to closer row spacing. Tunio, Rajput, Rajput & Rajput (1980) whilst carrying out a research on soybean also found out that the number of pods per plant increased with corresponding increase in row spacing. This increase of pods per plant in wider row spacing might be because, at wider row spacing the number of nodes and branches increased providing more fruit bearing area. Mohammed *et al*., (2019) found out that the effects of plant spacing was highly significant on the total number of pods per plant in groundnuts. They found out that a spacing of 60cm *10cm gave the highest number of pods per plant (45.003) while 40cm *10cm gave the lowest number of pods per plant. However, (Mengesha *et al*., 2015) differ with findings of others when they observed that plant spacing had no significant effect on number of pods per plant in common bean.

2.10.2 Number of seeds per pod

Findings have been reported by (Ihsanullah *et al*., 2002) who found no significant effect of row spacing on number of seeds per pod in mung bean. Mengesha *et al*., (2015) reported that number of seeds per pod of common bean was not affected by plant spacing. In contrast, however, (Turk & Tawaha, 2002) reported that plant density was negatively correlated with number of seeds per pod in faba bean (Masa *et al*., 2017)

2.10.3 Hundred seed weight

Mengesha *et al*., (2015) reported that plant spacing has no major effect on this parameter in common bean. El Naim *et al*., (2011) whilst working in a groundnut experiment found out that weeding twice resulted in increased 100-kernel weight and they concluded that this may be due to better availability of nutrients and better translocation of photosynthates from source to sink, resulting in higher accumulation of photosynthates in the seeds. Mohammed & Getnet (2019) found out that inter-row spacing was highly significant on hundred seed weight of groundnuts. The highest seed weight (59.07 g) was recorded on 70cm *10cm spacing followed by (56.39g) on 60cm*10cm spacing. In addition the lowest seed weight (32.53g) was obtained on 40cm* 10cm. This decrease in hundred seed weight can be attributed to assimilate division between higher number of seed used in conjunction with the decreased inter-plant competition and increasing its yield components. On the contrary, wider spaced plants with less weed computation improve the supply of assimilates to be stored in the seed, hence, the weight of hundred seeds increased.

2.10.4 Grain yield

Blackshaw *et al*., (2000) observed that a reduction in row spacing from 69 to 23cm increased yield by 19% and an increase in density from 20 to 50 plants per m^2 increased yield by 17% in dry bean. Lakew *et al*., (2018) found out that highest sesame grain yield (758.32kg/ha) and 750.28kg/ha were obtained from a row spacing of 50cm and 40cm respectively. The decrease might be due to competition for resources per unit area. Mengesha *et al*., (2015) reported that grain yield of common bean was not affected by plant spacing. Mohammed & Getnet (2019) found out that the highest seed yield of groundnuts of 2360.15kg /ha was obtained in 60cm *10cm while 40cm *10cm yielded 922.21kh/ha and they concluded that decreasing plant spacing, decreased seed yield per hectare due to competition.

2.11 Effect of frequency of weeding on growth traits and yield of cowpea

2.11.1 Plant height

Akter, Samad, Zaman & Islam (2013) conducted an experiment to evaluate the effect of weeding on growth, yield and yield contributing traits of mung-bean using three stage weeding that is emergence to flowering, flowering to pod setting and pod setting to maturity and he found that the highest plant height was 58.62cm. Mekonnen *et al.,* (2017) concluded that weeding significantly affected shoot length, and he observed that weeds decreased plant height. He also reported that the highest shoot was obtained when weeding was done twice. Mohammed & Getnet (2019) working on a field trial in groundnuts found out that weeding frequency was highly significant on plant height in groundnuts. Plant height ranged from 30.34cm with zero weeding to 49.87cm with three times weeding. Mohamed (2002) reported that there was no significant effect of planting pattern on plant height of cowpea and in contrast (Bitew *et al*., 2014) found out that tallest plants were from closer row spacing in cowpea. Similar results were reported by (Turk & Tawaha, 2002) who also found out that denser plant population increased the plant height due to competition among plants in faba bean. Derya, (2013) indicated that in field pea denser plant population increased plant height due to competition among plants and he concluded that this might be due to close row spacing and the space for plant spreading was less and hence plant height increased significantly. Yousaf, (1999) observed that there was reduction in plant height under closer row spacing in chickpea and this variable may be due to difference in canopy structure and or growth habit.

2.11. 2 Number of branches

Mekonnen *et al.,* (2017) reported that weeding had significant effect on the number of branches per plant. Yadava & Kurnar, (1981) reported that weed control in peanut led to increased number of branches per plant compared to unweeded plants. This result may be attributed to vigorous plant with less competition for light, nutrients, and free space in weed free environment. Weeds decreased the number of branches per plant. The highest number of branches per plant was obtained at weeding twice.

2.11.3 Days to 50% flowering

Gupta (2011) identified that plants in un-weeded plots took the highest time to reach 50% flowering. This is in agreement with Sunday & Udensi, (2013) who stated that treating plots with chemicals and supplementing with hand weeding at intervals was helpful in reducing the number of days to flowering and maturity. Mohammed & Getnet (2019) revealed that effect of weeding frequency was significant in groundnuts where crops that had no weeding flowered earlier (31.88 days) and flowered late (44.17 days) when three times weeding was done. They attributed this to the increase in resource utilization efficiency and reduced weed competition.

2.11.4 Days to 95% physiological maturity

Mekonnen, Sharma, Negatu & Tana (2015) concluded that the effect of location, treatments and their interaction had a significant effect on 95% physiological maturity of cowpea. The results among location treatments had no significant difference in days to maturity. However, (Sunday & Udensi, 2013) are in contrast as they have stated that using herbicides and hand weeding at intervals reduced number of days to maturity. Mohammed and Getnet (2019) reiterated that weeding frequency influenced groundnut physiological maturity significantly as crops that were weeded two and three times took longer time for maturity which was 165.3 and 164.09 days respectively. Early maturity was observed in plots that had no weeding which was 136.69 days. The days to maturity were shorter at low weeding frequency than at high weeding frequency. This can be due to inter and intra plant competition and early crop maturity rather than continuing vegetative growth.

2.11.5 Number of pods per plant

Mohammed & Getnet, (2019) in an experiment in groundnuts found out that weeding three times gave the highest number of pods per plant (45.003) whilst zero time weeding gave the lowest number of pods per plant (20.92). The highest pod per plant could be due to less weed-crop competition that leads to efficient use of resources. Weeding has a significant effect on the number of pods per plant as weeds infestation increase, the number of pods per plant decrease. Also other studies on mung bean indicated that with the decrease in weeds biomass, the number of pods per plant increased (Khan, Zammurad, Muhammad & Hussain, 2008).

2.11.6 Number of seeds per pod

Akter *et al*., (2013) conducted an experiment in mung bean and he observed that the highest number of seeds were obtained from three stage weeding (Emergence-Flowering, Flowering – Pod setting and Pod setting-Maturity). Mengesha *et al*., (2015) found out that beans which were kept weed free the entire season had the highest number of seeds per pod (6.5) and they attributed this to more translocation and assimilation of photosynthates towards grain formation since there was no weed competition. Mohammed & Getnet (2019) found out that frequency of weeding had no significant effect on the number of seeds per pod of groundnuts.

2.11.7 Hundred seed weight

Mengesha *et al*., (2015) found out that bean plants that were kept weed-free for the entire season had the highest (15.7 g) hundred seed weight This might be due to reduced competition for growth resources, which might have enabled the plants access to availability of nutrients and better translocation of photosynthates from source-to-sink, resulting in higher accumulation of photosynthates in the seeds. Plants, which were not weeded throughout the season, had the lowest (14.2 g) hundred seed weight. Similarly, it was reported that season-long weed competition significantly reduced hundred seed weight of white bean (Malik, Swanton & Michaels, 1993). In an experiment on groundnuts (Mohammed & Getnet, 2019) found out that three time weeding produced the highest seed weight (59.07g) followed by (56.39g) with two time weeding. The lowest weight (32.53g) was recorded on plots with zero weeding. This decrease in hundred seed weight might be because of assimilates division between higher numbers of seed used in connection with the decreased inter plant competition and increasing its yield components. On the contrary, wider spaced plants with less weed computation improve the supply of assimilates to be stored in the seed, hence, the weight of hundred seeds increased.

2.11.8 Grain yield

Rezene & Kedir, (2008) reported that one time early weeding at 25days after crop emergence resulted in 70% yield increase of common bean compared to no weeding. Akter *et al*., (2013) conducted an experiment on the effects of weeds on growth, yield and yield components of mung bean in Bangladesh and he found out that the highest seed yield (1.38 t/ha) was obtained from three stage weeding (Emergence-Flowering and Flowering-Pod setting and Pod setting-Maturity) whilst the lowest seed yield was obtained under no weeding condition. Yield loss in cowpea due to weeds have been reported to be in the range of 41-80% and grain yield reduction during the crop's entire growing period has been found to be as high as 50-70% as a result of weeds. The first 3-4 weeks of cowpea growth are critical since failure to commence weed control will lead to significant yield loss (Akobundu, 2005). Olayinka, Lawal, Abdulbaki, Ayinla, Oladokun, Udo, Akinwunmi & Etejere (2019) conducted an experiment on cowpeas and found out that the highest pod yield was obtained in plots were three hand weeding at 3, 6 and 9 weeks after planting as compared to the weedy check plot which had the lowest grain yield and this can be attributed to removal of early and late weeds thereby availing adequate resources to plants for pod growth and filling. Mohammed & Getnet (2019) found out that weeding frequency had a significant effect on seed yield. The highest seed yield (2360.15 kg/ha) was obtained in a plot that received two times weeding while 922.21kg/ha was obtained from a plot that received zero weeding.

2.12 Weed competition and crop yield losses

Bleasdale, (1960) says "Two plants are in competition with each other when the growth of either one or both of them is reduced or their form modified as compared with their growth or form in isolation." The first plants to establish in an area of soil whether small or large tend to exclude others. Land preparation, depth of seeding, sowing date and other agronomic practices should make crops avoid competition with weeds. Weeds that appear after crop establishment have negligible effects. Weeds that germinate together with crops have higher competition. Weed species and crops growing in association usually compete for light, nutrients, water, space and carbon dioxide as a result of which yields are greatly reduced. Crop yield loss as a result of weeds is usually proportional to the amount of light, nutrients and water used by the weeds at the expense of the crop.

2.12.1 Light

Plant height and vertical leaf area distribution are the important elements of crop weed competition. When water and nutrients are in good supply weeds have an advantage over crops and grow taller. Effects of competition for light are seen during early crop growth as weed growth becomes denser crop seedlings are smothered (Rana & Rana, 2015).

2.12.2 Water

When moisture stress increases, crop- weed competition becomes critical. For weeds to produce dry matter they transpire more water than field crops. Evapotranspiration is higher in a weedy crop field than from a weed free crop field. Weeds can remove moisture from up to 90cm soil depth whilst the uptake of moisture by wheat is limited to 15cm soil depth (Rana & Rana, 2015). It has been observed that weeds growing in fallow land can consume as much as 70-120mm of soil moisture and it has been noted that this moisture can produce 15-20 g of grain per ha in the following season (Rana & Rana, 2015). It has been observed that weeds growing in fallow land can consume as much as 70-120 mm of soil moisture and it has been noted that this moisture can produce 15-20 g of grain per ha in the following season (Rana & Rana, 2015).

2.12.3 Nutrients

Nutrients are a very important aspect of crop -weed competition. Absorption of minerals and nutrients by weeds is faster than crop plants (Rana & Rana, 2015). Weeds can accumulate large amounts of nutrients than crop plants. Huge losses are incurred in each crop season which is twice that of crop plants.

2.12.4. Space/CO_2

Crop weed competition for space is done as a requirement for carbon dioxide and the competition occurs when there is crowded plant community condition. A more efficient use of carbon dioxide by C4 weeds contributes to their rapid growth over C_3 crop type (Rana & Rana, 2015).

2.13 Weed control in cowpea

Weed control encompasses reduction of the interference ability of an existing population of weeds in a crop, establishment of a barrier to further weeds infestation in the crop, and the prevention of weed problems in future crops either from the existing weed reservoir or from additions to that weed flora (Rana & Rana, 2015). Manual weed control is the most common method used by farmers in cowpea production. Hand weeding is considered useful because it does not only control the weeds but also improves soil physical conditions. Besides, the practice of hand weeding known to loosens the soil surrounding the rhizosphere of crop plants and thereby enhances crop growth and yield.

2.13.1 Cultural weed control

One of the widely researched cultural methods that could potentially provide weed suppression and increase cowpea yield is planting density (or row spacing). Grain legumes planted with narrow spacing generally have quicker ground cover that provides shades for weed suppression. Minotti & Sweet (1980) reported that the most predictable and manageable form of competition (against weeds) is early shade and this is achievable through narrow spacing or increased plant density.

2.13.2 Physical Weed Control

Hand weeding is the most widely used physical weed control in cowpea production. It is considered useful since it does not control weeds alone but also improves soil physical condition. It loosens the soil around the crop plants thereby enhancing crop growth. For example, Ahlawat *et al*., (2005) reported that one hand weeding at 25 days after sowing (DAS) resulted in 90% increase in cowpea yield as compared to weed infested plots in north western Indo-Gangetic Plains of India.

Dugje *et al*., (2009) reiterated that two hand weedings in cowpea twice, first at 2 weeks after planting, and second at 4-5 weeks after planting had similar yield with chemical weed control. Hand pulling should be carried out in time and early in the crop growth. Weeds in cowpea can be controlled effectively with hand weeding done at 3 and 6 weeks after sowing. Closer spacing (row to row) suppresses the germination and growth of weeds hence crops are free from weeds as weeds get less space, light and nutrients for growth (Rana & Rana, 2015).

2.14 Summary

The taxonomy, origin, distribution, description and agronomic requirements of cowpea were discussed. Cowpea is a crop of social and economic importance as it provides nutrient requirements to people and livestock. Cowpea is an important crop as it fixes nitrogen into the soil. Weeds compete with cowpea for nutrients, moisture, space / carbon dioxide and light. Weeds in cowpea can be controlled using physical and cultural methods.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The research study was carried out at Nyakomba Irrigation Scheme, 17.791035 S, 32.976 160 E, Nyanga north during the 2020/21 summer season. An ox drawn plough and harrow were used for ploughing and levelling respectively. The experiment was laid out using RCBD experimental design. The semi-indeterminate cowpea variety was used at a seed rate of 30kg/ha. the crop received 200kg/ha Compound D and aphids were controlled using Acetamiprid. Two experiments were conducted. Experiment one looked at the effects of row spacing on growth and yield of cowpea. Experiment two looked at the effects of frequency of weeding on growth and yield of cowpea. Data was collected on plant height, number of leaves per plant, number of branches per plant, number of pods per plant, number of seeds per pod, 100 seed weight, aboveground dry biomass yield, grain yield and yield loss for both experiments. Data analysis was done using Minitab statistical package. Ethics were observed during the research study and information will be shared among students, farmers, extensionists and researchers.

3.2 Location of study area

The experiments were carried out at Nyakomba Irrigation Scheme 17.791035 S, 32.976 160 E and an altitude of 860.3m.Nyakomba is situated in the eastern side in the district of Nyanga, Manicaland Province and borders Mozambique. It is 76km from Nyanga town. The area received 585.2mmduring 2019/20 season, distribution was erratic (rainfall figures given in Appendix 1). It is in natural region II. Soils are clay loam soils. Cowpea was grown during the summer season of 2019/20 under rain fed conditions.

3.3 Materials and methods

For experiment 1 an ox drawn plough was used to till the land and an ox drawn harrow was used to create a fine tilth suitable for planting. A hoe was used for weeding. Cowpea seed variety used was CBC2, a semi-determinate variety. The variety is an erect type and produces reddish-brown grains with light brown hilum. The seed is very small in size with a smooth seed coat. Most of the pods occur above the canopy. CBC2 matures in 70-80 days and can yield up to 3t/ha under optimum conditions. It flowers in 30-40 days after emergence.

A seed rate of 30kg/ha was used. Basal fertiliser at a rate of 200kg/ha compound D was applied uniformly at planting in the net plots. Planting was done on 6 January 2020. Crop emergence was on 12 January 2020. Three seeds were placed per planting station and they were later thinned two weeks after emergence, leaving one plant per hill. The operation was carried out when the soil was moist so as not to disturb plant roots. Weed removal was carried out by hand pulling and hoeing. Gross plots and net plots were divided using pegs. A distance of 0.5m and 1m was left between plots and net plots respectively to allow movement when carrying out various operations and recordings.

Acetamiprid was used to control aphids at a rate of 50g/ha and a 15litre knapsack sprayer. Was used for spraying the chemical. There were no incidence of disease outbreaks hence no control was done. Harvesting was done on 28 March 2020.

3.4 Experimental design

The experimental design used for the experiment was RCBD and the procedures explained by (Gomez & Gomez,1984) were followed. RCBD helps to reduce the effect of uncontrolled variation and blocking improves accuracy of an experiment. Gomez and

Gomez (1984) explains that randomisation is done in each block and each treatment should appear in each block only once. Variation observed in the experimental area was a result of soil fertility and slope due to land leveling that was done before, during irrigation development hence RCBD was ideal since blocking helped in reducing the effect of these uncontrolled factors. Randomisation was carried out using the drawing lot method as explained by Gomez & Gomez (1984).

3.4.1 Experiment 1: Effects of row spacing on growth and yield of cowpea.

3. 4.1.1. Experimental Layout

Three inter- row spacing's were used that is 75*15cm, and 60*15cm and 45*15cm. The cowpea variety CBC 2 was used. Seeds were planted at 2.5cm deep. Planting was carried out on 6 January 2020 and emergence was on 12 January 2020. Three seeds were planted per station and later thinned to one plant per hill at two weeks after emergence. The experimental design used was RCBD with three replications (blocks). There were 3 blocks with three sub-blocks (net plots) per block thus giving a total of 9 net plot areas for the whole experiment. The pathway between net plots area was 0.5 m, to facilitate movement to different plots for various operations and data recording. Each net plot measured 5m * 2.25m giving an area of 11.25m^2

3.4.2 Experiment 2: Effects of frequency of weeding on growth and yield of cowpea.

3.4.2.1 Experimental layout

The experiment was carried out using the Randomised complete block design with three replications. There were six weeding frequencies as treatments. One hand weeding and hoeing at 2 weeks after crop emergence (WAE), one hand weeding and hoeing at 3

WAE, one hand weeding and hoeing at 4 WAE, two hand weeding and hoeing at 2 and 5 WAE, weed free check and weedy check.

The cowpea was planted at a row spacing of 45*15 cm and at a depth of 2.5cm. Planting was done on 6 January 2020 and emergence was on 12 January 2020. Three seeds were placed in a hill and later thinned to one plant per station two weeks after crop emergence. There were 18 net plot areas with three blocks that is 6 net plot areas per block. Each net plot area measured 2.5m *3m giving 7.5m^2. The pathway between net plots area was 0.5 m, to facilitate movement to different plots for various operations and data recording.

3.5. Data collection

Phenological data

a) Days to 50% emergence
b) Days to 50% flowering
c) Number of days to 95% physiological maturity

Plant growth variables

a) Plant height
b) Number of leaves per plant
c) Number of branches per plant
d) Number of days to podding

Yield and Yield components

ii. Number pods per plant

iii. Number of seeds per pod

iv. Pod length (cm)

v. 100 seeds weight (g)

3.6 Data collection procedure

Data collection started 14 days after crop emergence, when thinning had been completed and repeated every two weeks until harvesting was done. During the experimental trial there were five sampling periods. Ten plants selected randomly were pre-tagged from each net plot for recording various growth variables. Extreme ends of the rows were avoided due to possible border effect. Morphological growth characters such as plant height, number of leaves, number of branches, were determined during the growing period until at harvesting. Phonological data was determined by visual observation.

3.6.1. Phenological variables

Days to 50 % flowering

It was recorded as the number of days from the date of emergence of cowpea to the date when 50% of the plants per net plot area, produced at least one flower.

Days to 90% physiological maturity

Time to physiological maturity was taken as the number of days from the date of emergence to the period when 90% of plants in the experimental area turned yellow (physiological maturity) based on visual observation. Leaves were shedding and pods had turned colour to yellow.

3.6.2 Growth variables

Plant height (cm)

Ten plants were tagged in the second row at random from each net plot and they were measured from the base of the plant to the tip of the main stem (apical bud)of each plant from the net plot area and an average was obtained and expressed in cm . A measuring tape was used. Plant height was measured two weeks after crop emergence and thereafter was done on 14days interval until physiological maturity.

Number of leaves per plant

Were recorded on the main stem as well as on branches for the ten randomly selected and tagged plants from each net plot area at 50% flowering stage of the plant. The number of leaves was counted from the selected plants the mean was taken as the number of green leaves per plant.

Number of branches per plant

The total numbers of all primary branches were counted from each of the ten tagged randomly selected plants per net plot area at physiological maturity and their mean value was taken as the number of branches per plant.

3.6.3 Yield and Yield components

Number of pods/plant

It was determined by counting the number of pods per plant of the ten randomly selected non-border tagged plants from each net plot area at harvest and the mean was calculated and expressed as number of pods per plant.

Number of seeds/pod

Seeds were collected from 10 randomly selected pods from the 10 tagged plants from each net plot area at harvest. The seeds were separated from the pods and the number of seeds were counted and added together then averaged to give the number of seeds per pod using the following formula:

$$\text{Number of seeds per pod} = \frac{\text{total number of seeds counted}}{\text{number of pods counted}}$$

Pod length (cm)

Ten pods were collected at random from the tagged plants and their length was measured in cm and the mean was calculated and expressed as the length of the pod.

Hundred seed weight (g)

It was determined by taking weight of 300 seed lots randomly selected from the total harvest from each net plot area (treatment) and weighed using an electronic scale and the results were expressed as means of the three batches in grams.

Aboveground dry biomass yield (kg /ha)

Above ground dry biomass yield was determined after physiological maturity. The seeds were separated from the pods. The straw and shell of harvested area (net plot) was sun dried for five days. The dry weight was carried out using an electric scale then recorded. This was considered as the above ground dry biomass weight. The data obtained were expressed in kg/ha. The summation of grain yield and aboveground biomass yield is the biological yield.

Harvest index (%)

Was calculated using the procedure of (Beadle, 1987) as the ratio of total grain yield (Economic yield) to total biomass yield (Total dry matter) and expressed in percentage.

$$\text{Formula: HI} = \frac{\text{seed yield (kg/ha)}}{\text{Above ground dry biomass (kg/ha)}} * 100$$

Grain yield (t/ha)

Grain yield measured after threshing the harvested plants from each net plot area. The pods were sun dried for three days. Crops from a net plot area were harvested and threshed separately. The grain was weighed separately as per net plot area. An electronic scale was used to determine the weight of grain. The seed yield was expressed in kg/ha.

Final seed yield was determined as follows:

$$\text{Seed yield (kg/ha)} = \frac{\text{Seed weight (kg) of plot}}{\text{Harvested area } (m^2)} \times 10000\ m^2$$

3.6.4 Weed data collection

Weed identification was started 14days after crop emergence and continued at 14 day intervals for the weedy check plots during crop growth. Weeds that were found at each site were recorded

Weed identification

The weeds present in the net plot areas were recorded and classified.

Weed density

Data on weed density was collected from each treated plot at 14 day intervals for the weedy check plots. This was done by throwing a 1m*1m quadrant randomly at two different spots in each net plot area. The quadrant was placed in the central rows of the plot. Weeds inside the quadrant were counted and recorded. Relative weed density was calculated using the following formula:

$$RWD = \frac{\text{Density of individual weed species in the community}}{\text{Total density of all weed species in the community}} * 100$$

3.6.5 Data Analysis

The collected data was analysed statistically using ANOVA technique. Differences were compared using LSD values at the 5% level of significance. The statistical package Minitab version 18 was used for data analysis.

3.6.6 Ethical Considerations

The researcher ensured that all rights to the environment, property, individuals were protected. This ethical consideration is necessary to maintain the integrity of the study as well as the integrity of the researcher. The research conformed to Africa University Research Ethics (AUREC) guidelines and regulations. The results were disseminated to relevant stakeholders who included extension personnel, students, fellow researchers and other development partners involved in agriculture. The information will be published in journals and other electronic media with full acknowledgement of the work of other researchers.

3.6.7 Summary

The research study was carried out to determine the effects of row spacing and frequency of weeding on the growth and yield of cowpea. The experimental design was the RCBD because it is simple and block unexplained variations in the experiment. Data collection was done on various variables as per collection schedule. Experiment 1 had 3 treatments that were replicated 3 times to get 9 experimental units. Experiment 2 involved 6 treatments replicated 3 times to get 18 experimental units. The data analysis involved the use of Minitab software. Ethical considerations were observed for the integrity of the research.

CHAPTER 4 DATA PRESENTATION, ANALYSIS AND INTERPRETETION

4.2 Experiment 1 The effect of row spacing on growth and yield of cowpea

4.2.1 The effect of row spacing on plant height, number of leaves per plant and number of branches per plant.

There was no significant difference in plant height across the three treatments (Table 1). There was a significant difference in the number of leaves per plant across the three treatments. Treatment (45*15 cm) had the highest mean number of leaves (81,067) per plant followed by treatment (60*15 cm), then lastly treatment (75*15 cm) had the lowest mean number of leaves(75,000) (Table 1). There was no significant difference among the three treatments on number of branches per plant (Table 1)

Table 1 The effect of row spacing on plant height, number of leaves per plant and number of branches per plant.

Treatment	Plant height (cm)	Number of leaves	Branches per plant
75*15	65.733	75.000 a	5.667
60*15	66.667	79.067 b	5.900
45*15	67.300	81.067 b	5.967
P value	0.476	0.006	0.412
Significance	NS	NS	NS
LSD	4.967	6.421	0.2456

NS= No significant difference

There was no significant differences ($p<0.05$) in plant height between the three treatments due to changes in row spacing in this study. This can be attributed to growth habit of the crop.. These findings are in agreement with (Mekonnen et al., 2017). In contrast Yayew (2014) found out that tallest plants were from closer row spacing in cowpea. Khalil et al., (2010), Thalji (2010) and Derya (2013) found out that denser plant population had a bearing on plant height as there was a tendency to increase plant height due to intra competition among plants in faba beans.

There was no significant differences ($p>0.05$) among treatments on the number of leaves per plant, although close spacing of 45cm*15cm had plants which produced the highest mean number of leaves per plant (81.067). This can be attributed to the fact that an increase in plant population whilst row spacing decreases leads to intra competition for limited resources and a number of branches per plant are produced hence more leaves are produced per plant. However these results obtained from the study are in contrast with those obtained by (Shegaw *et al*., 2018) who found out that the highest number of leaves were recorded at 60cm (49.83) row spacing while the lowest number of leaves per plant were recorded at 40cm row spacing (31.40) in a research on sesame.

Row spacing had no significant effect ($p>0.05$) on the number of branches per plant. The number of branches is an important parameter in the final yield of any crop. This can be attributed to the growth habit of the cultivar grown. These results are supported by (Ahmed *et al*., 2010) who reported that row spacing had no significant effect on mean number of branches per plant in cowpea. In contrast, Shegaw *et al*., (2018) found out that there was a high significance on mean number of branches per plant in sesame at row spacing of 60cm (2.86) and the lowest mean number of plants were obtained at 40cm (1.33).

4.2.2. The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on days to 50% flowering, days to 90% maturity and number of pods per plant.

There was no significant difference (p>0,05) in number of days to 50% flowering, number of days to 90% maturity and number of pods per plant (Table 2) due to effect of row spacing.

Table 2 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on days to 50% flowering, days to 90% maturity and number of pods per plant.

Treatment	Days to 50% flower	Days to 90% maturity	Number of pods per plant
75*15	38.667	71.333	17.367
60*15	39.000	71.667	19.167
45*15	39.000	72.000	20.667
P value	0.927	0.842	0.418
Significance	NS	NS	NS
LSD	1.5	1.5	1.5

NS= No significant difference

4.2.3 Days to 50% Flowering and 90% Maturity.

In this experiment it was found out that row spacing had no significant effect (p>0.05) on days to 50 % flowering and days to 90% maturity. The reason could be genetically characteristic of the cultivar than environmentally controlled. The results are supported by (Mengesha *et al*., 2015) who reported that days to flowering in common bean were not affected by plant spacing. In contrast Ahmad *et al*., (2002) reported that row spacing significantly affected number of days to flowering and they attributed this to the fact that at wider spacing plants had access to adequate nutrients that led to vegetative growth.

Geshaw *et al*., (2018) in an experiment on sesame found out that the crop took longer days to reach physiological maturity. The experimental results are also supported by

Blackshaw *et al*., (2000) who found out that maturity of dry bean is not affected by row spacing.

4.2.4 Number of pods per plant

There was no significant difference ($p>0.05$) between treatments on mean number of pods. This maybe an attribute of the cultivar that was grown rather than managerial factors. Mengesha *et al*., (2017) support these findings when they also found out that row spacing had no significant effect on mean number of pods per plant in common bean. This is in contrast with results obtained by (Mekonnen *et al*., 2017) whilst carrying an experiment on cowpea in Ethiopia found out that there was a reduced number of pods per plant at closer spacing and an increased number of pods per plant in wider spacing. They attributed this to the fact that vigorous plants produced at wider spacing produced more branches leading to higher number of pods per plant in common bean. Also in contrast to the results obtained in this study (Yayeh *et al*., 2014) in an experiment on field pea found out that the highest number of pods per plant were obtained from wider row spacing as compared to closer spacing.

4.2.5 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on number of seeds per pod, pod length and 100 seed weight.

There was no significant difference on the number of seeds per pod, pod length and 100 seed weight among the treatments (Table 3).

Table 3 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on number of seeds per pod, pod length and 100 seed weight.

Treatment	Seeds per pod	Pod length(cm)	100 seed weight (g)
75*15	15.433	18.533	13.567
60*15	16.100	18.833	12.700
45*15	16.267	19.233	15.300
P value	0.598	0.595	0.132
Significance	NS	NS	NS
LSD	2.362	2.774	2.87

NS=No significant difference

4.2.6 Number of seeds per pod

There were no significant differences (p>0.05) among treatments on the number of seeds per plant in this study. This can be attributed to varietal characteristic of the crop. The results obtained from the experiment are supported by (Ihsanullah *et al*., 2002) who found no significant effect of row spacing on number of seeds per pod in mung beans. Also (Mengesha *et al*., 2015) reported that the number of seeds per pod in common bean was not affected by plant spacing. However (Turk & Tawala, 2002) reported that plant density was negatively correlated with number of seeds per pod in faba beans. Mekonnen *et al*., (2017) also found out that mean number of seeds per pod per plant was affected significantly by row spacing in cowpea.

4.2.7 100 seed weight

Experimental findings obtained from this study indicated that there was no significant differences (p>0.05) between treatments on 100 seed weight. Results from the study are in line with those obtained by (Ahmad *et al*., 2002) in sesame. The findings are supported by similar findings by (Mengesha *et al*., 2015) who reported that row spacing has major effect on 100 seed weight in common bean. However, (Shegaw *et al*., 2018) reported that there were significant differences in 100 seed weight as a result of row spacing in sesame and they attributed this to better availability of nutrients and better translocation of photosynthates to the seeds.

4.2.8 Above ground dry biomass yield

There were significant differences among treatments on the above ground dry biomass yield obtained in this present study. This can be attributed to growth and yield traits of cowpea at a closer spacing (45cm*15cm) than the other row spacing. The results are in line with those of (Galwab & Kamau, 2017) who also found out that there was significantly higher aboveground biomass yield in cowpea due to row spacing. The results are in contrast with those of (Mengesha *et al*., 2015) who found out that there were no significant difference in dry matter yield of common bean due to row spacing. The results obtained are in contrast with those of (Worku *et al*., 2018) who found out that there was a significant difference in biomass yield between plant space of 20cm and 40cm between rows and they attributed this to high performance of growth and yield components which resulted in the increase in grain yield and aboveground biomass yield.

4.2.9 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on above ground dry biomass yield, harvest index (%) and weight of pods/plant (g).

There was a significant difference among the three treatments on the aboveground dry biomass yield. Treatment 1 (75cm*15cm) and 2 (60cm*15cm) were not significantly different from each other. Treatment 3 (45cm*15 cm) had a significantly higher above ground dry biomass yield ($p<0.05$) compared to treatments 1 and 2. There was no significant difference in harvest index (%) among the three treatments. There was no significant difference in weight of pods per plant among the three treatments, although treatment 3 (45cm*15cm) had a larger mean of 27.56 grams per plant (Table 4).

Table 4 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on above ground dry biomass yield, harvest index (%) and weight of pods per plant (g).

Treatment	above ground dry biomass yield	harvest index	weight of pods/plant (g)
75*15	5362.9	38.100	20.413
60*15	5127.6	34.633	17.823
45*15	6785.2	40.500	27.650
P value	0.029	0.282	0.053
Significance	**	NS	NS
LSD	997.2	3.46	3.343

** Significant difference at p=0.01
NS = No significant difference

4.2.10 Harvest index

The harvest index was not significantly affected by row spacing in this study. This can be attributed to the fact that there was no luxurious growth which might have helped plants to convert total dry matter into economic yield. Mengesha *et al*., (2015) obtained similar results in common bean when they found out that harvest index was not significantly affected by row spacing.

4.2.11 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on grain yield.

There was a significant difference in the yield (tons per hectare) across the three treatments. Treatment 3 (45cm*15cm) had the largest tonnage (2.8000 t/ha) at $p<0.05$ and was significantly different from both treatments 1 (75cm*15cm) with 2.0333 t/ha and treatment 2 (60cm*15cm) with 1.8000 t/ha. (Table 5).

Table 5 The effect of row spacing 75*15cm, and 60*15cm and 45*15cm on grain yield

Treatment	grain yield (t/ha)
75*15	2.0333
60*15	1.8000
45*15	2.8000
P value	0.047
Significance	*
LSD	3.46

* Significant difference at p=0.05

The treatments showed that grain yield was significantly affected ($p<0.05$) by row spacing. The higher yield of 2.8000 t/ha was obtained from a row spacing of 45cm*15cm. in contrast to these findings (Mengesha *et al*., 2015) in an experiment on common beans found out that yield was not significantly affected by plant spacing. These results are in agreement with those of (Blackshaw *et al*., 2000) who found out that a reduction in inter- row spacing increased yield by 17% in dry beans. Also these results are in agreement with (Adigun *et al*., 2014) in an experiment on cowpea who found out that an increase in grain yield was associated with a decrease in row spacing. The reasons for this increase in grain yield with a decrease in row spacing can be attributed to the fact that crops formed a better canopy formation which enhances weed suppression and moisture conservation. Mohammed *et al*., (2019) disagrees with these results when he noted that decreasing plant spacing leads to a decrease in seed yield per hectare due to competition. Easha, (2014) found similar results in mung bean and concluded that seed yield is greatly influenced by different row spacing.

4.3.Experiment 2: Effect of frequency of weeding on growth and yield of cowpea

4.3.1 The effect of frequency of weeding on plant height, number of leaves per plant and number of branches per plant.

There were significant differences among the treatments in plant height with the highest mean plant height produced by W6 (81.0). This can be attributed to competition between weeds and the crop. Weedy free check (W5) was kept weed free during the entire season and this resulted in less competition with weeds and had the shortest plant height (Table 4.6). There were significant differences ($p<0.05$) among the treatments on number of leaves per plant, the highest mean number of leaves were obtained in treatment W5 (69.0) whilst the lowest mean number of leaves were obtained in treatment W6 (60.0) (Table 6). The lowest mean number of branches were obtained in W6 (3.4) and the highest mean number of branches were in W5 (4.8).

Table 6 The effect of frequency of weeding on plant height, number of leaves per plant and number of branches per plant

Treatment	Plant height (cm)	Number of leaves	Branches per plant
W1.	74.3	71.0	4.13
W2.	75.67	74.67	4.67
W3	77.0	77.0	4.67
W4	72.33	69.67	4.07
W5	69.0	79.0	4.8
W6	81.0	60.0	3.4
P value	0.038	0.000	0.000
Significance	**	**	**
LSD	4.9	6.4	0.24

*= Significant difference at p=0.05

** = Significant difference at p=0.01

Key to treatments:

W1= One hand weeding and hoeing at 2 Weeks After Crop Emergence (WAE)

W2= One hand weeding and hoeing at 3WAE

W3= One hand weeding and hoeing at 4WAE

W4= Two hand weeding and hoeing at 2 and 5WAE

W5= Weed free check

W6= Weedy check

4.3.2 The effect of frequency of weeding on days to 50% to flower, days to 90% maturity and number of pods per plant

There were significant differences in days to flower, days to 90% maturity and number of pods per plant(Table 7) however W6 treatment had the longer mean days to flower (43.0), mean days to maturity (74.3) and less mean number of pods per plant (9.3)). The highest mean number of pods per plant were obtained in treatment W5 (19.4), W6 had the lowest mean number of pods per plant (9.3) and W3 also had a higher mean number of pods per plant (16.6).

Table 7 The effect of frequency of weeding on days to 50% to flower, days to 90% maturity and number of pods per plant

Treatment	Days to 50% flower	Days to 90% maturity	Number of pods per plant
W1.	39.0	72.0	14.4
W2	38.7	72.0	16.4
W3	39.0	72.0	16.6
W4	39.0	72.0	16.4
W5	37.7	70.0	19.4
W6	43.0	74.3	9.3
P value	0.000	0.000	0.003
Significance	**	**	**
LSD	0.756	0.756	0.756

**=Significant difference at p=0.01

Key to treatments:

W1= One hand weeding and hoeing at 2 Weeks After Crop Emergence (WAE)

W2=One hand weeding and hoeing at 3WAE

W3=One hand weeding and hoeing at 4WAE

W4=Two hand weeding and hoeing at 2 and 5WAE

W5=Weed free check

W6=Weedy check

4.3.3 The effect of frequency of weeding on number of seeds per pod, pod length and 100 seed weight

There were significant differences (p<0.05) among the treatments on number of seeds per pod, and 100 seed weight (Table 8). The lowest mean number of seeds per pod were obtained from the treatment W6 (9.7), the treatment W5 had a mean of 16.4 and W3 had a mean of 16.2. W6 had the lowest mean 100 seed weight of 9.233 and W5 had 16.233 followed by W4 with 15.433. On pod length there was no significant difference among the treatments.

Table 8 The effect of frequency of weeding on number of seeds per pod, pod length and 100 seed weight

Treatment	Seeds per pod	Pod length(cm)	100 seed weight(g)
W1	15.367	16.867	14.000
W2	14.933	18.233	14.233
W3	15.167	16.967	14.433
W4	14.867	17.567	15.433
W5	16.400	15.967	16.233
W6	9.700	12.933	9.233
P value	0.000	0.102	0.000
Significance	**	NS	**
LSD	2.362	0.785	1.343

**=Significant difference at p=0.01 NS=No significant difference

Key to Treatments:

W1=One hand weeding and hoeing at 2 Weeks After Crop Emergence (WAE)

W2=One hand weeding and hoeing at 3WAE

W3=One hand weeding and hoeing at 4WAE

W4=Two hand weeding and hoeing at 2 and 5WAE

W5= Weedy check

W6= Weed free check

4.3.4 The effect of frequency of weeding on above ground dry biomass yield, harvest index (%) and weight of pods/plant (g).

There were significant differences between treatments on above ground dry biomass yield, harvest index and grain yield (Table 9). The lowest mean aboveground dry biomass was obtained in treatment W6 with 3822.2kg/ha, W4 had a mean of 6400.0 kg/ha and W5 had 6622.2kg/ha. The lowest mean harvest index was in treatment W6 (15.600 %), W4 (38.167%) and W3 had 36.467%. The highest mean grain yield of 2800.0 kg/ha was obtained from treatment W5 followed by 2440.0 kg/ha and the lowest grain yield was obtained in treatment W6 with 573.3 kg/ha (Table 9).

Table 9 The effect of frequency of weeding on above ground dry biomass yield, harvest index (%) and grain yield (tons/ha).

Treatment	above ground dry biomass kg/ha	harvest index (%)	grain yield kg/ha
W1	6711.1	32.0	2151.1
W2	6088.9	35.3	2155.5
W3	6089.0	36.5	2240.0
W4	6400.0	38.2	2440.0
W5	6622.2	42.2	2800.0
W6	3822.2	15.6	573.3
P value	0.000	0.000	0.000
Significance	***	***	***
LSD	1458.0	5.271	0.6716

***=significant difference at p=0.001

Key to treatments:

W1=One hand weeding and hoeing at 2 Weeks After Crop Emergence (WAE)

W2=One hand weeding and hoeing at 3WAE

W3=One hand weeding and hoeing at 4WAE

W4=Two hand weeding and hoeing at 2 and 5WAE

W5= Weed free check

W6= Weedy check

4.3.5 The effect of frequency of weeding on yield loss and weed density.

The highest mean yield loss of 79.457% was obtained in treatment W6 and mean weed species were abundant (322.33). Treatment W5 had no yield losses because it was kept weed free for the entire season took place. W4 had a mean yield loss 12.92%, followed by W3 (20.037%) (Table 10).

Table 10 The effect of frequency of weeding on yield loss and weed density.

Treatment	yield loss (%)	weed density/m^2
W1	23.223	46.33
W2	23.09	48.58
W3	20.037	75.67
W4	12.92	52.17
W5	0.0	0.0
W6	79.457	322.33
P value	0.000	0.000
Significance	***	***
LSD	6.125	14.06

***= Significant difference at p=0.001

Key to Treatments:

W1=One hand weeding and hoeing at 2 Weeks After Crop Emergence (WAE)

W2=One hand weeding and hoeing at 3WAE

W3=One hand weeding and hoeing at 4WAE

W4=Two hand weeding and hoeing at 2 and 5WAE

W5= Weed free check

W6= Weedy check

4.3.6 Plant height

The results from the experiment revealed that plant height was significantly affected by weeding frequencies. The results showed that plants that were weeded throughout the entire season were shorter than the rest of the treatments (69.0 cm). Plots that were unweeded for the rest of the season were taller than all the treatments. This can be attributed to inter competition between weeds and crops for resources like sunlight, space, nutrients and water. Also a decrease in crop height due to weed competition may be attributed to a reduction in cell division, growth and development of the crop (Kroof & Van Laar, 1993). The results obtained were in agreement with (El Naim & Ahmed, 2010) who found out that weeding many times increased plant height. Also, (Mekonnen *et al*., 2017) in an experiment in cowpea found out similar results that cowpea height in weedy check plots were due to competition from weeds during the entire season, and light was the chief limiting factor and thus competition enhanced plant height. Williams & Lindquist (2007) stated that weed competition increased height of sweet corn.

4.3.7 Number of leaves per plant

Results from the study showed that there was a higher number of leaves in all the other treatments compared to the weedy check as reflected in the number of leaves across the treatments. This can be attributed competition from weeds for resources. Similar results were obtained by (Adigun *et al*., 2014) in cowpea.

4.3.8 Number of branches per plant

Weeding had a significant effect on the number of branches per plant. The lowest number of branches per plant were obtained in weedy check treatments due to more competition for light, nutrients, space. Results obtained are supported by (El Naim *et al*.,2010) who reported that weeds decreased the number of branches per plant in groundnuts. Yadava & Kumar (1981) reported that weed control in groundnuts led to the increase in number of branches per plant compared to non-weeded plants. The results of the study concluded that the number of branches per plant was influenced by the presence of weeds in weedy check plots.

4.3.9 Days to 50 % flowering and days to 90% maturity

Days to flowering and maturity were significantly affected by weeding frequencies. Results obtained from the study indicated that hoeing and hand weeding in treatments were it was done had a significant effect on number of days to flowering and maturity as compared to the weedy check. Plants in the other treatments flowered and matured earlier than the weedy check treatments and this can be attributed to the weed infestation in the plots. Shading of crops by weeds could have resulted in less sunlight penetrating through the canopy and this prolonged the vegetative phase there delaying flowering and maturity. Contrary to these results, (Kissi & Dargie, 2017) found out that cowpea in weedy check plots flowered and matured earlier than the other treatments due to resource competition that caused forced phenological growth of the crop. The results from the study are also confirmed by (Mekonnen *et al*., 2015) who reported that cowpea in unweeded plots took longer days to flower and mature. Also results from the study are supported by (Malik et al., 2012) who reported that with increase in dry weight of *Parthenium* the duration required by common bean to reach physiological maturity was prolonged

4.3.10 Number of pods per plant

From the experiment results showed that the highest mean number of pods per plant were obtained in treatment that were kept weed free throughout the season and this can be attributed to absence of inter competition from weeds. The study showed a very strong relationship between weed and crop competition and number of pods per plant is the greatest yield contributing factor that is affected most. The growth and development of the plant was as a result of improved photosynthetic efficiency hence leading to large number of pods realised. The findings are in line of those of (Mengesha *et al*., 2015) whilst carrying an experiment on the effect of spacing and frequency of weeding in common bean and they concluded that weed interference significantly decreased the number of pods per plant. The reduced number of pods per plant in treatments that were unweeded though out the season was due to a greater time the crop was exposed to inter competition from weeds. These results are in line with those of (Malik *et al*., 1993) who found out that season long weed competition had a significant reduction on the number of pods per plant for white bean.

4.3.11 Number of seeds per pod

This experimental study showed that cowpea plants that were kept weed free throughout the season showed that they had the highest mean number of seeds per pod than all the other treatments. This can be attributed to reduced weed competition and this greatly improved translocation of photosynthates towards seed grain formation unlike in the weed check treatments. The longer period weeds were allowed to compete with cowpea resulted in a reduction in the number of seeds per pod. These results are in agreement with those of (Malik *et al*., 1993) who found out similar results and attributed this to season long competition that significantly reduced number of seeds per pod of common bean. Mekonnen *et al*., (2017) contradicts with these current findings as they suggest that the number of seeds per pod is not affected controlling weeds using any control measures due to the fact that number of seeds per pod is genetically controlled and it is part of the plant characteristics.

4.3.12 Pod length

There was no significant difference among all the treatments for pod length and this can be attributed to the characteristics of the plant rather than on management of the crop.

4.3.13 Hundred seed weight

The lowest 100 seed weight was obtained in weed infested treatments whilst the highest mean 100 seed weight was obtained in treatments that were weeded. Cowpea plants that were grown in free weed environment were not affected by inter competition. The higher number of leaves in weed free environment increased the number of leaves per plant and this had a bearing on photosynthesis .This can be attributed to the improved supply of assimilates from the source to the sink which were stored in the seed and this increased the weight of 100 seeds. This is in line with findings with previous research by (Malik *et al*., 1993) who reported that inter competition for the entire season significantly reduced hundred seed weight of white bean. These findings in the study are not in agreement with findings of (Negash *et al*., 2008) who asserted that there were no so significant difference that were found in 100 seed weight as a result of weed management practices in common bean.

4.3.14 Above ground dry biomass yield

The lowest above ground dry biomass yield was obtained in fields that were weed infested for the entire season and the highest was obtained in treatments that were weeded throughout. The lower above ground dry biomass yield was as a result of the poor soil condition that is aeration, moisture retention, and reduced microbial activity important for nitrogen fixation. This promoted weed –crop competition for resources resulted in reduced above ground dry biomass yield. In treatments that were hoed and then hand weeded the competition effect was reduced, thus promoting the competitive ability of the crop hence improving vegetative growth.

Findings from the study concur with those of (Mizan *et al*., 2009) whilst carrying a research in sesame reiterated that increased biomass yield was a function of the length of weed free period.

4.3.15 Grain yield

Significance differences in grain yield were observed in the various treatments, the weedy check treatment realised the lowest grain yield whilst the highest grain yield were obtained in treatments that were weeded throughout the season. The reason of having low grain yield in the weedy check treatments can be ascribed to weed competition and crops obtained inadequate resources, that is light, nutrients, water and space resulting in reduced growth, development and photosynthetic activity of the crop. This is in agreement with (Prakash *et al*., 2000) who found out that season long crop weeds competition reduced the green pod yield of peas. Higher yields obtained in weed free check treatments can be attributed to better utilisation of resources like nutrients, light, water and space resulting in higher yields. Mekonnen *et al*., (2017) reiterated that better translocation of photosynthates from source to sink area due to lesser weed competition is one of the reasons for obtaining higher yields. Osipitan *et al*., (2014) reported that the impact of weeds on yield of crops were a function of crop, weed species, weed density, environment, stage of crop growth and duration of exposure to weeds.

4.3.16 Harvest index

There were variations in harvest index across treatments due to differences in weed control treatments. Higher harvest index shows that there will be higher portioning of dry matter into grain. However there was lower harvest index in weedy check treatments and this can be attributed to intense weed competition with crops for resources and this in turn affected growth and development of crops. Similar results were obtained by (Mekonnen *et al*., 2017) who found that among weedy check treatments there was lower harvest index and they attributed this to effects of environmental factors, and other cultural variations that influences harvest index in cowpea. Mekonnen *et al*., (2017) further reiterates that severe weed interference can decrease shoot/root ratio, increase vegetative growth duration and allocation of more assimilates for shoot rather than root growth.

4.3.17 Yield Loss

In this study results obtained showed that if weeds are not controlled for the entire season there will a yield loss of 79%. This yield loss can be attributed to weed competition Similar results have been reported by (Ghadiri & Payat, 2004) who found out that when weeds are not controlled they reduced yields of Pinto bean by 75%. Mukhtar, (2012) noted that unrestricted weed growth reduced common bean grain yield by 58% and the yield of white bean by 70% when compared to weed free treatments. Also, (Mekonnen *et al*., (2015) found out that there was a yield reduction of 89.3-91.6% in weedy checks in cowpea. Madukwe *et al*., (2012) reported that in Nigeria 53-60% yield loss in legumes including cowpea was as a result of weeds. Sunday & Udensi, (2013) reiterated that inadequate weed control in cowpea accounts for 40-80% grain yield reduction in cowpea. According to (Osipitan *et al*., 2016), and (Adigun *et al*., 2014) weeds are a major constraint in crop production and yield losses caused by weeds can range from 25-76% and apart from reducing crop yields, they also cause less efficient of land use, higher cost of production when controlling pests and diseases, reduces crop quality, there are water management problems and efficient utilisation of labour (Patil *et al*., 2014; Prabhu *et al*., 2015). Weeds may cause yield losses through their releasing allelopathic compounds into the environment (Marinov-Serafimov, 2015). Li *et al*., (2004) found out that 12.7-60% yield loss in cowpea is as a result of weeds (Tripathy & Singh, 2001) reported a yield loss of as much as 82%.

4.3.18 Weed density in the un-weeded check plots

Conditions favorable for growing cowpea is also favorable for the growth of numerous kinds of weeds that cause competition with the crop. This competition for nutrients, space, light and moisture interfere with crop growth resulting in poor yields. At harvest no weeds were found growing in the treatment that received hoeing and hand pulling. Higher weed density was observed in the weed check plot. It can be noted that hoeing and hand weeding significantly reduced weed density in treatments that received this practice as compared to the weedy check treatments. The majority of weeds found were broadleaved weed and some grasses. The dominant weeds that affected cowpea were *Corchorus olitorius* (62/m^2), relative density (19%), *Richardia scabra* (45 weeds/m^2, relative density13.8%), *Achathospermum hispidium* (18 weeds/m^2, relative density 5.5%), *Eleusine indica* (11weeds/m^2, relative density 3.3%), *Cynodon dactylon* (4weeds/m^2, relative density 4.3%), *Urochloa panicodes* (23 weeds/m^2 relative density 7%) (Table 11). Tripathi & Singh, (2001) have reported that *Eleusine indica* is a major weed flora in cowpea. Weed density at harvest was low in some treatments because hand weeding uprooted the weeds and also the crop canopy had suppressed weed during growth of the crop. The poor performance of cowpea in the weedy check treatments can be attributed to high degree of infestation and this shows that cowpea could not compete with these weeds as shown by the results obtained. Tripathi & Singh (2001) pointed out that cowpea usually faces critical growth challenges in the presence of weeds. Their observation can be confirmed by the results obtained in this study as weed density greatly affected growth and yield of cowpea and (Njagu, 2003) reiterated that the inability of cowpea plants in weed check plots to produce more leaves that necessitates covering of the ground is as a result of the adaptive mechanism to the competitive growth conditions as cowpea faces great challenges to the growth of cowpea when there is greater weed density.

Table 11 Weed density in the un-weeded check plots.

Weed species Scientific name	Common Name	Life cycle	Weed Density/m^2	Relative density (%)
Ipomea plebia	Sabi morning glory	annual	8	2.46
Bidens pilosa	Black jack	annual	8	2.46
Tagetes minuta	Mexican marigold	annual	14	4.31
Schkuhria pinnata	Dwarf marigold	annual	12	3.69
Physalis angulata	Wild gooseberry	annual	6	1.85
Nicandra physalodes	Apple of Peru	annual	6	1.85
Leucas martinicensis	Bobbin weed	annual	7	2.15
Ageratum conyzoides	Billy goat weed	annual	8	2.46
Richardia scabra	Mexican clover	annual	45	13.85
Acanthospermum hispidium	Upright starbur	annual	18	5.54
hibiscus meeusiei	Wild stockrose	annual	6	1.85
Chenopodium album	Lambquarters	annual	12	3.69
Amaranthus hybridus	Pigweed	annual	9	2.77
Portulaca oleracea	Purslane	annual	7	2.15
Corchorus olitorius	Indian jute	annual	62	19.08
Galinsoga parviflora	Galinsoga	annual	16	4.92
Setaria pumila	Annual timothy	annual	11	3.39
Urochloa panicodes	Garden urochloa	annual	23	7.08
Milenis repens	Natal red top	annual	13	4.0
Eleusine indica	Rapoko grass	annual	11	3.38
Panicum maximum	Sabi panicum	annual	9	2.77
Cynodon dactylon	Bermuda grass	perennial	14	4.31
TOTAL			325	100

4.4 Summary

Data was analysed, presented and interpreted so as to enable drawing up of conclusions and recommendations for the research. The variables plant height, number of leaves per plant, number of branches per plant. number of pods per plant, number of seeds per plant, harvest index, aboveground dry biomass yield, grain yield and weed density as determined by row spacing and frequency of weeding were looked at as specified by the objectives of the study. References to other scholarly works was used to make a comparison between results obtained.

CHAPTER 5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Yield components and yield data was collected on number of pods per plant, number of seeds per pod, 100 seed weight, aboveground dry biomass yield and grain yield. Generally the production of cowpea is affected by poor weed management. Hand weeding and hoeing are some of the commonest methods used by farmers in Zimbabwe. The experiment was carried out in Nyakomba during the 2019/20 season and the experimental design was RCBD to determine the effects of frequency of weeding on growth and yield of cowpeas. The variety CBC 2 was used. Data was collected on variable such as plant height, number of leaves per plant, number of branches per plant, days to 50% flowering, days to 90% physiological maturity, number of pods per plant, number of seeds per plant, pod length, 100 seed weight, aboveground dry biomass yield, harvest index, grain yield, yield loss and weed density. Six treatments were used; hand weeding hoeing and at two weeks after emergence, hand weeding and hoeing at 3 weeks after emergence, hand weeding and hoeing at 4weeks after emergence, two hand weeding and hoeing at 2 and 5 weeks after emergence, weed free check and weedy check.

5.3 Conclusions

This study revealed that row spacing had no significant effect on plant height, number of leaves per plant, number of branches per plant, number of seeds per pod and 100 seed weight. The study's results showed that row spacing had an effect on aboveground dry biomass yield and grain yield at $p<0.05$. it can be concluded that 45cm*15cm had the highest grain yield of 2.800t/ha compared to 60cm*15cm (1.8000t/ha) and 75cm*15cm

(2.033t/ha). Therefore it can be concluded that a plant spacing of 45cm*15cm be adopted for growing cowpea.

It can be concluded from the study that two hand weeding and hoeing at 2 and 5 weeks after emergence significantly influenced pod length, 100 seed weight, aboveground dry biomass yield, harvest index, grain yield (2440.0t/ha) than all the other treatments. This show that early removal of weeds reduces competition for resources; light, space, water and nutrients. Delays in removing weeds after 35 days results in yield loss of above 79%.

5.4 Implications

The results from the study infer that frequency of weeding significantly influenced plant height, number of leaves per plant, number of branches per plant, days to 50% flowering, days to 90% maturity, number of pods per plant, number of seeds per plant, 100 seed weight, aboveground dry biomass yield, harvest index, grain yield, yield loss. The weed free check had the highest grain yield of 2800.0t/ha followed by treatment W4 which had 2440.0t/ha and the lowest yield was obtained in weedy check treatment of 573.3t/ha. it therefore shows that weeds reduce yield of crops. The highest yield loss (79.457%) was obtained in the weedy check treatment and in the weed free check there was no yield loss.

5.5 Recommendations

- The spacing of 45cm*15cm should be adopted by farmers as higher yields were obtained than the other wider spacing of 60cm*15cm and 75cm*15cm.
- There is need for farmers to weed cowpea twice at 2 and 5weeks after emergence with hand weeding and hoeing as most cannot afford herbicides.

5.6 Suggestions for Further Research

- These experiments should be done elsewhere in Zimbabwe so that results for the treatments can be compared.
- There is need to experiment with herbicides, hand weeding and hoeing for the same treatments.

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APPENDICES

Appendix 1.1 Rainfall for Nyakomba for the 2019/20 season.

MONTH	AMOUNT (mm)
November 2019	56.2
December 2019	78.4

January 2020	141.6
February 2020	258.5
March 2020	20
April 2020	30.5
TOTAL	585.2

Source: Nyakomba AGRITEX Office, May 2020.

Appendix 1.2. MINITAB RESULTS ANALYSIS

One-way ANOVA: PLANT HEIGHT versus TREATMENT

```
Analysis of Variance for PLANT HE
Source     DF        SS        MS        F        P
TREATMEN    2      3.73      1.86     0.84    0.476
Error       6     13.27      2.21
Total       8     17.00
                                   Individual 95% CIs For Mean
```

```
                                    Based on Pooled StDev
Level       N      Mean     StDev   ---+---------+---------+---------+---
1           3    65.733     1.193    (------------*------------)
2           3    66.667     1.514          (------------*------------)
3           3    67.300     1.709             (-------------*------------)
                                    ---+---------+---------+---------+---
Pooled StDev =    1.487             64.0      65.6      67.2      68.8
```

One-way ANOVA: No. OF LEAVES/PLANT versus TREATMENT

```
Analysis of Variance for No. OF L
Source     DF        SS        MS        F        P
TREATMEN    2     40.72     20.36    13.80    0.006
Error       6      8.85      1.48
Total       8     49.58
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level       N      Mean     StDev   ----+---------+---------+---------+--
1           3    75.900     0.800    (------*-----)
2           3    79.067     1.102                (------*------)
3           3    81.067     1.604                        (------*------)
                                    ----+---------+---------+---------+--
Pooled StDev =    1.215              75.0      77.5      80.0      82.5
```

One-way ANOVA: NO.OF BRANCHES/PLANT versus TREATMENT

```
Analysis of Variance for NO.OF BR
Source     DF        SS        MS        F        P
TREATMEN    2    0.1489    0.0744     1.03    0.412
Error       6    0.4333    0.0722
Total       8    0.5822
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level       N      Mean     StDev   ----+---------+---------+---------+--
1           3    5.6667    0.2517   (------------*------------)
2           3    5.9000    0.1000           (------------*-----------)
3           3    5.9667    0.3786             (------------*------------)
                                    ----+---------+---------+---------+--
Pooled StDev =   0.2687               5.40      5.70      6.00      6.30
```

One-way ANOVA: DAYS TO 50% FLOWERING versus TREATMENT

```
Analysis of Variance for DAYS TO
Source     DF        SS        MS        F        P
TREATMEN    2      0.22      0.11     0.08    0.927
Error       6      8.67      1.44
Total       8      8.89
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level       N      Mean     StDev   --+---------+---------+---------+----
1           3    38.667     1.528   (-------------*-------------)
2           3    39.000     1.000      (-------------*-------------)
```

```
3           3    39.000     1.000      (-------------*-------------)
                                    --+---------+---------+---------+----
Pooled StDev =    1.202            37.2      38.4      39.6      40.8
```

One-way ANOVA: DAYS TO 90% MATURITY versus TREATMENT

```
Analysis of Variance for DAYS TO
Source     DF        SS        MS        F        P
TREATMEN    2      0.67      0.33     0.18    0.842
Error       6     11.33      1.89
Total       8     12.00
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level       N      Mean     StDev   --------+---------+---------+--------
1           3    71.333     1.528    (------------*------------)
2           3    71.667     1.528      (------------*------------)
3           3    72.000     1.000        (------------*------------)
                                    --------+---------+---------+--------
Pooled StDev =    1.374                   70.5      72.0      73.5
```

One-way ANOVA: NO.OF PODS/PLANT versus TREATMENT

```
Analysis of Variance for NO.OF PO
Source     DF        SS        MS        F        P
TREATMEN    2     16.38      8.19     1.01    0.418
Error       6     48.52      8.09
Total       8     64.90
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level       N      Mean     StDev   --+---------+---------+---------+----
1           3    17.367     1.893   (-----------*----------)
2           3    19.167     3.690        (-----------*----------)
3           3    20.667     2.658             (----------*-----------)
                                    --+---------+---------+---------+----
Pooled StDev =    2.844            14.0      17.5      21.0      24.5
```

One-way ANOVA: NO.OF SEEDS/POD versus TREATMENT

```
Analysis of Variance for NO.OF SE
Source     DF        SS        MS        F        P
TREATMEN    2      1.17      0.58     0.56    0.598
Error       6      6.23      1.04
Total       8      7.40
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level       N      Mean     StDev   ----+---------+---------+---------+--
```

```
1           3    15.433     0.924   (-----------*-----------)
2           3    16.100     1.473        (-----------*-----------)
3           3    16.267     0.306          (-----------*-----------)
                                   ----+---------+---------+---------+--
Pooled StDev =    1.019             14.4      15.6      16.8      18.0
```

One-way ANOVA: POD LENGTH versus TREATMENT

```
Analysis of Variance for POD LENG
Source     DF        SS        MS        F        P
TREATMEN    2     0.740     0.370     0.57    0.595
Error       6     3.920     0.653
Total       8     4.660
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    18.533     1.007   (----------*-----------)
2           3    18.833     0.757      (----------*-----------)
3           3    19.233     0.611          (----------*-----------)
                                   -------+---------+---------+---------
Pooled StDev =    0.808                18.0      19.0      20.0
```

One-way ANOVA: 100 SEED WEIGHT versus TREATMENT

```
Analysis of Variance for 100 SEED
Source     DF        SS        MS        F        P
TREATMEN    2     10.52      5.26     2.89    0.132
Error       6     10.91      1.82
Total       8     21.42
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    13.567     1.206       (---------*--------)
2           3    12.700     1.000   (--------*---------)
3           3    15.300     1.732              (---------*--------)
                                   -------+---------+---------+---------
Pooled StDev =    1.348                12.0      14.0      16.0
```

One-way ANOVA: ABOVE GROUND DRY BIOMASS YIELD(versus TREATMENT

```
Analysis of Variance for ABOVE GR
Source     DF        SS        MS        F        P
TREATMEN    2   4825736   2412868     6.74    0.029
Error       6   2147445    357908
Total       8   6973181
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
```

```
Level        N      Mean     StDev  --------+---------+---------+--------
1            3    5362.9     135.8     (--------*-------)
2            3    5127.6     206.8   (-------*--------)
3            3    6785.2    1006.2                  (--------*-------)
                                    --------+---------+---------+--------
Pooled StDev =     598.3                  5000      6000      7000
```

One-way ANOVA: HARVEST INDEX (%) versus TREATMENT

```
Analysis of Variance for HARVEST
Source      DF        SS        MS        F        P
TREATMEN     2      52.2      26.1     1.57    0.282
Error        6      99.5      16.6
Total        8     151.7
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev  ---+---------+---------+---------+---
1            3    38.100     5.009          (----------*-----------)
2            3    34.633     4.255   (----------*-----------)
3            3    40.500     2.563              (-----------*-----------)
                                    ---+---------+---------+---------+---
Pooled StDev =     4.073            30.0      35.0      40.0      45.0
```

One-way ANOVA: WEIGHT OF PODS/PLANT(g) versus TREATMENT

```
Analysis of Variance for WEIGHT O
Source      DF        SS        MS        F        P
TREATMEN     2     155.6      77.8     5.00    0.053
Error        6      93.4      15.6
Total        8     249.0
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev  ----------+---------+---------+------
1            3    20.413     2.440       (--------*--------)
2            3    17.823     2.791  (---------*--------)
3            3    27.650     5.739                   (--------*--------)
                                    ----------+---------+---------+------
Pooled StDev =     3.945                    18.0      24.0      30.0
```

One-way ANOVA: T/ha versus TREATMENT

```
Analysis of Variance for T/ha
Source      DF        SS        MS        F        P
TREATMEN     2     1.642     0.821     5.32    0.047
Error        6     0.927     0.154
Total        8     2.569
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev  ----------+---------+---------+------
1            3    2.0333    0.2517       (--------*--------)
```

```
2           3    1.8000    0.3000   (--------*--------)
3           3    2.8000    0.5568                   (---------*--------)
                                   ----------+---------+---------+------
Pooled StDev =   0.3930                  1.80      2.40      3.00
```

One-way ANOVA: kg/ha versus TREATMENT

```
Analysis of Variance for kg/ha
Source     DF        SS        MS        F        P
TREATMEN    2   1556408    778204     5.00    0.053
Error       6    933749    155625
Total       8   2490158
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----------+---------+---------+------
1           3    2041.3     244.0       (--------*--------)
2           3    1782.3     279.1  (---------*--------)
3           3    2765.0     573.9                   (--------*--------)
                                   ----------+---------+---------+------
Pooled StDev =    394.5                 1800      2400      3000
```

Experiment 2 Analysis

One-way ANOVA: PLANT HEIGHT versus TREATMENT

```
Analysis of Variance for PLANT HE
Source     DF        SS        MS        F        P
TREATMEN    5     251.8      50.4     3.39    0.038
Error      12     178.0      14.8
Total      17     429.8
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----+---------+---------+---------+--
1           3    74.333     2.082            (-------*-------)
2           3    75.667     1.528              (-------*-------)
3           3    77.000     2.000                (-------*-------)
4           3    72.333     2.887        (--------*-------)
5           3    69.000     7.937   (-------*-------)
6           3    81.000     2.646                      (-------*-------)
                                   ----+---------+---------+---------+--
Pooled StDev =    3.851             66.0      72.0      78.0      84.0
```

One-way ANOVA: NUMBER OF LEAVES versus TREATMENT

```
Analysis of Variance for NUMBER O
Source     DF        SS        MS        F        P
TREATMEN    5     694.4     138.9    10.46    0.000
Error      12     159.3      13.3
Total      17     853.8
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -+---------+---------+---------+-----
1           3    71.000     2.646                (-----*----)
2           3    74.667     2.309                     (----*-----)
3           3    77.000     1.000                        (----*-----)
4           3    69.667     4.041              (-----*-----)
```

```
5           3    79.000     1.000                          (-----*----)
6           3    60.000     7.000  (-----*-----)
                                   -+---------+---------+---------+-----
Pooled StDev =    3.644          56.0      64.0      72.0      80.0
```

One-way ANOVA: NUMBER OF BRANCHES versus TREATMENT

```
Analysis of Variance for NUMBER O
Source     DF        SS        MS        F        P
TREATMEN    5    3.7244    0.7449    27.93    0.000
Error      12    0.3200    0.0267
Total      17    4.0444
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    4.1333    0.2309                  (---*---)
2           3    4.6000    0.0000                           (---*---)
3           3    4.4667    0.1155                        (---*---)
4           3    4.0667    0.1155                (---*---)
5           3    4.8000    0.2000                               (---*---)
6           3    3.4000    0.2000   (---*---)
                                   -------+---------+---------+---------
Pooled StDev =   0.1633                 3.50      4.00      4.50
```

One-way ANOVA: DAYS TO 50% FLOWERING versus TREATMENT

```
Analysis of Variance for DAYS TO
Source     DF        SS        MS        F        P
TREATMEN    5    50.944    10.189    16.67    0.000
Error      12     7.333     0.611
Total      17    58.278
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    39.000     0.000         (----*----)
2           3    38.667     0.577       (----*----)
3           3    39.000     1.000         (----*----)
4           3    39.000     1.000         (----*----)
5           3    37.667     0.577  (----*----)
6           3    43.000     1.000                             (----*----)
                                   -------+---------+---------+---------
Pooled StDev =    0.782                38.0      40.0      42.0
```

One-way ANOVA: DAYS TO 90 % MATURITY versus TREATMENT

```
Analysis of Variance for DAYS TO
Source     DF        SS        MS        F        P
TREATMEN    5   28.2778    5.6556   101.80    0.000
Error      12    0.6667    0.0556
Total      17   28.9444
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ------+---------+---------+---------+
1           3    72.000     0.000                (-*-)
2           3    72.000     0.000                (-*-)
3           3    72.000     0.000                (-*-)
```

```
4           3    72.000     0.000                (-*-)
5           3    70.000     0.000     (-*-)
6           3    74.333     0.577                               (-*-)
                                     ------+---------+---------+---------+
Pooled StDev =    0.236                 70.5      72.0      73.5      75.0
```

One-way ANOVA: No. OF PODS/ PLANT versus TREATMENT

```
Analysis of Variance for No. OF P
Source     DF        SS        MS        F        P
TREATMEN    5    173.38     34.68     6.69    0.003
Error      12     62.21      5.18
Total      17    235.59
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
1           3    14.400     0.265             (-----*-----)
2           3    16.367     2.043                 (-----*----)
3           3    16.600     2.100                 (-----*-----)
4           3    16.433     2.139                 (-----*-----)
5           3    19.367     2.318                       (-----*----)
6           3     9.267     3.536   (-----*----)
                                   --------+---------+---------+--------
Pooled StDev =    2.277                  10.0      15.0      20.0
```

One-way ANOVA: No. OF SEEDS PER POD versus TREATMENT

```
Analysis of Variance for No. OF S
Source     DF        SS        MS        F        P
TREATMEN    5     84.34     16.87    11.87    0.000
Error      12     17.05      1.42
Total      17    101.39
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
1           3    15.367     1.361                     (----*----)
2           3    14.933     0.850                    (----*----)
3           3    15.167     0.153                     (----*----)
4           3    14.867     0.321                    (----*----)
5           3    16.400     1.136                         (----*----)
6           3     9.700     2.128  (----*----)
                                   ---+---------+---------+---------+---
Pooled StDev =    1.192               9.0      12.0      15.0      18.0

Fisher's pairwise comparisons
```

One-way ANOVA: POD LENGTH versus TREATMENT

```
Analysis of Variance for POD LENG
Source     DF        SS        MS        F        P
TREATMEN    5     52.39     10.48     2.38    0.102
Error      12     52.90      4.41
Total      17    105.29
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ------+---------+---------+---------+
1           3    16.867     2.268              (--------*--------)
2           3    18.233     1.940                   (--------*--------)
3           3    16.967     1.790               (--------*-------)
```

```
4           3    17.567     0.907                  (--------*-------)
5           3    15.967     3.564            (--------*--------)
6           3    12.933     0.902  (--------*--------)
                                   ------+---------+---------+---------+
Pooled StDev =    2.100               12.0      15.0      18.0      21.0

Fisher's pairwise comparisons
```

One-way ANOVA: 100 SEED WEIGHT versus TREATMENT

```
Analysis of Variance for 100 SEED
Source     DF        SS        MS        F        P
TREATMEN    5    89.923    17.985    32.83    0.000
Error      12     6.573     0.548
Total      17    96.496
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    14.000     0.889                     (---*---)
2           3    14.233     0.681                      (---*---)
3           3    14.433     1.026                       (---*--)
4           3    15.433     0.513                           (---*--)
5           3    16.233     0.503                              (---*---)
6           3     9.233     0.681  (---*---)
                                   -------+---------+---------+---------
Pooled StDev =    0.740                10.0      12.5      15.0
```

One-way ANOVA: ABOVE GROUND DRY BIOMASS YIELD(versus TREATMENT

```
Analysis of Variance for ABOVE GR
Source     DF        SS        MS        F        P
TREATMEN    5  17398486   3479697    13.10    0.000
Error      12   3187905    265659
Total      17  20586391
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----+---------+---------+---------+--
1           3    6711.1     407.3                           (----*----)
2           3    6088.9     384.9                     (-----*----)
3           3    6089.0      77.1                     (-----*----)
4           3    6400.0     533.3                        (----*-----)
5           3    6622.2     154.0                          (----*-----)
6           3    3822.2     982.8  (-----*----)
                                   ----+---------+---------+---------+--
Pooled StDev =    515.4             3600      4800      6000      7200
```

One-way ANOVA: HARVEST INDEX (%) versus TREATMENT

```
Analysis of Variance for HARVEST
Source     DF        SS        MS        F        P
TREATMEN    5   1297.89    259.58    64.78    0.000
Error      12     48.09      4.01
Total      17   1345.98
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    32.000     0.361                  (--*--)
2           3    35.333     0.839                      (-*--)
```

```
3           3    36.467     2.754                           (-*--)
4           3    38.167     0.643                             (-*--)
5           3    42.233     1.159                                 (-*--)
6           3    15.600     3.724  (--*-)
                                   -------+---------+---------+---------
Pooled StDev =    2.002                  20        30        40
```

One-way ANOVA: GRAIN YIELD versus TREATMENT

```
Analysis of Variance for GRAIN YI
Source     DF        SS        MS        F        P
TREATMEN    5   8856047   1771209    66.15    0.000
Error      12    321300     26775
Total      17   9177347
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ------+---------+---------+---------+
1           3    2151.1     154.5                      (--*-)
2           3    2155.5     188.7                      (--*--)
3           3    2240.0     220.3                       (--*--)
4           3    2440.0     174.9                          (--*-)
5           3    2800.0     135.3                              (--*--)
6           3     573.3      61.1   (-*--)
                                   ------+---------+---------+---------+
Pooled StDev =    163.6                 800      1600      2400      3200
```

One-way ANOVA: YIELD LOSS versus TREATMENT

```
Analysis of Variance for YIELD LO
Source     DF        SS        MS        F        P
TREATMEN    5   11265.6    2253.1   208.40    0.000
Error      12     129.7      10.8
Total      17   11395.3
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
1           3    23.223     2.308           (*-)
2           3    23.090     3.504           (*-)
3           3    20.037     5.969         (-*-)
4           3    12.920     2.041       (*-)
5           3     0.000     0.000  (-*-)
6           3    79.457     2.733                                  (-*)
                                   --+---------+---------+---------+----
Pooled StDev =    3.288              0        25        50        75
```

One-way ANOVA: WEED DENSITY versus TREATMENT

```
Analysis of Variance for WEED DEN
Source     DF        SS        MS        F        P
TREATMEN    5  202000.2   40400.0   649.47    0.000
Error      12     746.5      62.2
Total      17  202746.6
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -+---------+---------+--------+-----
1           3     46.33      3.82       (*)
```

```
2           3     48.58     17.70        (*)
3           3     75.67      4.16           (*)
4           3     52.17      4.65        (*)
5           3      0.00      0.00   (*)
6           3    322.33      2.57                                 (*)
                                    -+---------+---------+---------+-----
Pooled StDev =     7.89              0       100       200       300
```