AGRONOMIC EVALUATION OF COWPEA (*VIGNA UNGUICULATA* L. WALP) AND COTTON (*GOSSYPIUM HIRSUTUM*) INTERCROPPING AND EFFECTS OF FOLIAR CHEMICAL SPRAYS APPLIED ON COTTON ON INCIDENCE OF COWPEA PESTS.

MSc. (AGRONOMY) THESIS

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UNIVERSITY OF MALAWI

BUNDA COLLEGE OF AGRICULTURE

NOVEMBER, 2014.

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BSc. Agriculture (Crop Science), Malawi.

A THESIS SUBMITTED TO THE FALCULTY OF AGRICULTURE IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY.

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NOVEMBER, 2014.

DECLARATION

I, Louis Hortensius Mwamlima, declare that this thesis is a result of my own original effort and work and that to the best of my knowledge, the findings of this study have never been previously presented to the Lilongwe University of Agriculture and Natural Resources or elsewhere for the award of any academic qualification. Where assistance was sought, it has been accordingly acknowledged.

Louis Hortensius Mwamlima

Signature : ------------------------------------

Date : ------------------------------------

CERTIFICATE OF APPROVAL

We, the undersigned, certify that this thesis is a result of the students own effort, and that to the best of our knowledge, it has not been submitted for any other academic qualification within the Lilongwe University of Agriculture and Natural Resources or elsewhere. The thesis is accepted in the form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on ---.

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DEDICATION

This humble effort, the fruit of my thoughts and studies, is dedicated to my lovely and wonderful son Praise for being deprived of the fathers' love and care at the age of one.

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ABSTRACT

Land pressure and increased costs of of insect pests' management in sole cotton and cowpea crops limit production of cotton and cowpea in Malawi. In this regard, experiments were conducted at Bunda College Crop Science Student Research Farm and on farmers' fields in Rivirivi and Mpingu Extension Planning Areas (EPAs) in Balaka and Lilongwe districts respectively during 2011/2012 season to assess performance of different intercropping systems and effectiveness of foliar pesticides applied on cotton on incidences of intercropped cowpea pests. The experiment at Bunda College had 10 treatments: sole sprayed cotton, sole unsprayed cotton, sole sprayed cowpea, sole unsprayed cowpea, 1:1 strip (same time) intercropping, 1:1 strip (delayed) intercropping, 2:2 strip (same time) intercropping, 2:2 strip (delayed) intercropping, within row intercropping (Sudan) and within row intercropping (IT82E-16). Six treatments were evaluated on farm namely sole sprayed cotton, sole sprayed cowpea, 1:1 strip (same time) intercropping, 2:2 strip (delayed) intercropping, within row intercropping (Sudan) and within row intercropping (IT82E-16). Experiments at Bunda and in Mpingu EPA were laid out as Randomized Complete Block Design while at Rivirivi EPA farmers were taken as replicates. Data were subjected to analysis of variance in Genstat statistical software and significant means were separated using Least Significant Difference (LSD). Intercropping productivity was assessed using Land Equivalent Ratio, Area Time Equivalent Ratio and Crop Performance Ratio. Bunda results indicate that cotton and cowpea growth and yield parameters were significantly influenced by intercropping systems (<0.001). The 1:1 and 2:2 strip cropping gave seed cotton yields that were similar to sole sprayed cotton at all sites. Lowest seed cotton yields were registered from within row intercropping treatments at all sites. At Bunda, sole sprayed cowpea gave highest cowpea grain

yields followed by 1:1 strip (delayed). In Rivirivi and Mpingu EPAs, strip 2:2 (same time) and within row intercropping (Sudan) gave highest grain yields respectively. Delaying cowpea sowing reduced cowpea grain yields by 19%, number of pods per plant by 18% and seed size by 10% at Bunda. All biological indices had values greater than 1.0 indicating more productivity of intercropping over sole cropping. Pesticides applied on cotton to control cotton pests significantly reduced pests populations of intercropped cowpea. Delaying cowpea planting significantly ($P<0.001$) reduced *Maruca testulalis* and *Anoplocnemis curvipes* but increased thrips damage at Bunda. Simultaneous sowing of cotton and cowpea is recommended for increased production of the two crops. Growers are encouraged to use either 1:1 or 2:2 strip cropping with the choice dependent of the objectives of the grower.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREBIATIONS AND ACRONYMS

ANOVA	Analysis of variance
ASWAP	Agricultural Sector Wide Approach
ATER	Area Time Equivalent Ratio
CAN	Calcium Ammonium Nitrate
Cm	Centimetre
CPR	Crop Performance Ratio
CTD	Cotton Development Trust
CV	Coefficient of Variation
EC	Emulsifiable Concentrate
ERP	Economic Recovery Plan
EPA	Extension Planning Area
FISP	Farm Input Subsidy Programme
GOM	Government of Malawi
HI	Harvest Index
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Centre for Africa.
JIRCAS	Japan International Research Centre for Agricultural Sciences
LER	Land Equivalent Ratio
LSD	Least Significant Difference
M	Metre
MAI	Monetary Advantage Index
Masl	meters above sea level
Mg	Milligram
MER	Monetary Equivalent Ratio

MoAFS	Ministry of Agriculture and Food Security
N	Nitrogen
ns	not significant
OM	organic matter
P	Phosphorous
PAR	Photosynthetic Active Radiation
pH	Power of Hydrogen
RCBD	Randomized Complete Block Design
RH	Relative Humidity
RUE	Radiation use Efficiency
TDM	Total Dry Matter
WAP	Weeks after planting
WP	Wettable Powder

CHAPTER ONE

INTRODUCTION

1.1 Main growing areas of cotton and cowpea in Malawi

Malawi has four major ecological zones for cotton production as described by the Ministry of Agriculture Irrigation and Food Security (2005a). These are the Shire valley with altitude below 100 m above sea level and rainfall ranges of between 500 to 800 mm per annum. This zone comprises Chikwawa and Nsanje districts. The second zone is the lakeshore area which covers Mangochi, Salima, Nkhota-kota and Karonga districts. Altitude is 500 to 600 m above sea level with rainfall ranging from 600 to 1000 mm per annum. The third is the medium altitude agro-ecological zone which has altitude ranging from 500- 1000 metres above sea level and rainfall ranges between 500- 900 mm per annum. Areas in this zone include Mwanza, Neno, Blantyre and Phalombe plain, Machinga, Balaka, Nkhamanga plains and the Henga / Kasitu valley in Rumphi and Mzimba districts. The fourth is a high altitude agro-ecological zone with altitude of over 1000 m above sea level and rainfall above 1000 mm per annum. Areas in the high altitude areas include Shire highlands, the Lilongwe West plain through Mchinji and Kasungu. In Malawi it is estimated that a total of 200,000 farm families are engaged in the production of cotton on about 50,000 hectares of land (CDT, 2010). Average seed cotton yields in Malawi range from 700 – 800 kg per hectare which are generally lower than cotton yields obtained in other sub-Saharan countries. The low cotton yields are attributed to poor crop and insect pest management practices (MoAFS, 2005a).

Cowpea is grown all over the country particularly in warm areas with low rainfall like the Shire valley, Bwanje valley, lakeshore and Phalombe plains as well as many dry areas (MoAFS, 2005b). In Malawi, average cowpea yields for both pure and mixed cropping range from 300 - 600 kilogrammes per hectare (MoAFS, 2005b) and these low yields have been attributed to use of low yielding and late maturing varieties, low plant density and insect pest damage (MoAFS, 2005b; Mbwaga, et al., 2007). Overall cowpea yields in Malawi have been fluctuating over time and estimated cowpea production under smallholder and estate farming have ranged from 35,392 – 105,315 kg per annum between 1992 and 2008 (MoAFS, 2010b).

1.2 Economic importance of cotton and cowpea production in Malawi

Cotton (*Gossypium hirsutum L.)* and Cowpea (*Vigna unguiculata* L. Walp) have the following importance to the social and economic development of the country and humankind:

1.2.1 Human nutrition

Food deficits resulting from declining agricultural productivity may result in severe malnutrition. Severe malnutrition may be caused by failure by the rural poor to produce enough food to feed them to the next crop growing season and that the diets of the vast majority of Malawians may lack necessary food nutrients such as proteins, oils and vitamins (Lipita and Kanyenda, 2008). The large amount of protein and energy (in form of oils) which provide an important nutritional benefit to the relatively carbohydrate-rich Malawian Maize-based diet come from legumes, fibres and oil seed crops where cowpea and cotton graciously belong. Oil is necessary for the absorption of fatty soluble vitamins, such as Vitamins A, D, E and K.

Vitamin A is necessary because its deficiency leads to sight problems. The addition of even a small amount of nutrition-rich cowpea (Table 1.1) to a human diet ensures the nutritional balance of the diet and enhances protein quality by the synergistic effect of high protein and high lysine from cowpea and high methionine and energy from cereals (Mbwaga, et al., 2007).

Table 1.1 Chemical composition of cowpea (%) per 100g.

Element	**Dry grain**	**Young green pods**	**Hay**	**Leaves**
Carbohydrates	56-66	7.4	-	8
Protein	22-24	3.4	-	4.7
Water	11.0	86.2	18	85
Crude fibre	5.9-7.3	1.8	9.6	2
Ash	3.4-3.9	0.9	23.3	-
Fat	1.3-1.5	0.3	11.3	0.3
Phosphorous	0.146	-	2.6	0.063
Calcium	0.076-0.104	-	-	0.256
Iron	0.005	-	-	0.005

Source: Quinn (1999)

1.2.2 Food Security and mitigation of rural poverty

More than 80% Malawi's population lives in rural areas where poverty is high and more than half of the population lives below the poverty line. Cotton and early maturing cowpea genotypes have a ready domestic and export markets and therefore play an important role at increasing farmers' incomes resulting in attainment of household food security in the country. As such, promotion of these crops has a very important impact on the rural community especially women farmers who have tended to be excluded from growing Malawi's traditional cash crops.

Cotton also plays an important role as a raw material for cloth manufacturing industries (Lipita and Kanyenda, 2008).

1.2.3 Animal nutrition

Cowpea and cotton greatly contribute to animal production because of their good oil and protein contents. Oil is necessary for absorption of fatty soluble vitamins such as A,D,E,K (Quinn, 1999). Cowpea can be used to make poultry rations thereby promoting production of poultry products which are currently being imported from neighbouring countries (GOM, 2006). By-products from cowpea and cotton such as cowpea and cotton seed cakes can be fed to livestock and are a very good source of protein and energy (Banda and Masambo, 1995; GOM, 2006). Cotton seed and legume meals comprise 15-30% of livestock and 70% of poultry diets with nutritional values of 22% crude protein, 57% carbohydrates and 4% fibre depending on variety used and method of processing (Rathore, 2007; Safalaoh, 2007).

1.2.4 Foreign Exchange earnings

Legume crops such as pigeon pea, common beans, soybeans, cowpea and groundnut have big export market potential both in the SADC and European markets. The advancement of tobacco anti-smoking lobby globally has seen reduction of tobacco exports and increased demand for cotton products from Malawi (Lipita and Kanyenda, 2008; GOM, 2012). In 2010, export of legumes accounted for 6.3% of total Malawi exports representing an annual growth rate of 21.4% between 2001 and 2010. During the same period annual growth rate for tobacco export was at 7.8% (GOM, 2012).

Cotton ranks fourth as a foreign exchange earner for the country after tobacco, tea, and sugar (MoAFS, 2006). Cotton seed is used as a primary source of cooking oil and livestock feed (Lipita and Kanyenda, 2008).

1.2.5 Improvement of soil fertility

Cowpea contributes to the sustainability of cropping systems and soil fertility improvement on marginal lands through nitrogen fixation, provision of ground cover and plant residues, which minimize erosion and subsequent land deterioration (IITA, 1997). Cowpeas fixes about 40-80 kg N/ha (Giller, 2001) through the biological nitrogen fixation depending on crop growth duration, species density, soil pH and availability of inorganic N and P. Some of the fixed N is exported from the field through grain harvests (IITA, 1997; Giller, 2001).

1.3 Cotton and cowpea production systems

Cotton is ideally suitable for intercropping because of the relatively longer growth duration and its slow growth in the initial stages (Sankaranaraynan, 2011). At global level, the common practice of cotton cultivation is inter or mixed cropping with pulses and vegetables such as radish, beetroot and coriander. In most sub Saharan African countries, including Malawi, cotton is largely monocropped but where intercropping is practiced, cotton is intercropped with pulses such cowpea. In some sub Saharan African countries, cotton is mostly grown under contract farming where smallholder farmers enter into contract with larger agribusiness firms that provide farmers with inputs on credit and extension services in return for a guaranteed delivery of produce. Cowpea is a major component of cropping system of the drier parts of the tropics, particularly sub-Saharan Africa.

In sub Saharan Africa region, cowpea is grown as a sole stand or intercropped with other field crops such as cereals, vegetables, or cotton (IITA, 1997). Blade, et al. (1997) reported that 98% of cowpea grown in sub-Saharan Africa has been intercropped for long time due to its shade tolerance. In Malawi cowpea production is mainly rain fed and is largely grown by small scale farmers either a sole crop or in mixed cropping with cereals such as maize. Within row intercropping system is the most commonly used intercropping system of cowpea and other crops that is used by smallholder farmers in Malawi.

1.4 Cotton and cowpea production constraints

Constraints to large scale cowpea and cotton production and utilization have been widely documented and affect producers and consumer decision to invest in the production and utilization of the two crops. The major constraints include inadequate availability of good quality seed, use of inappropriate and/or poor agronomic practices, limited access to production inputs, insect pest and disease problems, low market prices, limited processing knowledge and skills, limited access to markets and market information systems and high HIV/AIDS prevalence amongst the workforce which reduces labour availability (Ennin Kwabia and Osei Bonsu, 1993; MoAFS, 2006; Gandebe, et al, 2010). Cotton and cowpea production is also limited by land shortages due to increased human population.

1.5 Problem Statement

Cowpea is usually intercropped with cereals or other crops although it is also grown as a sole crop. Its productivity is limited by high infestation with insect pests (MoAFS, 2005b) so that spraying against such insect pests is important for good yields. Similar to cowpeas, insect pests equally limit cotton production. Thus insecticide application is recommended for optimal yields. However, profit margins of cotton and cowpea have recently been reduced as a result of rising costs of insecticides (Natarajan and Sheshadri, 1988; MoAFS, 2010a). Therefore for both crops, interventions are needed to increase returns in order to make their production more attractive. One way of optimizing such profit margins would be to intercrop cotton and cowpea so that the cowpea benefits from insecticide sprays applied on cotton; where cowpea would be a bonus crop to the growers. The success of this principle though depends on identification of a compatible cowpea - cotton intercropping system that would not negatively impact on the productivity of either crop. Not much research has been done in Malawi that could not only help identify intercropping systems that would help optimize cowpea and cotton crops growth and yields when grown simultaneously in the same field, but also that could help assess the effectiveness of pesticides applied on cotton to control cotton pests at reducing the abundance of cowpea insect pests. In view of the above, it was important for this study to simultaneously identify the best intercropping arrangement of growing cotton and cowpea that would optimize cowpea and cotton yields in the context of dwindling landholding sizes for Malawi smallholder farmers in addition to assessing the potential of reducing cowpea insect pests' population pesticides drifts from cotton.

1.6 Justification

Cotton and cowpea are among the most important crops grown in Malawi by most smallholder farmers. The identification of an ideal intercropping system of cotton and cowpea will help many farmers to produce the two crops in a cheaper way resulting in increased profits. With reduced earnings from a traditional cash crop tobacco during the last three to four seasons, the Malawi Government and various stakeholders in the agriculture sector have been promoting production of cotton on smallholder farms in upland areas that are not traditionally associated with cotton production. Increased cotton production from non-traditional cotton growing areas through better cotton and cowpea intercropping systems would ease the economic downturn caused by poor performance of the agricultural sector. Similarly, with increasing costs of animal proteins and growing demand of legumes for domestic consumption and as a raw material for agro-based processing industries, legume crops like cowpea are being promoted for production in many cotton growing areas. While the Agricultural Sector wide Approach programme (ASWAP), a Malawi Government prioritized and harmonised agricultural development agenda, aims at stimulating the production of diversified foods with high nutritional value such as cowpea to help attain sustainable nutritional security, the Malawi Growth and Development Strategy (II) targets up-scaling of cotton and leguminous crops like cowpea as a short and medium term measure of improving the country's economy (GOM, 2006). Much as cotton and cowpeas are being promoted for production among smallholder farmers, productivity is limited by insect pest damage and the management of such pests require huge investments. Cotton is a host to a number of pests such as bollworms, leaf chewing and sucking insects. On the other hand, flower and pod borers (*Maruca testulalis*), African bollworm *(Helicoverpa amigera)* sucking bugs (*Anoplocnemis curvipes*) and flower thrips (*Taemothrips sjostedti*) attack cowpeas. This shows that both cotton and cowpeas require considerable investment in insect pest management if meaningful returns are to be obtained from the two crops. When grown in pure stands, the combined costs of insect pest management in the two separate cotton and cowpea fields can prohibit farmers from investing in the production of the two crops. Because of high poverty levels, most smallholder farmers are dependent on financial support from government programmes such as the Farm Input Subsidy Programme (FISP) and loans from financial institutions in the agriculture sector to improve crop production (GOM, 2006). The government of Malawi (2006) reported that the smallholder agriculture sector had the worst growth rates with a decline of 1.8 percent between 2000 and 2005. These were the years when financial support for farm inputs was withdrawn. This emphasizes the need for the development of farming systems such as intercropping that would help reduce the burden of high production costs resulting from insect pest management. In addition, the increasing human population in Malawi has brought pressure on land to an extent that farmers are prioritising the types of crops to grow. With the growing population, customary land which is the basis for smallholder agricultural production has become more fragmented and land holding sizes have declined to an average land size holding per household of 1.2 hectares while the average land per capita is at 0.33 hectares (GOM, 2006). An alternative to growing pure cowpea and cotton stands with a resultant decrease on land pressure is to practice the intercropping of the two crops. Since some insects that attack cotton such as the African bollworms, aphids and leaf eaters also attack cowpeas and are controlled by the same insecticides (MoAFS, 2005b), the intercropping of the two crops may be an alternative in reducing production costs associated with pests' management of both crops and also help up-scaling of cowpea production among smallholder and estate growers in cotton growing areas. In the intercrop, cowpeas would benefit from foliar chemical sprays applied to control cotton pests other than applying the insecticides on both crops independently. However, much as the intercropping of cotton and cowpea may seem to be very feasible in reducing insect pest management costs and land pressure, the effectiveness of foliar chemical sprays applied on cotton on incidences of cowpea pests and an appropriate intercropping pattern to maximize potential yields of the two crops are not scientifically confirmed.

1.7 Research Questions

The study was conducted to provide answers to the following questions:

- Which intercropping systems would optimize growth and yield of cotton and cowpea?
- Would foliar pesticides applied to control cotton pests be effective against cowpea pests in cotton - cowpea intercropping?
- Does time of planting cowpea affect performance of cotton and cowpea in intercropping?
- What is the effect of intercrop system on occurrence and abundance of cotton and cowpea pests in cotton - cowpea intercrop?

1.8 Hypotheses

The research was carried under the following hypotheses.

- Strip intercropping optimizes cowpea and cotton growth and yields in a cowpea and cotton intercropping.
- Foliar insecticides applied on cotton to control cotton pests reduce cowpea pests in intercropped cowpea.

- Cotton and cowpea intercropping reduces occurrence and abundance of cotton and cowpea pests.

- Planting cowpea two weeks after cotton in a cotton-cowpea intercropping enhances growth and productivity of cotton as a companion crop.

- Cotton plant growth and seed cotton yields are positively influenced by cowpea growth habit in within row intercropping.

1.9 Objectives

The main objective of the study was to assess the performance of cotton and cowpea under different intercrop systems and the effects of foliar insecticides applied to control cotton insect pests on the management of cowpea insect pests.

The following were the specific objectives.

- To determine an appropriate cotton and cowpea intercropping system for optimum growth and yields of cowpea and cotton crops.
- To determine the effectiveness of foliar chemical insecticide sprays applied on cotton to control cotton insect pests at reducing the occurrence and abundance of cowpea insect pests.
- To determine the effect of intercropping systems on the occurrence and abundance of cotton and cowpea insect pests.
- To determine an appropriate time for sowing cowpea in cotton - cowpea intercrop.
- To determine the performance of determinate and indeterminate cowpea varieties in within row intercropping.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and types of cotton and cowpea

Cotton has been cultivated in the warmer climates of the world since prehistoric times. India, where cotton has been an important product for more than 3,000 years, was one of the first countries to develop cotton industry. It was grown and used for clothing in Brazil, Peru and Mexico long before the discovery of America (Poehlman, 1977). Cotton belongs to the genus *Gossypium* (Soomro, 2010). Twenty species of *Gossypium* are now recognized, including cultivated and wild species. The cultivated species have spinnable seed fibers called lint while wild species have only short seed fuzz (Poehlman, 1977). Four species *of Gossypium*, also known as cultivated species, are grown on commercial scale. These include *G. hirsutum* L, *G barbadense* which are allopolyploids (2n= 52), *G. arboretum* L. and *G. herbaceum* L. which are diploids (2n = 26). *G. arboretum* originated in the Indo-Pak sub-continent, *G herbaceum* originated in Southern Africa, *G. barbadense* originated in Peru while *G. hirsutum* originated from Mexico (Poehlman, 1977). The most commonly cultivated species in the world is *G. hirsutum* L. (90%) while *G barbadense* accounts for about 9% of the world's cotton production (Poehlman, 1977).

The genus Vigna, where cowpea belongs, currently includes around eighty species distributed throughout the tropics (Pasquet, 2001). It comprises seven domesticated species five of which are Asiatic and two are of African Origin. The Asiatic group consist of green grum *[V. radiatta* (L) Wilczeck], black grum [*V. mungo* (L) Hepper], moth bean [*V. aconitifolia* (Jack) Ohwi et Ohashi], adzuki bean [*V.angularis* (Wild) Ohwi et Ohashi) and rice bean [*V.umbellate* (Thumb) Ohwi et Ohashi]. The African group comprises Bambara groundnut [*V. subterranean* (L) Verdc] and cowpea [*V. unguiculata* (L) Walp]. The cultivated cowpea *[Vigna unguiculata* (L) Walp] is believed to have originated from Central Africa where it spread in early times through Egypt or Arabia to Asia and the Mediterranean. It was introduced to West Indies in the 16th Century by the Spaniards and was introduced to America in about 1700 AD. Cowpeas are now widely grown in the tropics and the sub tropics (Pasquet, 2001). Cowpea is largely distinguished by its growing habit where it can either be classified as indeterminate (trailing type) or determinate (erect, non-trailing)

2.2 Cotton production trends in Malawi

The objective of the Malawi government is to increase cotton production and improve quality in order to meet local demand and export any surplus (MoAFS, 2006). Production can be increased by improving yield towards potential and expanding hectarage in all suitable areas (MOAFS, 2005b). Cotton production in Malawi is solely dependent on rainfall and is presently mostly grown by smallholder farmers (MoAFS, 2006). In the lower Shire valley, cotton is probably the most reliable cash crop and farmers mostly depend on it for their livelihoods (Banda and Masambo, 1995). The sector is characterized by many growers with small pieces of land ranging from 0.2 to 1.6 hectares. Previous studies have shown that large scale commercial farmers had cultivated the crop in Malawi but due to declining profitability resulting from reduced prices on the international markets over the past 15 years, high labour and pest management costs, many commercial farmers substituted cotton production with other cash crops (MOAFS, 2006). The lower Shire valley districts of Chikwawa and Nsanje produce about 31,144 tonnes of cotton out of a national total cotton production of close to 50,000 tons annually.

Cotton average yields vary between countries ranging from as low as 400 kg ha^{-1} in Mozambique to as high as 800 kg ha^{-1} in Zimbabwe (Gwarazimba, 2009). In India average cotton yields are at 599 kg ha^{-1} slightly higher than the average world production of 590 kg ha^{-1} (Balakrishnan, et al., 2010). In Malawi farmers' average seed cotton yields have remained stagnant at about 500 kg ha^{-1} for many years but use of recommended varieties, proper pest management and use of appropriate agronomic practices have the potential to increase seed cotton yields to over 2,500 kg per hectare (Banda and Masambo 1995; MoAFS, 2010a). Between 2001 and 2011, the cotton total annual production has fluctuated between 29,000 metric tonnes and 76,000 metric tonnes per annum giving an average of 54,000 tonnes annually which is still below the potential of 100,000 metric tonnes of seed cotton that the country can produce (MoAFS, 2010b).

2.3 Cowpea production trends in Malawi

Cowpea is the second most important legume in the world after soya beans and is grown on 11.4 million hectares worldwide; 97% of which is grown in the sub-Saharan Africa (IITA, 2009). Total cowpea area harvested in Malawi has risen by 30 -38% representing an area of about 115, 000 hectares between 1994 and 2008 while world cowpea production and yields have increased by 88% and 35% in the same time period (IITA, 2009). Despite this dramatic increase in cowpea production in Southern Africa, cowpea yields remain one of the lowest among all food legumes (Gomez, 2004).

2.4 Recommended pesticides for cotton and cowpea pests in Malawi

Cotton and cowpea may host some similar pests which are either grouped according to the period they attack the crops (early, mid and late season pests) or part of the plant they feed on (bollworms, pod borers, leaf eaters, sucking pests), (MoAFS, 2005a). The effective control of insect pests both in cotton and cowpea is dependent on the use of right pesticide, the dosage used, time of application and stage of plant growth among other factors (Pedigo and Rice, 2009). In Malawi some of the pesticides recommended for the control of cotton and cowpea pests are as shown in Table 2.1. The recommended pesticides are also widely used in the control of various pests in different crops.

Table 2.1 Some recommended pesticides for the control of selected cotton and cowpea pests in Malawi.

Pesticide name	**Cotton pests controlled**	**Cowpea pests controlled**	**Recommended rates**
Cypermethrin and	African bollworm *(Helicoverpa armigera)*	legume pod borer *(Maruca testulalis*)	20 EC, 10 millilitres, 14 litres water
Carbaryl	red bollworm *(Diparopsis castanea)*	cowpea beetle *(Ootheca mustabilis)*	85 WP. 85 g, 14 litres water
	pink bollworm (*Pectinophora gossypiella)*	African bollworm *(Hericoverpa armigera)*	
	spiny bollworm *(Earias spp.*		
Dimethoate	cotton aphid *(Aphis gossypii)* red spider mites *(Tetranychus spp.)*	cowpea aphids *(Aphis craccivora).* flower thrips *(Taeniothrips sjostedti).* red spider mites *(Tetranychus spp.).*	40EC, 17 millilitres water

Source: MoAFS, (2005b)

2.5 Intercropping Systems

There are different types of intercropping ranging from regular arrangements of the component crops to cases where the different component crops are intermingled. In mixed intercropping, the plants are totally mixed in the available space without arrangement in distinct rows, whereas in alternate-row intercropping, two or more plant species are cultivated in separate alternate rows.

Another option is that of within-row intercropping where the component crops are planted simultaneously within the same row in varying seeding ratios. With strip intercropping, several rows of plant species are alternated with several rows of another plant species. In strip intercropping, multiple crops are grown in narrow adjacent strips that allow interaction between different crop species. The response of crops grown in strip intercropping is most determined by the number of rows in the strip. Wider strips tend to reduce the shading effect of the shorter component crop (Johnson, 1999). Intercropping also uses the practice of sowing a fast-growing crop with a slow-growing crop so that the first crop is harvested before the second crop starts to mature. This practice requires some kind of temporal separation, e.g. different planting dates of the component crops so that the differential influence of weather and in particular temperature on component crop growth can be modified (Midmore, 1993). Further temporal separation is found in relay intercropping where the second crop is sown during the growth, often near the onset of reproductive development or fruiting of the first crop, so that the first crop is harvested to make room for the full development of the second crop (Andrews and Kassam, 1976).

2.5.1 Principles and concepts of intercropping

Sustainable agriculture seeks to use nature as a model for designing agricultural systems and that some benefit of diversity can be realised by planting mixtures of different crops (Sullivan, 2003). The following are the underlining principles and concepts of intercropping as provided by Sullivan (2003).

- Cooperation is more apparent than competition. This principle asserts that in an ecosystem there is a symbiotic association amongst organisms.

- Stability tends to increase with increasing diversity. The more complex and diverse communities become the fewer fluctuations in numbers of given species, and the more stable communities tend to be.

In intercropping, each crop must have adequate space to maximize cooperation and minimise competition between them. To accomplish this, four concepts to be considered in intercropping are spatial arrangement, plant density, maturity dates of crops being grown and plant architecture (Sullivan, 2003).

2.5.2 Advantages of intercropping

2.5.2.1 Efficient resource utilization, yield and labour advantage

The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Willey, 1979). Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops, which exploit the variation of the mixed crops in characteristics such as rates of canopy development, final canopy size (width and height), photosynthetic adaptation of canopies to irradiance conditions, and rooting depth (Midmore, 1993; Morris and Garrity, 1993; Tsubo, et al., 2001). This yield advantage occurs when the component crops do not compete for the same ecological niches and the interspecific competition for a given resource is weaker than the intraspecific competition (Fukai and Trenbath, 1993; Keating and Carberry, 1993; Lithourgidis, et al., 2011).

Normally, complementary use of resources occurs when the component species of an intercrop use qualitatively different resources or they use the same resources at different places or at different times (Tofinga, et al., 1993). Improved resource use gives, in most cases, a significant yield advantage, increases the uptake of other nutrients such as P, K, and micronutrients, and provides better rooting ability and better ground cover as well as higher water use efficiency (Midmore, 1993; Morris and Garrity, 1993). Intercropping would also encourage crop diversification thereby reducing labour costs.

2.5.2.2 Insurance against crop failure

Intercropping provides high insurance against crop failure in areas subjected to extreme weather conditions such as drought, flood. Intercropping provides greater financial stability for farmers, making the system particularly suitable for labour-intensive small farms (Lithourgidis, et al., 2011). If a single crop may fail because of adverse conditions such as drought, flood, or even pest attack, farmers reduce their risk for total crop failure by growing more than one crop in their field (Clawson, 1985; Horwith, 1985). Consequently, intercropping is much less risky than monocropping considering that if one crop of a mixture fails, the component crop(s) may still be harvested. Moreover, farmers may be better able to cope with seasonal price variability of commodities which often can destabilize their income. Combinations involving crops with slightly differing growth duration, e.g. millet and sorghum or mixtures of early- and late-maturing cultivars of the same species are used in areas with growing seasons of variable-length to exploit the occasional favourable season yet insure against total failure in unfavourable seasons (Rao, 1986).

If the growing season is long, the late-maturing type takes advantage of the abundant resources, whereas if the growing season is short, the early-maturing type can provide a reasonable yield (Lithourgidis, et al., 2011).

2.5.2.3 Soil conservation

Intercropping with legumes is an excellent practice for controlling soil erosion and sustaining crop production (El-Swaify, et al., 1988). Where rainfall amount is excessive, cropping management systems that leave the soil bare for great part of the season may permit excessive soil erosion and runoff, eventually resulting in infertile soils with poor characteristics for crop production (Lithourgidis, et al., 2011). Full canopy cover from component crops in strip intercropping help reduce the impact of rain drops leading to reduction in soil loss. Deep roots, as may be the case with cotton in this study, penetrate far into the soil breaking up hardpans and use moisture and nutrients from deeper down in the soil while shallow roots bind the soil at the surface and thereby help to reduce erosion (Lithourgidis, et al., 2011).

2.5.2.4 Improvement of soil fertility

Legumes enrich soil by fixing the atmospheric nitrogen changing it from an inorganic form to forms that are available for uptake by plants Biological fixation of atmospheric nitrogen can compliment nitrogen fertilization in N limited farming systems. International Institute of Tropical Agriculture (2009) reported that cowpea contribute about 40-80 kg N/ha through biological nitrogen fixation. When nitrogen fertilizer is limited, biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping (Fujita, et al., 1992; Adu-Gyamfi, et al., 2007).

Since high rates of inorganic fertilizers may contribute to environmental damage such as nitrate pollution, legumes grown in intercropping are regarded as an alternative and sustainable way of introducing N into lower input agro ecosystems (Lunnan, 1989; Fustec, et al., 2010). The benefits of a legume intercrop with respect to nitrogen is the direct transfer of nitrogen to companion crops that occurs mainly by excretion of nitrogen from the legume nodules, representing an immediate source of nitrogen to the cereal. The main pathway of conservation of other nutrients is through the return and decomposition of crop residues (Adu-Gyamfi, et al., 2007; Rahman, et al., 2009). Crop residues represent a major resource of fertilization for the small-scale farmer and manipulation of the fate of the nutrient released by the decomposition of crop residue is thus a main target for improving nutrient use efficiency of cropping systems (Lithourgidis, et al., 2011). This is because minerals from the soil become available for development of aboveground biomass (Lithourgidis, et al., 2011). Transfer of other nutrients, such as P, might occur through mycorrhizal bridges (Newman, 1988).

2.5.2.5 Improvement of forage quality

Intercropping field cowpeas with wheat helps to improve forage dry matter and percentage of dry matter compared to cowpea sole crop. This also enhances crude protein, neutral detergent fibre content, and water-soluble carbohydrates compared to sole crops (Lithourgidis and Dordas, 2010). Intercropping cereals with legumes is far more effective than cereal monocrop to produce higher dry matter yield and roughage for silage with better quality (Geren, et al., 2008). Increases in crude protein content by 11-51% have been recorded for the various intercrop treatments over most sole crops (Javanmard, 2009; Lithourgidis, et al., 2011). Furthermore, intercropping legumes with maize significantly reduces neutral detergent fibre and acid detergent fibre content increasing digestibility of the forage (Lithourgidis, et al., 2011).

2.5.2.6 Lodging resistance to prone crops

Intercropping can provide better lodging resistance for some crops highly susceptible to lodging (Trenbath, 1976; Assefa and Ledin, 2001). Lodging, which is commonly observed in some crops, can reduce plant growth severely (Lithourgidis, et al., 2011). Some of the damage is often attributable to subsequent disease infections and mechanical damage whereas loss of plant height reduces efficiency of light interception (Lithourgidis, et al., 2011). In addition, lodged crops may slow harvest operations or may cause harvest loss. Improved standing ability commonly results in increased harvestable yield, improved crop quality, and increased efficiency of harvest (Lithourgidis, et al., 2011).

2.5.2.7 Reduction of pest and disease incidence

Components of intercrops are often less damaged by various pest and disease organisms than when grown as sole crops, but the effectiveness of this escape from attack often varies unpredictably (Trenbath, 1993). Crops grown simultaneously on the same piece of land enhance the abundance of predators and parasites, which in turn prevent the build-up of pests, thus minimizing the need of using expensive and dangerous chemical insecticides (Lithourgidis, et al., 2011). Mixed crop species can also delay the onset of diseases by reducing the spread of disease carrying spores and by modifying environmental conditions so that they are less favourable to the spread of certain pathogens (Lithourgidis, et al., 2011). The simplification of cropping systems as in monoculture can affect the abundance and efficiency of the natural enemies which depend on habitat complexity for resources (Lithourgidis, et al., 2011). Compared to monoculture, adding more plant species to a cropping system can affect herbivores in two ways. Firstly, the environment of the host plants, e.g. neighbouring plants and microclimatic conditions, is altered and secondly, the host plant quality, e.g. morphology and chemical content, is altered (Langer, et al., 2007). Changes in environment and host plant quality lead to direct effects on the host plant searching behaviour of herbivorous insects as well as indirect effects on their developmental rates and on interactions with natural enemies (Bukovinszky, et al., 2004; Lithourgidis, et al., 2006). Variety mixtures provide functional diversity that limits pathogen and pest expansion due to differential adaptation, i.e. adaptation within races to specific host genotypic backgrounds, which may prevent the rapid evolution of complex pathogen types in mixtures (Finckh, et al., 2000). In general, intercrops may show weed control advantages over sole crops in a number of ways. First, greater crop yield and less weed growth may be achieved if intercrops are more effective than sole crops in usurping resources from weeds (Olorunmaiye, 2010) or suppressing the growth of weeds through allelopathy (Lithourgidis, et al., 2011). Alternatively, intercrops may provide yield advantages without suppressing the growth of weeds below levels observed in sole crops if intercrops use resources that are not exploitable by weeds or convert resources into harvestable materials more efficiently than sole crops. In addition, good crop cover may suppress weeds growth (Liebman and Dyck, 1993; Lithourgidis, et al., 2011).

2.5.2.8 Promotion of biodiversity

Intercropping is one way of introducing biodiversity into agro ecosystems thereby increasing the number of different crop species and ecosystem services (Hauggard-Nielsen, et al., 2003). Biodiversity may be associated with nutrient cycling that often help regulate soil fertility (Russell, 2002), limit nutrient leaching losses (Hauggaard-Nielsen, et al., 2003), and significantly reduce the negative impacts of pests and weeds (Hauggaard- Nielsen, et al., 2001; Lithourgidis, et al., 2011). Intercropping of compatible plants promotes biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. Stable natural systems are typically diverse, containing numerous different kinds of plant species, arthropods, mammals, birds, and microorganisms. As a result, in stable systems, serious pest outbreaks are rare because natural pest control can automatically bring populations back into balance (Altieri, 1994; Scherr and McNeely, 2008).

2.5.3 Disadvantages of intercropping

Depending on crop mixtures, competition for light, water and nutrients, or allelopathic effects may occur between mixed crops which may result in yield losses (Willey, 1990). Sakala (1998) pointed out that one of the limitations of intercropping is that the growth environment encountered by a component crop in intercropping may be different from that of the sole crop, the nature and degree depends strongly on the type of the associated crop. The environment modification may result in competition and have a significant negative impact on the growth and yield of the crop. Sakala (1998) further indicated that the most obvious modification of intercrop environment is where a short statured component is shaded by a taller one, consequently reducing the capture of photosynthetically active radiation resulting in reduced growth and yield of a shorter crop. Another disadvantage of intercropping is thought to be the difficulty with practical management, especially where there is a high degree of mechanization or when the component crops have different requirements for fertilizers, herbicides, and pesticides. Additional cost for separation of mixed grains, poor produce quality arising from mixtures, lack of marketing of mixed grains, problems at harvest due to lodging, and grain loss at harvest can also be serious drawbacks of intercropping (Lithourgidis, et al., 2011).

2.6 Intercropping and radiation use efficiency

The fraction of global radiation used by plants is called photosynthetically active radiation (PAR) (Keating and Carberry, 1993; Tsubo, et al., 2001; Rizzalli, et al., 2002). The importance of radiation lies in the vital role it plays in photosynthesis (Sinoquet, et al., 2000; Tsubo, et al., 2001; Yahuza, 2011a). Radiation has an important role in water use through effects on evaporation (Keating and Carberry, 1993; Singer, et al., 2011) and transpiration (Sinoquet, et al., 2000). Keating and Carberry (1993) reported that the productivity per unit incident radiation might be improved by the adoption of a cropping system that either increases the interception of radiation and/or maintains higher radiation use efficiency. Radiation use efficiency (RUE), which is defined as the ability of a crop to produce dry matter per unit of radiation intercepted and/or absorbed (Gallagher and Biscoe, 1978) is affected by factors such as crop species or cultivars involved, crop development stage, vapour pressure and drought (Awal and Ikeda, 2003). Intercropping is one of the sustainable ways to improve the interception of radiation by crops particularly during the early stages of growth (Awal, et al., 2006; Johansooz, et al., 2007). Yahuza (2011a) indicated that the amount of radiation intercepted by an intercrop can be improved through temporal and/or spatial manipulation of agronomic practices. Temporal resource use refers to a phenomenon where the intercrops make use of resources at different times such that competition is less (Willey, 1979; Ong, et al., 1991). Temporal complementarity in resource use is possible when crops of different durations are grown together, making demand for resources at different times of the growing season (Johansooz, et al., 2007). Spartial resource use refers to a phenomenon where the intercrops make use of resources at the same time but in different form due to either morphological and/or phenological attributes (Francis, 1989; Johansooz, et al., 2007). Spartial complementality is possible in situations where there is heterogeneity in the canopy and root systems of intercrops resulting in improved resource utilization (Willey, 1990).

2.7 Assessment of biological efficiency and economic profitability of intercrops

Irrespective of the index used in calculating intercrop efficiency, the performance of intercrops relative to sole crops is usually assessed in terms of seed or biomass yield (Fukai, 1993). Harris, et al. (1987) suggested resource use efficiency as an alternative way of evaluating biological efficiency of intercrops. Yahuza (2011b) indicated that irrespective of biological indices used in assessing intercrop advantages, there is need to indicate and assess the economic profitability of the intercrop if at least one of the component crops is a cash crop.

2.7.1 Biological indices

2.7.1.1 Land Equivalent Ratio (LER)

Land equivalent ratio (LER) is defined as the relative land area growing the sole crop that is required to produce the yields achieved when growing the intercrops (Baumann et al., 2001; Seran and Brintha, 2009). Land equivalent ratio is most basic biological index that most agricultural scientists generally employ to evaluate intercropping and LER helps to indicate the relative competitive abilities of component crops in the intercrops (Seran and Brintha, 2009). Yield advantages from intercropping, as compared to sole cropping, are often attributed to mutual complementary effects of component crops, such as better use of available resources (Thobatsi, 2009). Land equivalent ratio values of more than one indicate intercrop efficiency (Baumann, 2001), and LER values give an indication of magnitude of sole cropping required to produce the same yield on a unit of intercrop land (Thobatsi, 2009; Yahuza, 2011b). The partial land equivalent ratio (PLER) is a measure of relative competitive abilities of the individual components of an intercrop system (Willey, 1979). The species with higher partial LER is considered to be more competitive for growth limiting factors than the species with lower LER (Willey, 1979). In computing LER, the sole crop yields to be used as the divisor defines the method of standardization and this depends largely on agronomic objectives (Oyejola and Mead, 1982; Fukai, 1993). Three choices of sole crop yield include the average yield of all sole crops yields, the average yield of all the best sole crop treatment and yield of the best sole crop treatment averaged over blocks (Oyejola and Mead, 1982). However, Thobatsi (2009) indicated that when sole crop yields differ among cultivars, a higher LER may be obtained compared to cultivars with low sole crop yields. Thus for computation of

LER, the highest yield of a cultivar in sole cropping should be used. The major criticism of the LER is that it takes no account of the relative duration of each species within the intercrop or sole crop system (Hiesbsch and McCollum, 1987; Thobatsi, 2009). Because of this limitation, it is argued that published estimates of LER often exaggerate intercropping performance since the land left unused after the harvest of the shorter duration sole crop is not included in the calculations (Fukai, 1993). Another limitation of LER is that the index is not able to identify the physiological and physical processes responsible for any differences that may occur between intercrops and sole crops (Harris, et al., 1987, Azam-Ali, et al., 1990).

2.7.1.2 Area Time Equivalent Ratio (ATER)

Hiebsch and McCollum (1987) proposed the use of area time equivalent ratio (ATER) in calculating intercrop efficiency because crop production uses both time and land. Area time equivalent ratio which defines yield as a function of both land area and time was developed to correct the time deficiency in the LER concept (Fukai, 1993). ATER provides more realistic comparison of the yield advantage of intercropping than LER as it considers variation in time taken by component crops of different intercropping systems (Seran and Brintha, 2009). Smaller ATER values than LER values indicate over estimation of resource utilization in the later (Seran and Brintha, 2009). Hiesbsch and McCollum (1987), Tsubo, et al (2001) indicated that when time was included in the calculations of intercropping using ATER, the large land use advantage usually ascribed to intercrops relative to sole crops disappears; and that intercrops use the same land and area with the same efficiency as sole crops of the same species.

The major limitation of ATER is that it is unable to detect the physiological or physical processes responsible for any differences that may occur between intercrops and sole crops regardless of whether intercropping was beneficial or not (Azam-Ali and Squire, 2002). In addition, the two authors contend that neither ATER nor LER presents the absolute or relative biological efficiencies of the system in terms of the amount of biomass or yield fixed relative to the energy captured during the season. In other words, ATER might under estimate the advantage of intercropping especially when component crops differ in their growth duration. This is because in the semi-arid areas it is not possible to plant another crop after harvesting like in the humid tropics where the growing season is continuous (Fukai, 1993; Thobatsi, 2009).

2.7.1.3 Crop Performance Ratio (CPR)

Defined as the productivity of an intercrop per unit area of ground compared with that expected from sole crops grown in the same proportions, crop performance ratio calculates the efficiency with which sole crops and intercrops use resources to produce dry matter (Azam-Ali, et al., 1990). CPR was developed to fill the gaps (LER, ATER) in the determining the physiological and physical factors responsible for yield differences between sole crops and intercrops regardless of whether intercropping produces an advantage or not (Harris, et al., 1987).

2.7.2 Economic indices

Willey (1979), Willey (1985) reported that irrespective of indices used to assess intercropping advantages, there may be need to calculate some monetary values for intercropping if at least one of the component crops is a cash crop. Various economic indices are employed to indicate economic viability of intercropping.

2.7.2.1 Monetary Advantage Index (MAI)

Monetary advantage index is used to indicate the economic viability of a given intercrop system and its calculation assumes that appropriate economic assessment of intercropping should be in terms of increased value per unit area (Willey, 1979). A major limitation in the use of MAI is that it does not take into account time durations since it is a derivative of LER. In addition, the value of the index does not indicate profitability or otherwise since not all input costs are included in its computation (Yahuza, 2011a).

2.7.2.2 Monetary Equivalent Ratio (MER)

Monetary Equivalent Ratio is the sum of the ratios of the intercrop monetary returns to the highest sole crop monetary return from the entire land area occupied by all intercrops per unit time (Adetioye and Adekuncle, 1989). Monetary equivalent Ratio is used to evaluate economic superiority of the intercropping systems (Adetioye and Adekunle 1989; Seran and Brintha, 2009).

2.8 Intercropping studies in cotton and cowpea intercrops

2.8.1 Relative cotton and cowpea sowing dates in intercropping

Previous studies on cotton and cowpea intercropping generated a wide range of results. Olufajo and Singh (2002) suggested that being strongly competitive crop, cowpea reduces cotton yields when grown as intercrop in strip cropping and that the extent of yield reduction depends on cowpea sowing date. Results from Endondo and Samatama (1999) suggested that cowpea should be sown five to six weeks after sowing cotton in a cotton-cowpea intercrop. With simultaneous sowing, the intercropped cotton yield was 50% of sole crop yield whereas cotton yield was reduced by 16% and cowpea yield by 54% when cowpea was sown five to six weeks after cotton. High reduction in cowpea yields were attributed to shading effect from cotton. However, year to year differences indicated that in wetter years cowpea yield was reduced when cowpea sowing was delayed from two weeks after cotton, whereas in drier years, cowpea yields were not affected by sowing date (Myaka and Kabisa, 1996). In wetter years high soil moisture content could have negatively affected the BNF capacity of cowpea hence lower yields compared to drier years. Olufajo and Singh (2002) suggested that an important consideration with respect to cotton-cowpea intercropping is the time of insecticide application to the cotton component. Olufajo and Singh (2002) also pointed out that since farmers routinely apply insecticides to cotton whereas cowpea rarely receives insecticides protection, the main advantage of cotton-cowpea mixture is the ‘incidental’ benefit derived by the cowpea crop from the insecticides applied directly to cotton. It was suggested further by Olufajo and Singh (2002) that an increase in cowpea grain yield as a result of the insecticide applied to cotton could be as high as 400% and that further improvement in cowpea grain yield could probably be achieved by using early maturing cowpea varieties whose reproductive phase would coincide with the period of insecticide application in cotton. Natarajan and Sheshadri (1998) observed significantly higher population of beneficial coccinellids in cotton intercropped with cowpea compared to crop intercropped with soybean and onion. Interestingly, cotton alone recorded lower population of these beneficial insects. The parasites on spotted bollworm *(Earias insulana)* were higher when intercrops such as cowpea and soybean were grown with cotton (35.2 and 32.9% respectively) in comparison to sole cotton (18.2%). Jeykumar and Uthamasamy (2000) reported that cowpea and black gram were better intercrops and that advance sowing of intercrops (20 days advance to base crop) or synchronized sowing of both the crops recorded reduced incidence of leaf miner. Mote et al., (2001) found that among different intercrops tried with cotton, cowpea and green gram were beneficial in reducing the per cent boll damage, per cent locule damage besides reducing the incidence of jassids, aphids and thrips. Both the intercrops also recorded maximum predator population.

2.8.2 Row arrangement and density of cotton and cowpea intercrop

Traditional crop production system involves varied arrangement of component crops in time and space with implications for productivity and sustainability (Shetty, et al., 1995). Spatial arrangements and densities of component crops can be manipulated in order to enhance complementarity and reduce competition between the component crops so that physiological advantage from combining crop components is optimised (Olufajo and Singh, 2002).

Myaka and Kabisa (1996) found that alternating single rows of cotton with single rows of cowpea was superior to 2:2 or to 2:1 (cotton-cowpea) in terms of crop yield and control of cowpea pests by insecticides applied directly to cotton component in cotton-cowpea intercrop. Bezerra-Neto and Robichaux (1996) studied the effects of spatial arrangement and density on cotton-cowpea-maize intercrop and reported that the land equivalency ratio (LER) for yield was higher in the spatial arrangement of single rows of cowpea and maize between single rows of cotton. Land equivalent ratio for total biomass and grain yields were not affected as cotton density increased from 25000 to 75000 plants per hectare. However, Bezerra-Neto and Robichaux (1997) noted that component yields and biomass production could be significantly affected by alteration of spatial arrangement and density. They therefore concluded that the most appropriate sowing arrangements in cotton-cowpea intercrop should be determined by individual requirements for total biomass and grain yield. In a study to evaluate productivity of cotton-cowpea intercropping and its effects on N_2 fixation capacity on subsequent maize crop, Rusinamhodzi, et al. (2006) reported higher cowpea grain yields in sole crop (1.4 Mg ha^{-1}) than in the intercrops at 1.1 Mg and 0.7 Mg ha^{-1}) for 1:1 and 2:1 (cotton-cowpea) intercrop treatments respectively. However, intercrops were more productive than sole crops as was shown by higher LER values of greater than 1. The same trend was also observed for cotton lint yield with sole cotton recording 2.5 Mg ha^{-1}) but 2:1 intercrop treatment yielded higher lint (1.5 Mg ha^{-1}) than the 1:1 intercrop (0.9 Mg ha^{-1}) treatment. Both crops also recorded higher total above ground dry matter yield in sole crops compared to intercrops. Mkandawire and Likoswe (2002) reported lower cowpea yields from a cotton and cowpea intercrop compared to yields obtained from pure cotton and cowpea stands at Makoka and Chitala Research Stations in a study to assess the effect of intercropping cotton with cowpea on crop yields and yield components. Significantly higher seed cotton yields were reported from sprayed plots than from unsprayed treatment.

2.8.3 Cotton, cowpea intercropping with other crops

Apart from cotton-cowpea intercropping, studies have also been done on cotton and cowpea intercropping with other crops. Venugopal Rao, et al. (1995) reported that groundnut and setaria combination with cotton reduced the incidence of *H. armigera* larvae and bollworm damage. But, the damage of *H. armigera* in pigeonpea intercropped cotton plots were almost on par with sole cotton. This revealed the less suitability of pigeon pea combination.

Even though, setaria affected the main crop yields to certain extent, the yields of intercrop were high (2000 Kg ha^{-1}) indicating the benefits of such an intercrop in sustaining the cotton cultivation. Olufajo and Singh (2002) reported that planting component crops in strips in intercropping is advantageous in terms of ease of crop management, fertilizer and insecticide application, weeding and reduction of shading effect of cereal crops on cowpea. The same authors reported that strip cropping with 2 rows cereal: 4 rows cowpea offers opportunity for selective input application and better economic advantage than the traditional one row cereal: one row cowpea spatial arrangement. In an experiment to screen cowpea lines under intercropping with millet as well as sole cropping with and without insecticides application, Singh and Emechebe (1998) found out that intercropped cowpea grain yields were generally higher than yields from sole crop when no insecticides were applied indicating less insect damage under intercropping. Gandebe, et al. (2010) reported that when cowpea was planted as a sole or simultaneously with maize, the harvest index HI was significantly greater than when cowpea was planted 2 or 4 weeks after maize. These authors also suggested that growing cowpea as sole or simultaneously with maize significantly increased number of cowpea pods per plant at harvest than when cowpea was planted 2 or 4 weeks after maize. Gandebe, et al. (2010) reported further that delaying cowpea planting by 4 weeks significantly reduced 100 seed weight in cowpea as compared to when cowpea is either planted as sole crop, simultaneously sown with maize or when sowing the crop is delayed by a period of 2 weeks. In a study to design and evaluate a safe and environmentally friendly bollworm control strategy in cotton using biological control enhanced by intercropping in South Africa, Mamogobo (2008) indicated that intercropping cotton with either grain sorghum or pigeon peas reduced yield of seed cotton. Mamogobo (2008) however reported that intercropping cotton with grain sorghum or pigeon peas presented a greater advantage over growing these crops as sole crops as evidenced from higher than unity LER from intercropped treatments. Efforts have also been made to identify the effects of time of planting cowpea on the productivity of component crops in intercropping. Adipala, et al., (2002) studied the effect of time of planting cowpea relative to maize on growth and yield of cowpea. The authors reported that delaying cowpea sowing in maize reduced cowpea dry matter, number of seeds per pod, number of pods per plant and grain yield compared to simultaneous sown maize and cowpea. Adipala, et al., (2002) also reported that pure cowpea gave higher yields than intercropped cowpea and it was further pointed out by the authors that simultaneous planting generally showed a yield advantage (LER >1.00) of cowpea and maize intercropping systems irrespective of the cowpea varieties used, but declined when time of planting cowpea into maize was delayed. Mensah (1997) noted that alternating three rows of cowpea with two or three rows of sorghum and one to two insecticide applications gave a yield advantage of 58 to 69 %. Mensah (1997) also reported a low population density of post - flowering pests (*Maruca-vitrata* and a complex of pod-sucking insects) but a higher population density of flower pests (*Megalurothrips sjostedti*) in a crop mixture consisting of one row of sorghum alternated with two rows of cowpea.

Agbo-Noameshie, et al., (1997) studied pest populations on cowpea intercropped with cassava and found that the microenvironment created by the intercrop reduced the populations of flower thrips (*M. sjostedti*) and pod-sucking bugs (Heteroptera) but increased those of the pod borer *(M. vitrata*). Jakai and Adalla (1997) reviewed the effects of intercropping on insect pest of cowpea and indicated that intercropping does not necessarily reduce the pest load in any given situation; it depends on the crop(s) and pest(s) in question. Jakai and Adalla (1997) also indicated that although intercropping can contribute to the control of pests in integrated pest management context, often, pest damage to intercropped cowpea is generally not less than that to the monocrop at the time of harvest. Mohammed and Yusuf (2010) reported lower aphid infestation in a 1:1 sorghum: cowpea row arrangement compared to 2:2, 1:2 and 2:4 row arrangements. A 2:4 row arrangement registered the highest Maruca and pod damage, with a 1:1 and 2:2 row arrangement registering less Maruca and pod damage levels. Mohammed and Yusuf (2010) also indicated higher thrips infestation recorded at wider 2:4 row arrangement demonstrated the influence of intercrops and barrier effects of tall canopy crops such as sorghum on pest infestation and damage to intercropped cowpea. This effect as observed in the study was more effective at close cropping patterns (1:1) and decreased as density of, or distance between component crops increased or approached monocropping. In the same study (Mohammed and Yusuf, 2010), a 1:1 row arrangement had the highest number of days to 50% flowering while no significant differences were observed in other treatments. In a study to evaluate the productivity of millet and cowpea intercropping as affected by cowpea genotype and row arrangements in the Sudan Savanna of Nigeria, Mohammed, et al. (2008) were of the opinion that row arrangement had no effect on cowpea grain yield and yield attributes.

Nabirye, et al. (2003) reported increased pod borer and sucking bugs infestations in early planted cowpea and the authors suggested that this was probably due to the vigorous cowpea growth in the early season due to ideal growth conditions. This resulted in plants attaining denser canopies earlier providing conditions that are favourable for pod borer infestation. Balakrishnan, et al. (2010) observed a reduction in bollworm levels in cotton when cotton was intercropped with trap crops such as cowpeas, sunflower, sorghum, black beans. The reduction in bollworm levels in intercropping were attributed to the fact that in polyculture insects such as bollworms are unable to locate host plants as the visual and chemical stimuli get manipulated or altered, and also due to the disruption of host finding behaviour through aromatic odours of other plants. Aliyu, et al. (2011) reported lower populations of aphids and whiteflies in cotton-cowpea intercrops compared to unsprayed sole crop of cowpea. The authors attributed higher aphid and whitefly populations in the unsprayed cowpea sole crop to the absence of alternate host under sole cropping arrangement on which insect pests could feed and under such circumstances insect pests are left with no option but to continue feeding on the sole crop and hence more damage.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Study sites

The experiment was conducted during the 2011/2012 growing season at Bunda College Crop and Soil Science Students' Research Farm (33^{o} 76' E, 14^{o} 18' S, altitude 1158 masl) as an on station experimental site and on farmers' fields at Chitedze village in Mpingu Extension Planning Area (EPA) in Lilongwe district, central Malawi (33^{o} 33' E, 14^{o} 00' S, altitude 1159 masl); Sakaiko, Kanongwa, Khoswe and Kodo villages (Rivirivi EPA) in Balaka district in southern Malawi (35^{o} 04' E, 14^{o} 79' S, altitude 625 masl). All sites have a unimodal rainfall pattern which is experienced between November and April/May. Rainfall in all three sites was recorded using a standard rain gauge by field technicians. The amount of rainfall received during the 2011/12 season at all sites is shown in Figures 3.1, 3.2 and 3.3 while Table 3.1 provides minimum and maximum temperature as recorded at Chitedze Research Station which is 8 kilometres away from the experimental site. All sites the amount of rainfall received in the month of December was much lower than the 5-year average resulting in delayed planting of cotton crop.

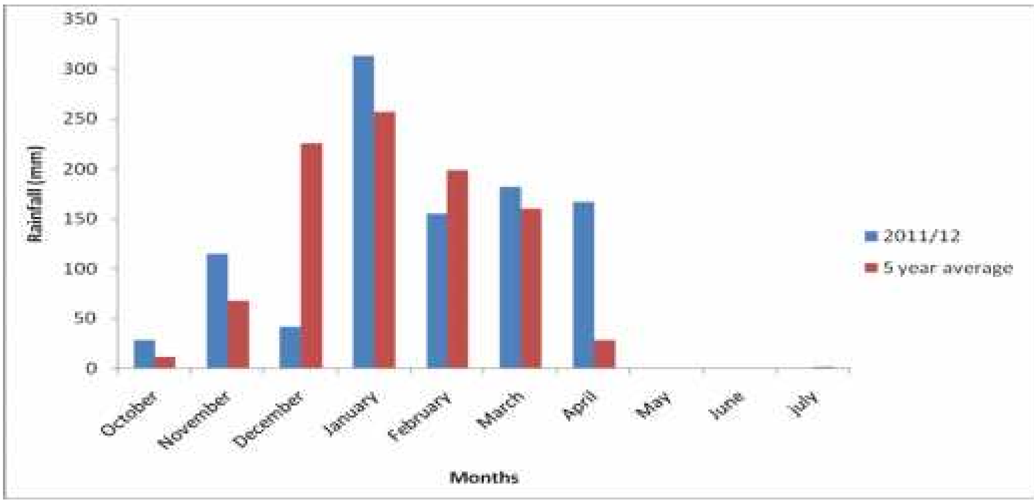

Figure 3.1 Monthly rainfall (mm) during 2011/12 season compared to a 5 year average at Bunda College.

Source: Bunda College Crop Science Department, (2012).

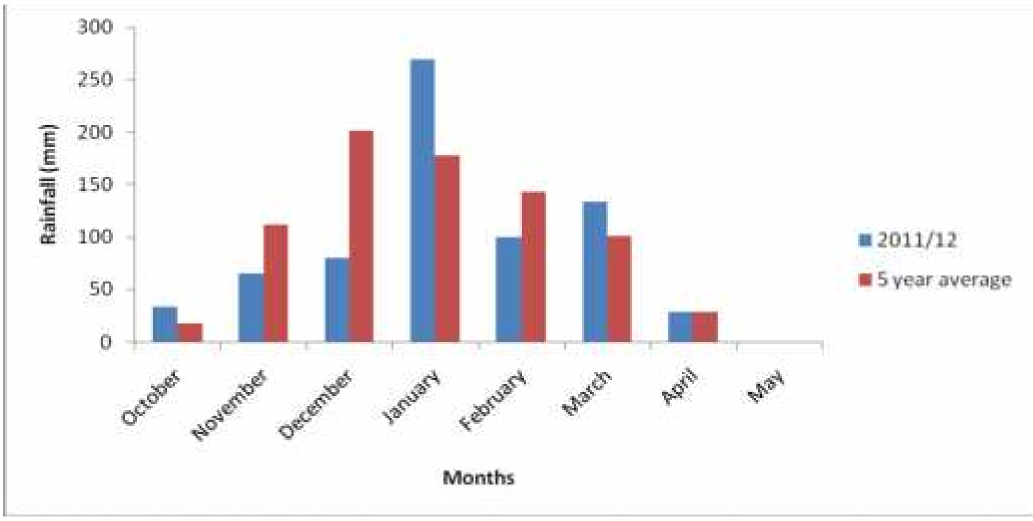

Figure 3.2 Monthly rainfall (mm) during 2011/12 season compared to a 5 year average at Rivirivi EPA in Balaka district.

Source: Rivirivi EPA Office, (2012)

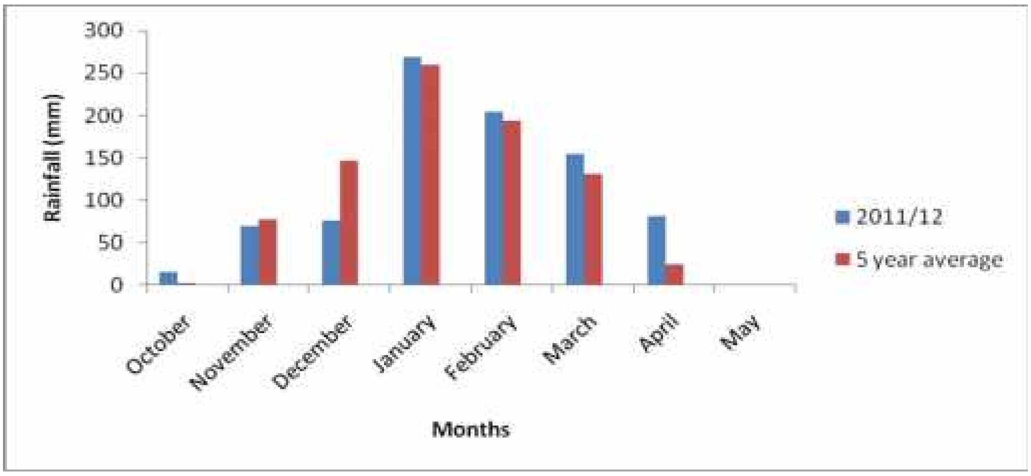

Figure 3.3 Monthly rainfall (mm) during 2011/12 season compared with a 5 year average at Chitedze Research Station in Lilongwe district.

Source: Chitedze Research Station Meteorological office, (2012).

Table 3.1 Monthly mean maximum and minimum air temperatures for Chitedze Research Station during 2011/2012 season.

Month	**Maximum temperature (^{o} C)**	**Minimum temperature (^{o} C)**
October	30.93	16.89
November	30.40	18.06
December	29.64	19.39
January	25.84	18.47
February	28.82	18.39
March	26.94	18.10
April	25.27	15.52
May	25.97	11.75
June	24.52	10.62
July	24.32	8.87
August	25.82	12.29
September	29.42	14.40

Source: Chitedze Research Station Meteorological Office, (2012).

3.2 Soil sampling and analysis

Soil analysis was performed to determine the initial quantities of total N, extractable K and available P in the soil prior to the application of inorganic fertilizers. Composite soil samples were collected from 0 -15 cm and 15-30 cm (Brady and Well, 2002; Faithfull, 2003) for the main experimental site at Bunda College Crop Science Students' Research Farm before the layout of the experiment. Soil samples for both on farm sites were not done due to limited resources. The physical soil properties (percent sand, clay, silt and textural class) and chemical properties [pH, total nitrogen (%), available P (ppm), extractable K (%), and organic matter (%)] were analysed at the crop and soil science laboratory at Bunda College using standard procedures as outlined below.

3.2.1 Soil organic matter analysis

The Walkley Black method was used for analysis of organic matter in the soil. The organic carbon in the soil sample was oxidized by using a measured excess of potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric acid. The oxidation was assisted by the spontaneous heat produced when the sulphuric acid was added to the aqueous solution of potassium dichromate. The amount of ($K_2Cr_2O_7$) used up on oxidation of the organic carbon was then determined by titrating with a reducing agent ammonium ferrous sulphate. Organic matter content was determined by loss upon ignition. A soil sample was weighed and placed in a high temperature (550^0C) oven where the organic matter turned to ash. The sample was then re–weighed and the difference in weight was taken as the organic matter content (Anderson and Ingram, 1993).

3.2.2 Soil nitrogen analysis

Kjeldahl method was used for the analysis of soil nitrogen. A soil sample was first digested to convert N into ammonium. This was done by treating the soil with concentrated sulphuric acid. The reaction being facilitated by K_2SO_4 which raises the temperature of digestion. Catalysts such as selenium, mercury and copper are used to promote oxidation of organic matter (Anderson and Ingram, 1993).

3.2.3 Soil potassium and phosphorous analysis

Potassium and phosphorous were analyzed using the Mehlich–3 method. The process involved weighing soil (2,5g) into an extraction bottle to which 25 ml of Mehlich -3 extracting solution was added. After standing for about 10 minutes, the soil solution was centrifuged and then filtered through whatman no. 2 filter paper. Blanks were then prepared following the same procedure. Finally potassium standards were prepared from the stock solution to develop the standard graph (Mehlich, 1984).

3.3 Test varieties

Makoka 2000 cotton variety was used in all cotton treatments at Bunda College and on farmers' field in Mpingu EPA in Lilongwe district. Albar SZ 9314 cotton variety was used on farmers' fields in Rivirivi EPA in Balaka district. Makoka 2000 is a cotton variety officially released by Malawi government for production in mid altitude areas of Malawi. Albar SZ 9314 is a cotton variety from Zimbabwe which was given to farmers by the Malawi Government under the farm input subsidy programme (FISP) and is not officially released for production in Malawi.

Albar SZ 9314 had been grown by farmers in Balaka for two seasons prior to this experiment and farmers indicated that they preferred Albar SZ 9314 to Makoka 2000 because Albar SZ 9314 was high yielding compared to Makoka 2000. IT82E-16, a determinate cowpea variety was used in all cowpea treatments except in treatment 9 for on station experiment and treatment 5 for on farm experiment where Sudan, an indeterminate cowpea variety was used. Sudan cowpea variety was used in treatments 9 (on station) and 5 (on farm) to assess the response of cotton intercropped with cowpea variety with spreading growth habits compared to cowpea variety with erect growth habits. Both cowpea varieties have a grain yield potential of 2 tonnes per hectare (Kabambe, et al, 2010a).

3.4 Experimental Design and Treatments

The experiments at Bunda College and Lilongwe on farm were laid out as a Randomized Complete Block Design (RCBD) with 4 replicates. In Balaka on farm experiment four farmers were each treated as a replicate. The on station experiment was researcher designed and researcher managed while on farm experiments were researcher designed but farmer managed. The 1:1 and 2:2 strip cropping treatments at Bunda College had 6 ridges, 10 metres long with ridge spacing of 75 cm apart. All sole cropping and within row intercrop treatments had gross plot size of 5 ridges, 10 m long and with between ridge spacing of 75 cm. All net plots for cotton treatments had 2 ridges, 6 meters long while cowpea treatments had net plots of 2 ridges, 5 m long and a ridge spacing of 75 cm apart. On farm experimental plots had gross plots of 4 ridges, 5 meters long and ridges spaced at 75 cm for sole and within row intercrops while the 1:1 and 2:2 intercropping patterns had gross plots of 6 ridges, 5 meters long, 75 cm between ridges.

Net plot sizes for all on farm treatments had 2 ridges, 3 m long and a between ridge spacing of 75 cm. On both on station and on farm sites, two strips of 1 row each of either cotton or cowpea made a net plot for 1:1 strip cropping while 1 strip of two rows of either crop made a net plot for 2:2 strip cropping treatments giving a net plot size of 7.5 m^2 in both cases (Murungu, et al, 2011; Egbe and Idoko, 2012). Various options in strip plot determination are used by different authors to meet different study objectives.

BLOCK I		BLOCK II		BLOCK III		BLOCK IV
6		8		4		3
4		3		5		2
2		7		9		10
7		9		10	2.5 m path	5
5		6		3		6
10		2		1		9
3		5		8		1
8		4		7		4
9		1		6		8
1		10		2		7

10 m ridges

Figure 3.4 Plot layout for the on station experiment at Bunda College.

The on station experiment at Bunda had 10 treatments as follows.

1. Cotton pure stand sprayed.
2. Cotton pure stand unsprayed.
3. Cowpea pure stand sprayed (cowpea planted in January as recommended, MoAFS, 2005b).
4. Cowpea pure stand unsprayed (cowpea planted in January as recommended, MoAFS, 2005b).

5. Cotton: cowpea 1:1 intercrop in alternating single ridges with cotton and cowpea planted at the same time.

6. Cotton: cowpea 1:1 intercrop in alternating single ridges with cotton planted first and cowpea planted 2 weeks after planting cotton.

7. Cotton: cowpea 2:2 intercrop in alternating double ridges with both crops planted at the same time.

8. Cotton: cowpea 2:2 intercrop in alternating double ridges with cotton planted first and cowpeas planted 2 weeks after planting cotton.

9. Cotton: cowpea within row intercrop with Sudan as cowpea variety (planted same time).

10. Cotton: cowpea within row intercrop with IT82E-16 as cowpea variety (planted same time).

The on farm treatments were as follows.

1. Cotton pure stand sprayed.

2. Cowpea pure stand sprayed (planted in January)

3. Cotton: cowpea 1:1 intercrop in alternating single rows (cowpea planted in January as recommended, MoAFS, 2005b).

4. Cotton: cowpea 2:2 intercrop in alternating double rows (cowpea planted in January as recommended, MoAFS, 2005b).

5. Cotton: cowpea within row intercrop with Sudan as cowpea variety.

6. Cotton: cowpea within row intercrop with IT82E-16 as cowpea variety.

For treatments 5 to 10 (on station) and 3 to 6 (on farm) chemical spraying was done on cotton plants only.

Figure 3.5 A 1:1 cotton and cowpea strip cropping treatment at 8 weeks after planting at Bunda College Experimental site.

3.5 Agronomic practices

3.5.1 Land preparation

The experimental land at Bunda College was deep ploughed, harrowed and ridges made using tractor drawn implements about two months before planting. On farmer's fields, ridges were made by rearranging ridges from previous cropping season using a hand hoe. Ridges were spaced at 75 cm apart (MoAFS, 2005b). At Bunda College and Lilongwe on farm experiments, experimental plots were the previous season sown to maize crop while in Balaka the experimental plots were sown to various mixed crops.

3.5.2 Planting

Planting of the main experiment at Bunda College (except for cowpea treatments 6 and 8) was done on 4th January 2012. The delayed cowpea treatments (treatments 6 and 8) were planted two weeks later, on 18th January 2012. The on farm experiment in Balaka district (Rivirivi EPA) was planted on 6th January 2012 (3 farmers) and on 17th January 2012 (1 farmer). The Lilongwe district on farm experiment was planted on 13th January 2012. At Bunda College and Lilongwe on farm, fuzzy cotton seed was used while acid delinted seed was used in Balaka. Five to ten cotton seeds were planted at 60 cm apart and after 3 weeks thinned to 3 plants per station. Gap filling in cotton was done 3 days after cotton germination (MoAFS, 2005b) and this gave the recommended plant population of 66,667 cotton plants per hectare for the sole and the within row intercropping treatment. Strip intercropping population for cotton was at 50% (33,333 plants) of the sole plant population. Two cowpea seeds were planted at 20 cm apart and this gave a plant density of 133,333 cowpea plants in sole cropped treatment. In all strip cropping treatments cowpea plant density was 50% of sole population (66,667 plants) while in the within row intercropping cowpea population was at 66 % of sole cowpea population (88,000 plants). In within row intercrop treatments, cowpea seeds were planted in between cotton plants. Seeds for both crops were planted about 2 cm deep (MoAFS, 2005b).

3.5.3 Fertilizer application and crop management

An N: P: K: S fertilizer, 23:21:0+4S, was used as basal dressing fertilizer and was applied to cotton at the rate of 100Kg N $ha^{-1.}$. Five (5) grams of 23:21:0+4S were applied per planting station one week after thinning (MoAFS, 2005a). Calcium Ammonium Nitrate (CAN) was used for top dressing cotton at the rate of 52 kg N ha^{-1}. Three (3) grams of CAN was applied per station at first flowering (MoAFS, 2005a). Weeding was done as weeds appeared using a hand hoe up to physiological maturity of the crops.

3.6: Data analysis

Data were subjected to analysis of variance (ANOVA) in GenStat 14th Edition. Statistically significant treatment means were separated using the least significant difference (LSD) test. Correlation coefficient (r) and coefficient of determination (r^2) and their significance at 0.05, 0.01 or 0.001 alpha levels were estimated for individual site means using GenStat 14th Edition to determine inter-character associations among straits. Comparison of contrasts of interest was done using ANOVA for contrasts. Total number of possible contrasts is 7 or 5 i.e. (n-1) for either cotton or cowpea treatments at Bunda College and on farm respectively. However due to limitation of space in tables, only selected contrasts are presented. Description of selected contrasts is presented in Table 3.2.

Table 3.2 Some important contrasts used in the data analysis.

Contrast	Description
Sole cropping vs. intercropping	Comparison between sole sprayed treatments with an overall performance of all intercropped treatments except the within row intercropping with Sudan
Sole cropping vs. strip cropping	Comparison between sole sprayed treatment with an overall performance of all strip 1:1 same time, strip 1:1 delayed, strip 2:2 same time and strip 2:2 delayed cropping treatments.
Strip 1:1 vs. strip 2.2	Comparison between combined performances of strip 1:1 same time, strip 1:1 delayed with strip 2:2 same time and strip 2:2 delayed.
Strip same time vs. strip delayed	Compares strip 1:1 same time, strip 2:2 same time with strip 1:1 delayed, strip 2:2 delayed.
Strip vs. within row intercropping	Compares all strip 1:1 same time, strip 1:1 delayed, strip 2:2 same time, strip 2:2 delayed with within row cowpea intercropping treatment with IT82E-16.

Strip (same time) = cotton and cowpea planted the same time, strip (delayed) = cowpea planted 2 weeks after cotton.

Treatment effects for cowpea and cotton data were analysed separately using the following general mathematical model by Gomes, et al., (2007).

$y_{ij} = \mu + \alpha_i + \rho_j + \varepsilon_{ijk}$

Where

y_{ijk} = k^{th} observation on i^{th} treatment in j^{th} block

μ = overall mean,

$\rho = (\rho_1 .... \rho_b)$ is a vector of block (parameter) effects

$\alpha = (\alpha_1 \ldots. \alpha_y) =$ is a vector of treatment (parameter) effects.

$\varepsilon_{ijk} =$ iid random error normally distributed with mean zero.

Analysis of data for some similar treatments across sites used the following model.

$y_{ijk} = \mu + C_i + S_j + (CS)_{ij} + \varepsilon_{ijk},$ where

$y_{ijk} = K^{th}$ observation on i^{th} intercropping system and j^{th} site.

μ = overall mean,

C_i = is the fixed effect of i^{th} intercropping system (i= 1...6)

$S_j =$ is the fixed effect of j^{th} site (j = 1, 2, 3).

$CS_{ij} =$ is the fixed effect of interaction of intercropping system x site

$\varepsilon_{ijk} =$ iid random error normally distributed with mean zero.

(Gomes, et al, 2007).

CHAPTER FOUR

EFFECT OF INTERCROPPING ON GROWTH AND YIELD OF COTTON AND COWPEA

4.1 Introduction

Cowpea [*Vigna unguiculata* (L.) Walp] is a major component of traditional cropping system in Africa, Asia and Central and South America where it is widely grown in mixtures with other crops in various combinations (Olufajo and Singh, 2002). In a survey of cowpea cropping systems in West and Central Africa, Singh (1999) identified 15 major cowpea cropping systems. The intercropping systems ranged from within-ridge sowing to alternate rows or hills of the crops depending on the farmers' food preferences and market demand. In these cropping systems cowpea was found intercropped with crops such as maize *(Zea mays)*, cassava *(Manihot esculenta* Crantz*)*, yam *(Dioscorea rotundata)*, groundnuts *(Arachis hypogeal L.)*, soya beans *(Glycine max L.)*, sorghum *(sorghum bicolour L.)*. Rao, et al. (2002) indicated that traditional intercropping systems consist of either mixing and broadcasting seeds of the component crops, or sowing of a few rows of intercrop between the rows of the base crop. The productivity of cowpea in such mixtures was reportedly low due to low plant populations, competition under intercropping and lack of crop protection measures (Olufajo and Singh, (2002). Studies have also shown that the productivity of cowpea in intercropping systems could be enhanced through use of improved crop varieties, appropriate date of planting with respect to other intercrops, suitable spatial arrangement and proper pest control (Mortimore, et al., 1997; Olufajo and Singh, 2002).

An ideal intercropping system should aim at producing higher yields per unit area, offer great stability in production, meet the domestic needs of the farmer and provide equitable distribution of farm resources (Ali, 1990; Rao, et al., 2002; Ajeigbe, et al., 2010). Sankaranarayanan (2011) indicated that the common cotton intercropping cultivation system is inter or mixed cropping with pulses, and that cotton is ideally suitable for intercropping because of the relatively longer duration and its slow growth in the initial stages. The magnitude of agro-economic advantages in intercropping depends on the type of intercropping system (Sankaranarayanan, 2011). In Malawi, high land pressure due to high population limits smallholder farmers' freedom of crop diversification while intercropping accords farmers' choice of growing more than one crop in mixture. Studies that report cotton and cowpea intercropping in Malawi are sparse and this chapter therefore identifies the best arrangement of growing cotton and cowpea under intercropping in the context of dwindling landholding sizes.

4.2 Objectives

- To determine an appropriate cotton and cowpea intercropping system for optimum productivity of the two crops.
- To determine the appropriate time for sowing cowpea in cotton and cowpea intercropping.
- To determine the performance of determinate and indeterminate cowpea varieties in within row intercropping.

4.3 Materials and Methods

This chapter focuses at addressing the above objectives by looking at the effect of intercropping systems on growth and yield attributes of intercropped cotton and cowpea crops. Treatments and methods of data analysis are as outlined in sections 3.3 and 3.6 respectively.

4.3.1 Cotton plant height and canopy measurement

Cotton plant height and canopy were measured on 10 randomly selected plants per net plot and a mean was calculated. Plant height and canopy measurements were done fortnightly starting from 4 weeks after planting and continued up to when 50% cotton bolls had split. Plant height was measured from the soil surface to the terminal growing point while canopy was taken at the maximum spread point of the plant (Agbogidi, 2010). Measurements were done using a 1 metre ruler with markings of 1 cm apart as indicated in Fig. 4.1 below.

Figure 1.1 Measuring cotton plant height using a 1 metre ruler

4.3.2 Number of sympodial (bearing) branches

Number of branches per plant bearing at least one cotton boll were counted to give number of sympodial branches per plant. The mean number of sympodial branches was estimated from 10 plants randomly selected from a net plot (Banda and Masambo, 1995).

4.3.3 Days to 50 percent flowering and boll opening

The number of days from planting to first flower bud on 50 percent of the plants per plot was recorded as days to 50 percent flowering. Days to 50 percent boll opening were counted from days from planting to days when 50 percent of the bolls per plot had split open.

4.3.4 Cotton yield and yield components

Seed cotton yields from the on station experiment at Bunda College were obtained from net plots of 2 ridges, 6 m long for cotton. On farmers' fields, net plots were 2 ridges, 3 m long. The smaller plot size on farm was due to limitation of land which was not the case with on station experiment. In both cases ridges were spaced at 75 cm apart. Plants within the net plots were picked by hand and seed cotton grain yields weighed using an electronic scale.

Seed cotton yield (kg ha^{-1}) 10, 000m^2 x Net plot yield (kg)/net plot area (m^2).

4.3.5 Boll size and number of bolls per plant

Boll size (g) was calculated as a mean weight of seed cotton yield from 20 cotton bolls randomly selected from the net plots.

The total number of matured and good open bolls picked till the end of last harvesting were counted and recorded and the mean calculated by dividing number of plants in the net plot.

4.3.6 Ginning Out Turn (GOT)

Ginning out turn, the ratio of lint to seed cotton expressed as a percentage (Singh, 2004), was calculated after roller ginning of 20 boll samples (Banda and Masambo, 1995) of the harvested seed cotton. Ginning out turn for each cotton treatment was computed using the following formula as given by Singh, 2004.

GOT (%) = [weight of lint in a sample (g) x 100]/ weight of seed cotton in that sample (g).

4.3.7 Cowpea plant height and canopy measurement

Cowpea plant height and canopy were measured on 10 randomly selected plants per net plot and a mean was calculated. Plant height and canopy measurements were done fortnightly starting from 4 weeks after planting and continued up to when 75% of cowpea plants had reached physiological maturity. Plant height was measured from the soil surface to the terminal growing point while canopy was taken at the maximum spread point of the plant (Agbogidi, 2010).

4.3.8 Cowpea yield and yield components

Moisture content of cowpea grain was determined on wet weight basis using oven drying method using the formula below after placing the grain in an oven at 72-80 degrees Celsius for 48 hours (Mloza- Banda, 1994)

Moisture content (%) = $[(w_1-w_2)/w_1] * 100$

Where W_1 = weight of seed before oven drying

W_2 = weight of seed after oven drying

Cowpea grain yield per net plot was then adjusted to 12% grain storage moisture using the formula below.

Grain yield per net plot = $DM_1 * Y/DM_2$

Where DM_1 = dry matter content of the seed when yield was weighed (i.e.100 – w_1).

DM_2 = dry matter content at which yield was reported (i.e.12% predetermined moisture content for yield determination).

Cowpea biomass from the whole plant at harvest was measured by randomly sampling 5 plants from the plot and these were dried at 80 degrees Celsius for 72 hours (Mloza Banda, 1994) and this was taken as dry matter (Rusinamhodzi, 2006).

Dry matter was calculated as follows.

Cowpea Dry Matter (kg ha^{-1}) = [Plant population (ha^{-1}) x dry mass of harvested plants (kg ha^{-1})] / Total number of plants harvested/net plot

(Rusinamhodzi, 2006).

On both on station and on farm sites, two strips of 1 row each of either cotton or cowpea made a net plot for 1:1 strip cropping while 1 strip of two rows of either crop made a net plot for 2:2 strip cropping treatments giving a net plot size of 7.5 m^2 in both cases (Murungu, et al., 2011; Egbe and Idoko, 2012). Seed cotton and cowpea grain yields from net plots were extrapolated to yield per hectare using the following formula.

Cowpea grain yield (kg ha^{-1}) $10{,}000m^2$ x Net plot yield (kg)/net plot area (m^2).

Shelling percent and harvest index for cowpea were calculated using the following formulae.

Shelling percent = Total seed weight * 100/Total seed weight + shells/empty pods (Mloza- Banda, 1994).

Harvest Index (dry weight) = Economic yield / biological yield

(Mloza- Banda, 1994)

4.3.9 Pod length, number of seeds per pod and number of pods per plant

Pod length and number of seeds per pod in cowpea was determined as mean of 20 pods randomly picked from a harvest of each cowpea treatment. Pod length was measured using a measuring tape. Counting of number of seeds per pod considered only the fully developed cowpea seeds per pod and a pod picked for recording pod length was the same used for recording number of seeds per pod. The total number of matured and well dried cowpea pods picked till the end of last harvesting were counted and recorded and the mean calculated by dividing number of plants in the net plot.

4.3.10 Seed size (100 seed weight)

Seed size was determined from a random sample of 100 seeds selected from the yield of the net plot. The 100 seeds weight was adjusted to standard storage moisture content of 12% (Mloza Banda, 1994).

4.3.11 Biological and economic indices

Different biological and economic indices to determine the advantage of intercropping with respect to monocropping used the following formulae.

4.3.11.1 Land equivalent ratio (LER)

(Yield of intercrop cotton/yield of monocrop cotton) + (Yield of intercrop cowpea/yield of monocrop cowpea) Seran and Brintha, (2009).

4.3.11.2 Area Time equivalent Ratio (ATER)

$(L_a t_a + L_b t_b) / T$

Where L_a, L_b = partial LER (ratio of yields of crops when grown as intercrops relative to their equivalent sole crops).

t_a, t_b = growth duration of crop a and b

T = duration of the whole intercrop system

(Hiebsch and Mc Collum, 1987)

4.3.11.3 Crop Performance Ratio (CPR)

$(Yi_a + Yi_b) / (Pi_a\ Ys_a + Pi_b\ Ys_b)$

Where Yi_a, Ys_a = yields per unit area of species ‘a’ in intercrop and sole crop respectively.

Pi_a, Pi_b = proportional sown area of species ‘a’ and ‘b’ in intercrop respectively.

Yi_a, Ys_b = yields per unit area of species ‘b’ in intercrop and sole crop respectively.

(Harris, et al., 1987).

4.3.11.4 Monetary Advantage Index (MAI)

{TIV (LER-1/LER)}

Where TIV = total intercrop value

LER = land equivalent ratio

(Willey, 1979)

4.3.11.5 Monetary Equivalent Ratio (MER)

$(r_a+r_b)/R_a$

Where r_a, r_b = monetary return from crops ‘a’ and ‘b’.

R_a = highest sole crop monetary return

$r_a = P_a * Y_a$

$r_b = P_b * Y_b$, where P_a and P_b are prices of unit weight of crops ‘a’ and ‘b’; Y_a, Y_b are yields of crops ‘a’ and ‘b’.

(Adetioye and Adekuncle, 1989)

4.3.12 Data analysis

In addition to general data analysis procedures outlined in section 3.6, covariance analysis with stand count as a covariate was performed to adjust seed cotton yield. This was the case considering that cotton stand count amongst the treatments at either site was supposed to be uniform (i.e. none significant) and therefore the significant differences in cotton stand count could have arisen from natural plant death rather than treatments effects.

This is unlike in cowpea where significant differences in stand counts is coming from reduced number of plants in the within row intercropping (treatment effects).

Covariance analysis used the following model.

$y_{ijk} = \mu + \alpha_i + \rho_j + \beta' x_k + \varepsilon_{ijk}$

Where

y_{ijk} = k^{th} observation on i^{th} treatment in j^{th} block.

μ = overall mean,

$\alpha = (\alpha_1 \ldots. \alpha_y) =$ is a vector of treatment (parameter) effects.

$\rho = (\rho_1 \ldots \rho_b)$ is a vector of block (parameter) effects

β' = is a parameter vector associated with the covariates

$\varepsilon_{ijk} =$ iid random error normally distributed with mean zero.

In the model the design matrices for the block design are singular but β', block and treatment contrasts of the form $\rho' \alpha = 0$, $\rho' 1 = 0$, $c' \rho = 0$, $c' 1 = 0$, are estimable (Gomes, et al., 2007).

4.4 Results and Discussion

4.4.1 Soil characterization at Bunda College

Soil analysis results (Table 4.1) shows that there was minimal variability of physical and chemical properties of soils between top and sub soils at the main experimental site at Bunda College. The soils were clay with average sand, silt and clay content of 42, 15 and 43 percent respectively for the top soil. The soils are acidic with the mean pH of 4.7. The acidity of the soils was slightly high for cotton and cowpea production considering that the required pH range for cotton is 6.2 - 7.5 (Munro, 1987) while that of cowpea is 5.5 - 6.5 (Davis, et al., 1991). The mean soil organic matter was high averaging 2.4 and 2.0 for top and sub soils respectively. The mean amounts of total N, extractable K and available P for the top soil were 0.1 %, 0.02 % and 18.4 ppm respectively. The quantities for available N and extractable K and total P were in the required amounts for production of cotton and cowpea crops (Purseglove, 1986; Munro, 1987; Rusinamhodzi, et al., 2006).

Table 4.1 Physical and chemical properties of soils of the main experimental site at Bunda College**.**

	Depth (cm)	Mean (n = 12)	Minimum	Maximum	SDEV	SEM
Sand (%)	0-15	42	40	43	1.72	0.78
	15-30	37	33	40	3.65	1.49
Silt (%)	0-15	15	13	20	2.79	1.14
	15-30	16	13	20	3.28	1.34
Clay (%)	0-15	43	40	47	2.51	1.03
	15-30	47	43	53	3.28	1.34
Textural class	0-15	Clay	-	-	-	-
	15-30	Clay	-	-	-	-
pH (in water)	0-15	4.7	4.5	5.2	0.27	0.11
	15-30	4.7	4.4	5.0	0.26	0.12
N (%) (Kjeldahl)	0-15	0.1	0.01	0.2	0.02	0.01
	15-30	0.1	0.08	0.1	0.02	0.01
Inorganic P (ppm) Mehlich-3)	0-15	18.4	11.4	29.5	8.02	3.27
	15-30	3.5	2.8	4.3	0.53	0.21
K (%) (Mehlich-3)	0-15	0.02	0.01	0.02	0.02	0.001
	15-30	0.01	0.0	0.02	0.01	0.003
OM (%) (Walkeley-black)	0-15	2.4	1.8	3.1	0.48	0.19
	15-30	2.0	1.5	2.4	0.38	0.16

SDEV = standard deviation, SEM = standard error of means.

4.4.2 Growth and yield parameters of cotton in intercropping

A summary of F- probabilities for the analysis of variance across three sites is given in Table 4.2. The analysis shows that there were significant intercropping systems and site effects on canopy diameter, plant height, number of bolls per plant, boll size and seed cotton yield. Interaction between intercropping systems and site were significant for canopy diameter, plant height and number of bolls per plant while boll size and seed cotton yield were not significant.

Table 4.2 Summary of F-probabilities from analysis of variance for cotton across three sites on canopy diameter, plant height, number of bolls per plant, boll size and seed cotton yield in cotton intercropped with cowpea.

		F-probabilities x Growth and yield parameters				
Source of variation	**DF**	**Canopy diameter**	**plant height**	**boll/ plant**	**boll size**	**seed cotton yield**
Intercropping system	4	<0.001	<0.001	<0.001	<0.001	<0.001
Site	2	<0.001	<0.001	<0.001	<0.001	<0.001
Intercropping X site	8	0.023	0.005	<0.026	0.431	0.684
Means	-	65.5	96.44	5.70	4.79	6.45
CV (%)	-	16.4	7.2	20.2	10.1	40.2

F-pr. = p-value.

The differences in performance of cotton across the three sites can in part be attributed to differences in temperature, rainfall and altitude which are some of the principal components distinguishing different ecological zones for cotton production in Malawi. Lilongwe and Balaka districts fall under high and medium altitude agro-ecological zones respectively that are characterised by lower temperatures (Lilongwe) and lower rainfall amounts (Balaka) (MoAFS, 2005a). In addition, some treatments differences in cotton growth and yield attributes can be due to genotype differences considering that two different cotton varieties were planted in Lilongwe (Bunda College and Mpingu EPA) and Balaka districts.

Makoka 2000 was planted in Lilongwe while Albar SZ 9314 was planted in Balaka. Variations in pests' populations across the sites could also have contributed to differences in growth and yield response of cotton across the sites.

4.4.2.1 Cotton canopy diameter and plant height

Results in Table 4.3 and Fig 4.2 for Bunda College show that there were statistically significant differences amongst the treatments for canopy diameter and plant height ($P<0.001$) at 50 % boll opening. At both Rivirivi and Mpingu EPAs on farm sites (Table 4.4), there were significant differences for canopy diameter and plant height amongst the treatments at 50% boll opening.

Table 4.3 Effect of intercropping systems on canopy diameter and plant height in cotton at Bunda College during 2011/12 season.

Treatments	**Canopy diameter (cm) at 50% boll opening**	**Plant height (cm) at 50% boll opening**
Sole sprayed	60.70	124.53
Sole unsprayed	56.62	123.70
Strip 1:1 same time	55.02	113.40
Strip 1:1 delayed	59.00	109.70
Strip 2:2 same time	61.87	120.30
Strip 2:2 delayed	57.17	121.60
Within row (Sudan)	40.85	89.20
Within row (IT82E-16)	42.27	87.60
Mean	54.19	111.3
F-pr.	<0.001	<0.001
LSD (0.05)	5.875	9.32
CV (%)	7.4	5.7
Contrasts	**F-pr.**	
Sole cropping vs. intercropping	0.018	<0.001
	(60.70 vs. 55.07)	(124.53 vs. 110.52)
Sole cropping vs. strip cropping	2.289	0.030
		(124 vs.116.25)
Strip 1:1 vs. strip 2:2	0.222	0.007
		(111.55 vs. 120.95)
Strip same time vs. strip delayed	0.858	0.706
	<0.001	<0.001
Strip vs. within row IT82E-16	(58.27 vs. 42.27)	(116.25 vs. 87.60)

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Table 4.4 Effect of intercropping systems on canopy diameter and plant height in cotton at Rivirivi EPA in Balaka district and Mpingu EPA in Lilongwe district during the 2011/2012 season.

	Rivirivi EPA		**Mpingu EPA**	
Treatments	**Plant height (cm) at 50% boll opening**	**Canopy diameter (cm) at 50% boll opening**	**Plant height (cm) at 50% boll opening**	**Canopy diameter (cm) at 50% boll opening**
Sole sprayed	120.60	95.00	80.8	72.0
Strip 1:1 same time	109.60	93.80	86.2	71.6
Strip 2:2 same time	106.30	82.70	81.6	74.1
Within row (Sudan)	97.10	79.80	68.9	49.9
Within row (IT82E-16)	92.30	70.00	68.2	53.5
Mean	105.20	84.2	77.2	64.2
F-pr.	0.002	0.006	0.029	<0.001
LSD (0.05)	11.54	12.93	12.59	11.18
CV (%)	7.1	10.0	10.6	11.3
Contrast		**F-pr.**		
Sole crop vs. intercropping	0.001 (120.60 vs.102.53	0.021 (95.0 vs. 88.25)	0.667	0.210
Sole crop vs. strip crop	0.008 (120.6 vs, 107.93)	0.217	0.543	0.843
Strip vs. within row IT82E-16	0.005 (107.93 vs. 92.30)	0.004 (88.25 vs. 70.00)	0.009 (83.90 vs. 68.2)	<0.001 (72.85 vs.68.20)

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

At all sites within row intercropping reduced cotton plant height and canopy diameter an observation also reported by Rusinamhodzi, et al. (2006). Treatment contrast at Bunda College (Table 4.3) shows that cotton plants in 2:2 strip cropping were taller at 50% boll opening (120.95 cm) than in 1:1 strip cropping (111.55 cm) but no significant differences were observed between the two treatments at both Riviririvi and Mpingu EPAs (Table 4.4). Overall, the within row intercropped cotton plants had a narrower canopy structure at all the three sites. This can be attributed to limited exposure of cotton plants to PAR considering that cotton plants were often overgrown and suffocated by cowpea plants (Figure 4.3). This deprived cotton plants of the required raw materials such as adequate light necessary for the production of carbohydrates needed for plant growth and development. At Bunda College (Table 4.3 and Figure 4.2) time of cowpea planting in both 1:1 and 2:2 strip cropping treatments did not have significant effects on cotton plant height and canopy diameter.

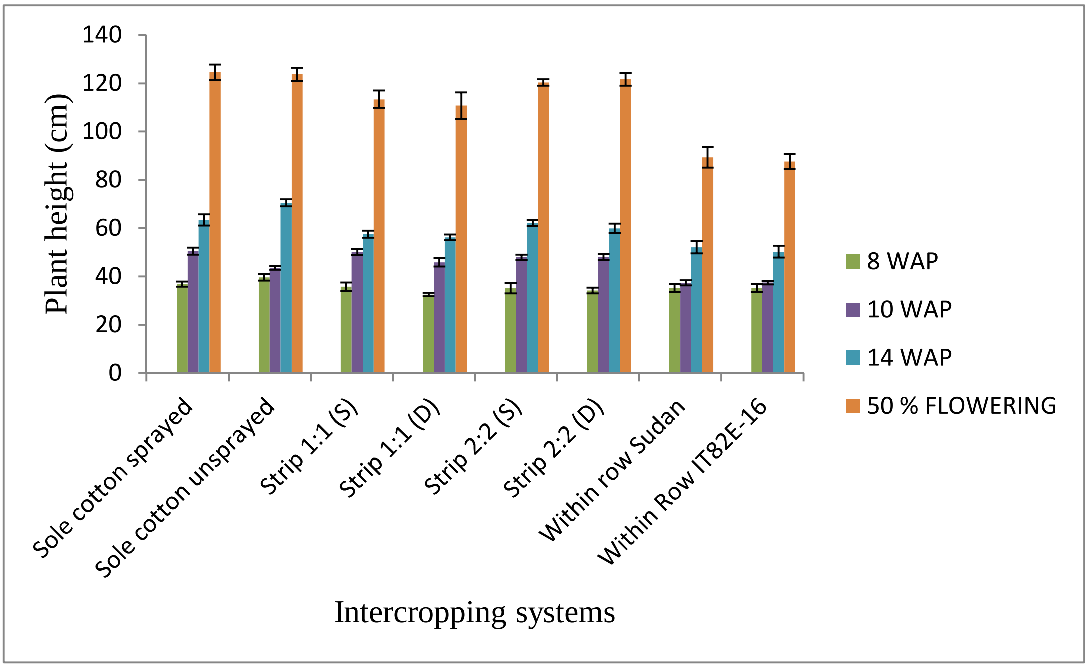

Figure 2.2 Cotton plant height as affected by intercropping systems at Bunda during 2011/2012 season.

WAP = weeks after planting, FL = flowering. Bars = standard error.

4.4.2.2 Days to 50 percent flowering and 50 percent boll opening in cotton

For proper timing and accurate observations, data on days to 50 % flowering and boll opening in cotton were collected at the main experiment site at Bunda College. The results in Table 4.5 indicate that cotton plants in all the treatments flowered almost at the same time but significant differences were observed amongst the treatments in time taken for cotton to start boll splitting. All treatment contrasts were not significant.

Table 4.5 Effect of intercropping systems on days to 50 % flowering and 50 % boll opening in cotton at Bunda College during 2011/2012 season.

Treatments	**Days to 50% flowering**	**Days to 50% boll opening**
Sole sprayed	90.00	190.00
Sole unsprayed	93.00	211.00
Strip 1:1 same time	90.00	195.80
Strip 1:1 delayed	90.00	195.80
Strip 2:2 same time	90.00	191.50
Strip 2:2 delayed	90.00	191.20
Within row (Sudan)	94.50	194.50
Within row (IT82E-16)	91.75	197.80
Mean	91.16	195.9
F-pr.	0.069	0.033
LSD (0.05)	3.432	11.72
CV (%)	2.6	4.1

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days.

Cotton plants in sole unsprayed treatment took more days (211) to attain 50% boll opening compared to all other treatments. This significant delay can in part be attributed to the effects of higher insect populations like that of African bollworms that were recorded in the unsprayed cotton unlike the sprayed treatments and the plants may have formed bolls late to compensate for loss due to insect damage (data in Chapter 5). Delayed maturity of cotton due to insect pest damage was reported by Gore and Adamezy (2004). Insect damage through puncturing and rasping of plant cells and buds stunts plant growth leading to flowering and fruiting at higher positions which delays maturity (Bacheler, 2012).

Generally, plants in all the treatments had taken more days to flower and start boll opening as compared to mean flowering and opening periods of 53 and 97 days respectively for Makoka 2000 cotton variety (MoAFS, 2005b). This delay can be attributed to lower temperatures that were experienced during the winter period in Lilongwe district as evidenced from monthly mean maximum and minimum temperatures for Chitedze Research Station and surrounding areas (Table 3.1). Munro (1987) indicated that the optimum temperature range for cotton growth and development range from 32 – 37.5 degrees Celsius and that lower temperatures are associated with delayed boll maturation and splitting. At temperatures below 12 degrees Celsius growth and development of cotton plant ceases (Munro, 1987). All contrasts on number of days to 50 % flowering and boll opening at Bunda College for sole versus intercropping, sole versus strip cropping, strip 1:1 versus strip 2:2, strip same planting versus strip delayed cowpea planting and strip versus within row intercropping were not significant.

4.4.2.3 Number of sympodial branches, bolls per plant and stand count at first harvest

Results on the effect of intercropping systems at Bunda (Table 4.6) show that there were significant differences on number of sympodial branches ($P<0.001$), number of bolls per plant ($P<0.001$) and stand count at first harvest (P 0.040). At Rivirivi EPA in Balaka district (Table 4.7) no significant differences were obtained amongst the treatments on number of bolls per plant and stand count at first harvest. At Mpingu EPA in Lilongwe district (Table 4.7), significant differences existed amongst the intercropping systems on number of bolls per plant while stand count at harvest was not significantly different.

Table 4.6 Effect of intercropping systems on number of sympodial branches, bolls per plant and stand count at first harvest in cotton at Bunda College during 2011/12 season.

Treatments	**No. of sympodial branches**	**No. of bolls/ plant**	**Stand count/ m^2**
Sole sprayed	5.50	7.25	2.93
Sole unsprayed	3.25	3.50	2.93
Strip 1:1 same time	6.00	9.25	2.90
Strip 1:1 delayed	6.50	10.75	2.87
Strip 2:2 same time	5.75	8.50	2.70
Strip 2:2 delayed	5.50	8.00	2.70
Within row (Sudan)	4.00	5.00	2.77
Within row (IT82E-16)	4.00	5.00	2.90
Mean	5.06	7.16	2.84
F-pr.	<0.001	<0.001	0.040
LSD (0.05)	0.956	1.450	0.181
CV (%)	12.8	13.8	4.3
Contrasts	**F-pr.**		
Sole cropping vs. intercropping	0.890	0.065	0.090
Sole cropping vs. strip cropping	0.242	0.003	0.052
		(7.25 vs. 9.21)	
Strip 1:1 vs. strip 2:2	0.068	0.002	0.007
		(10.8 vs.8.25)	(2.89 vs. 2.70)
Strip same time vs. strip delayed	0.704	0.322	0.789
Strip vs. within row IT82E-16	<0.001	<0.001	0.789
	(5.94 vs. 4.00)	(9.21 vs.5.00)	

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Table 4.7 Effect of intercropping systems on number of bolls per plant and stand count in cotton at Rivirivi and Mpingu EPAs during the 2011/2012 season.

Treatments	Rivirivi EPA No. of bolls/plant	Rivirivi EPA Stand count at first harvest (m^2)	Mpingu EPA No. of bolls per plant	Mpingu EPA Stand count at first harvest (m^2)
Sole sprayed	4.50	1.83	5.75	2.11
Strip 1:1 same time	5.50	2.22	7.0	2.11
Strip 2:2 same time	4.75	2.22	6.0	2.22
Within row (Sudan)	4.75	2.06	3.50	2.17
Within row (IT82E-16)	4.75	2.22	3.50	1.94
Mean	4.82	2.11	5.15	2.11
F-pr.	0.663	0.156	0.004	0.567
LSD (0.05)	1.441	0.371	1.876	0.366
CV (%)	19.3	11.4	23.6	11.2
Contrast		**F-pr.**		
Sole crop vs. intercropping	0.373	0.016 (1.83 vs. 2.22)	0.728	0.896
Sole crop vs. strip crop	0.297	0.002 (1.83 vs. 2.22)	0.334	0.709
Strip vs. within row IT82E-16	0.525	1.00	0.002 (6.50 vs.3.50)	0.156

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

The highest number of sympodial branches at Bunda (Table 4.6) was from 1:1 strip cropping with delayed cowpea planting and this was statistically different from number of sympodial branches obtained from sole sprayed cotton. Sole unsprayed cotton gave significantly lower number of sympodial branches (3.25) compared to all other treatments.

Treatment contrast results from Bunda College for different intercropping systems (Table 4.6) show that strip intercropping did not have a negative effect on number of sympodial branches produced by cotton suggesting that cowpea would be a suitable companion crop to cotton when planted in strip cropping. Within row intercropping significantly reduced number of sympodial branches compared to both strip and sole cropping treatments. Simultaneous sowing of cotton and cowpea in both 1:1 and 2:2 strip cropping treatments at Bunda College produced number of bolls that were at par with those obtained from 1:1 strip cropping with delayed planting of cowpea. The highest number of bolls per plant at Bunda College (Table 4.6) was obtained from 1:1 strip cropping with delayed cowpea planting and this was significantly higher than number of cotton bolls obtained from sole sprayed cotton. In 1:1 strip cropping, delayed introduction of cowpea significantly increased number of bolls per plant unlike in 2:2 strip cropping where delayed sowing of cowpea did not yield significant effects. Significantly lower number of bolls per plant at Bunda College came from sole unsprayed cotton. Both 1:1 and 2:2 strip cropping treatments with simultaneous planting of cotton and cowpea produced number of bolls that were at par with those obtained from sole sprayed cotton. The higher number of bolls per plant produced in the 1:1 strip cropping compared to the sole and 2:2 strip cropping treatments at Bunda College (Table 4.6) as shown from the treatment contrasts suggests that under 1:1 strip cropping system there was less inter and intra species competition as such cotton plants were able to use adequate light and had less competition for growth factors (Hadejia, 2011). In addition 1:1 strip cropping offered effective and less obstructed application of pesticides that would have led to a reduction in number of flower and fruit drop. This was unlike in sole and 2:2 strip cropping where movements of a sprayer operator and efficiency of pesticide application might have been affected by a dense canopy of cotton. Results from all three sites show that strip cropping was at par with sole sprayed cotton on number of bolls per plant produced by different intercropping systems. This suggests that in both strip cropping treatments, cowpea did not have a negative effect of growth of cotton. This however contradicts the observation made by Khan, et al. (2001) who reported reduced number of bolls per plant from cotton intercropped with cowpea in Pakistan. This could probably have arisen due to close inter and intra row spacing or less effective management of insect pests. At Mpingu EPA (Table 4.7) significantly lower number of bolls were obtained from the within row intercropping with either of the two cowpea varieties This could have resulted from competition for growth resources between cotton and cowpea crops planted on the same ridge. Cotton stand count at both on farm sites was generally lower than expected. This is a result of poor cotton establishment due to erratic rains at the time of planting.

Treatments contrasts for Bunda College (Table 4.6) indicate that there was better cotton plant establishment (stand count) in 1:1 strip cropping than 2:2 strip cropping. While general ANOVA did not show significant differences on stand count at Rivirivi EPA (Table 4.7), ANOVA for contrasts shows that there was significantly better cotton stand in intercropping than in pure stands.

4.4.2.4 Boll size, seed cotton yield and ginning outturn

Tables 4.8 and 4.9 present results on the effect of different intercropping systems on boll size, seed cotton yield and ginning outturn in cotton. The results for Bunda (Table 4.8) show that there were significant differences amongst the treatments for boll size and seed cotton yield but no significant effects on ginning outturn were observed.

At Rivirivi in Balaka district (Table 4.9), seed cotton yield and boll sizes showed significant differences amongst the treatments. While statistically significant effects for seed cotton yield were very apparent amongst the treatments at Mpingu EPA (Table 4.9), all treatments produced cotton bolls with similar weight.

Table 4.8 Influence of intercropping systems on cotton boll size, seed cotton yield and ginning outturn (GOT) at Bunda College during the 2011/2012 season.

Treatments	**Boll size (g)**	**Seed cotton yield (Kg ha^{-1})**	**GOT (%)**
Sole sprayed	4.55	1519	40.61
Sole unsprayed	3.32	637	41.49
Strip 1:1 same time	4.79	1433	41.60
Strip 1:1 delayed	4.79	1839	43.04
Strip 2:2 same time	4.50	1883	40.53
Strip 2:2 delayed	4.74	1912	41.53
Within row (Sudan)	4.06	728	41.13
Within row (IT82E-16)	3.26	605	45.06
Mean	4.22	1319	41.08
F-pr.	<0.001	<0.001	0.685
LSD (0.05)	0.60	515.0	5.346
CV (%)	9.7	24.9	8.7
Contrasts		**F-pr.**	
Sole cropping vs. intercropping	0.465	0.940	0.390
Sole cropping vs. strip cropping	0.705	0.235	0.604
Strip 1:1 vs. strip 2:2	0.952	0.198	0.420
Strip same time vs. strip delayed	0.234	0.202	0.506
Strip vs. within row IT82E-16	<0.001 (4.64 vs. 3.36)	<0.001 (767 vs. 605)	0.111

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Table 4.9 Effect of intercropping systems on cotton boll size and seed cotton yield at Rivirivi and Mpingu EPAs during the 2011/2012 season.

	Rivirivi EPA		Mpingu EPA	
Treatments	**Boll size (g)**	**seed cotton yield (kg ha^{-1})**	**Boll size (g)**	**Seed cotton yield (kgha^{-1})**
Sole sprayed	6.45	941	4.30	943
Strip 1:1 same time	6.75	1816	3.90	896
Strip 2:2 same time	6.75	1558	4.05	703
Within row (Sudan)	6.05	616	3.28	264
Within row (IT82E-16)	5.32	538	3.45	427
Mean	6.25	1054	3.80	649
F-pr.	0.015	0.012	0.078	0.035
LSD (0.05)	1.441	694.6	0.788	476.8
CV (%)	8.7	42.8	13.5	47.7
Contrast		**F-pr.**		
Sole crop vs. intercropping	0.588	0.276	0.116	1.46
Sole crop vs. strip crop	0.386	0.037 (941 vs. 1588)	0.320	0.434
Strip vs. within row IT82E-16	0.001 (6.75 vs. 5.32)	0.003 (1588 vs. 538)	0.119	0.073

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

At Bunda College (Table 4.8) all strip cropping treatments had boll sizes that were similar to those obtained from the sole sprayed cotton. The sole unsprayed cotton and the within row intercropping with IT82E-16 cowpea variety produced cotton bolls that had significantly lower boll weights. At Rivirivi EPA (Table 4.9), except for the within row intercropping with IT82E-16 treatment, all other treatments produced cotton bolls with similar weights.

Based on these results it is suggested that unlike within row intercropping, strip cropping would be an intercropping system of choice for smallholder agriculturalists when cotton and cowpea are to be grown in association with each other. The none significance amongst the treatments for GOT as observed from Bunda results (Table 4.8) was expected considering that only one cotton variety, Makoka 2000, was planted at the site. Munro (1987) indicated that GOT is in most cases genotype dependent. Ginning outturn values in all treatments were above the mean GOT value of 38.90 % for Makoka 2000 cotton variety (MoAFS, 2005b). All strip cropping treatments at Bunda College (Table 4.8) gave seed cotton yields that were at par with the sole sprayed cotton treatment meaning that in these treatments cowpea would be an ideal component crop to cotton. Time of sowing cowpea in 1:1 and 2:2 strip cropping treatments did not have any significant effects on seed cotton yield at Bunda however delaying cowpea planting gave slight advantage of increased seed cotton yield. Within row intercropping with either of the two cowpea varieties gave seed cotton yields that were significantly lower than all strip and sole sprayed cotton treatments but similar to pure unsprayed cotton treatment. In within row intercropped treatments, cowpea plants were suffocating cotton plants (Fig 4.3) depriving them of the required space, air and the required solar radiation for photosynthesis. Potential cotton yield is a result of progressively accumulated photosynthesis partitioned to different yield components such as bolls per plant thus indicating that a good source – sink relationship is a prerequisite to achieve increased crop yields (Ganajaxi, 2008). In addition, seed cotton yield, just like yields of most crops, is a manifestation of various growth and yield attributing characteristics (Ganajaxi, 2008). The seed cotton yield attributes like number of bolls per plant, boll size and number of sympodial branches were higher in strip cropping than in within row intercropping and this explains why overall the performance of the within row intercropped plants was inferior to the strip and sole cropped treatments at Bunda. Much as there were no significant differences in seed cotton yield between the sole unsprayed cotton treatment and the within row intercropped cotton treatments, the seed cotton from the unsprayed treatment was of poor quality as it was heavily stained by cotton stainers while the seed cotton from the within row intercropped treatment was clean and free of any cotton stainer damage. Contrasting sole and intercropping treatments at Rivirivi EPA (Table 4.9) reveals a none significant difference between sole and intercropped cotton in seed cotton yield. This none significant difference in seed cotton yield between sole and intercropped cotton emanates from none significant variations in cotton yield attributes such as number of bolls per plant and boll size. Strip cropping, however, gave significantly higher seed cotton yields (1588 kg ha^{-1}) than within row intercropping (538 kg ha^{-1}). The difference might have come from the fact that plants in the strip cropping treatments had un interrupted access to PAR unlike in the within row intercropping system where cotton plants had limited exposure to PAR. Number of cotton bolls per plant and size of cotton bolls were also not significantly different between the sole sprayed and strip cropping treatments. Seed cotton yields at Mpingu EPA in Lilongwe (Table 4.9) shows that 1:1 and 2:2 strip cropping treatments with simultaneous planting of cotton and cowpea gave seed cotton yields that were at par with seed cotton yields obtained from the sole sprayed cotton treatment. While the within row intercropping with Sudan gave lowest seed cotton yields at Mpingu EPA, the seed cotton yield obtained from this treatment were similar to seed cotton yields obtained from within row intercropping with IT82E-16 and 2:2 strip cropping with simultaneous planting of cotton and cowpea.

Figure 3.3 Cotton plants suffocated by cowpea plants in within row intercropped treatments at Bunda College.

4.4.2.5 Correlation analysis of some important quantitative traits in cotton

Results of correlation analysis of seed cotton yield and some quantitative traits at Bunda College (Table 4.10) show that there were significant and positive correlations for seed cotton yield and plant height, number of cotton bolls per plant, number of sympodial branches , boll size and canopy diameter. Positive but none significant association of plant height against number of bolls and sympodial branches was also observed. The coefficient of determination (r^2) for seed cotton yield with plant height, number of cotton bolls per plant, number of sympodial branches, boll size and canopy diameter indicate that 25%, 60%, 76%, 47% and 42% of variations in seed cotton yield among the treatments at Bunda can be attributed to differences in plant height, number of bolls per plant, number of sympodial branches, boll size and canopy diameter, respectively.

Table 4.10 Correlations coefficient (r), coefficient of determination (r^2) and their significance for seed cotton yield and other quantitative traits in cotton at Bunda College.

No.	Character combination (n = 32)	r	r^2	Significance
1	Plant height vs. seed cotton yield	0.4980	0.25	*
2	Number of bolls per plant vs. seed cotton yield	0.7729	0.65	***
3	Number of sympodial branches vs. seed cotton yield	0.8707	0.76	**
4	Boll size vs. seed cotton yield	0.6834	0.47	**
5	Canopy diameter vs. seed cotton yield	0.6447	0.42	***
6	Plant height vs. number of bolls per plant	0.2744	0.08	Ns
7	Plant height vs. number of sympodial branches	0.3037	0.09	Ns

ns = not significant, *, **, *** significant at 0.05, 0.01, 0.001 respectively.

At Mpingu (Table 4.11) there was a positive and highly significant association of seed cotton yield with plant height, number of bolls per plant, boll size and canopy diameter. This was also the case with the correlation between plant height and number of bolls per plant. The coefficients of determination (r^2) indicate that 51%, 62%, 76% and 52% of variations in seed cotton yield amongst the treatments at Mpingu are attributed to differences in plant height, number of bolls per plant, boll size and canopy diameter respectively. At Rivirivi (Table 4.12) there was positive and significant correlation of seed cotton yield with plant height and boll size.

Table 4.11 Correlations coefficient (r), coefficient of determination (r^2) and their significance for seed cotton yield and other quantitative traits in cotton at Mpingu EPA in Lilongwe district.

No.	Character combination (n = 20)	r	r^2	Significance
1	Plant height vs. seed cotton yield	0.7132	0.51	***
2	Bolls per plant vs. seed cotton yield	0.7227	0.62	***
3	Boll size vs. seed cotton yield	0.8742	0.76	***
4	Canopy diameter vs. seed cotton yield	0.7244	0.52	***
5	Plant height vs. bolls per plant	0.7043	0.50	***

*** Significant at 0.001.

Table 4.12 Correlations coefficient (r), coefficient of determination (r^2) and their significance for seed cotton yield and other quantitative traits in cotton at Rivirivi EPA in Balaka district.

No.	Character combination (n = 20)	r	r^2	Significance
1	Plant height vs. seed cotton yield	0.4776	0.23	*
2	Bolls per plant vs. seed cotton yield	0.1012	0.01	Ns
3	Boll size vs. seed cotton yield	0.4468	0.05	*
4	Canopy diameter vs. seed cotton yield	0.2296	0.05	Ns
5	Plant height vs. bolls per plant	0.0055	0.001	Ns

ns = not significant, * significant at 0.05.

The positive association between plant height and seed cotton yield as found in this study are in agreement with findings of Echekwu (2001). The results of this study are also supported by the findings of Suriya (1996), Santage, et al. (2000) and Hussain, et al. (2000) who reported significant and positive association between number of bolls per plant and seed cotton yield. Iqbar, et al. (2006), Salahuddin, et al. (2010) reported significant and positive association between number of sympodial branches, boll size and canopy diameter with seed cotton yield. The positive association of plant height and number of bolls per plant (at Bunda and Mpingu) and number of sympodials per plant (at Bunda) suggests that, up to a certain limit, the taller cotton plants will tend to produce more sympodial branches with a resultant increase in number of cotton bolls. This, therefore, explains why the increase in plant height has positively correlated with seed cotton yield. The strong correlation that exists between some yield and growth traits against seed cotton yield in this study is important in agronomy in that good farming practices such as intercropping that may contribute towards attainment of more bolls and sympodial branches per plant, among other traits, would directly contribute towards increased cotton yields.

4.4.2.6 General performance of cotton in intercropping with cowpea

In summary, cotton intercropping results from Bunda, Lilongwe and Balaka on farm sites show that there was similar performance between the pure sprayed and the strip cropped cotton on seed cotton yield, number of bolls per plant and seed size. However intercropping reduced cotton plant height and canopy diameter. No significant differences were also obtained between1:1 and 2:2 strip cropped cotton in most growth and yield parameters recorded. Time of planting cowpea in 1: 1 and 2: 2 strip cropping systems did not in general influence the performance of cotton in a cotton and cowpea intercrop. Within row intercropping was secondary to strip and pure cropped cotton as it consistently gave lower seed cotton yields, less number of bolls, narrower and shorter cotton plants. The results also indicated that time to flowering and boll splitting was not affected by the intercropping system.

4.4.3 Performance of cowpea in intercropping

F-probabilities for analysis of variance across the sites for cowpea growth and yield attributes (Table 4.13) indicate that there were significant intercropping systems and site differences for pod length, number of pods per plant, number of seeds per pod, shelling percent, 100 seed weight and grain yield. The interaction between intercropping systems and site was significant for canopy diameter and grain yield otherwise all other variables were not significantly different for the site and intercropping system interaction.

Table 4.13 Summary of F-probabilities from analysis of variance for cowpea across three sites on number of pods per plant, pod length, number of seeds per pod, shelling %, 100 seed weight and grain yield of cowpea intercropped with cotton.

		F-probabilities x Growth and yield parameters					
Source of variation	**DF**	**pods/ plant**	**pod length**	**seeds/ pod**	**shelling %**	**100 seed weight**	**grain yield**
Intercropping system	4	0.029	<0.001	<0.001	<0.001	<0.001	<0.001
Site	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Intercropping x site	8	0.071	0.190	0.262	0.431	0.684	0.002
Means	-	14	15.0	12.63	64.80	11.39	1328
CV (%)	-	22.1	5.0	9.4	5.8	8.6	21.0

F-pr. = p-value.

Highly significant differences in growth and yield performance of cowpea across the sites can be attributed, among other factors, to differences in environmental factors (temperature, rainfall and soil types) and pests' populations. Significant pests' populations for aphids, *Maruca testulalis*, *Anoplecnemis curvipes* and thrips were recorded across the sites (Table 5.2) which could have led to differences in response by cowpea. Differences in amounts of rainfall received across the sites (Figures 3.1, 3.2, 3.3) meant different growth, yield and yield related responses in cowpea. Awal and Ikeda (2003) indicated that cowpea crop ability to maximise growth and production of dry matter is affected by such factors as vapour pressure and rainfall (drought).

4.4.3.1 Canopy diameter, number of days to 75 % physiological maturity, Total dry matter (TDM) and stand count

Results for Bunda College on cowpea canopy diameter, number of days to 75 % physiological maturity, total dry matter and stand count at first harvest at are presented in Table 4.14 and Figure 4.4. Intercropping systems has significant effects on canopy diameter ($P<0.001$), number of days to 75% physiological maturity ($P<0.001$), total dry matter ($P< 0.001$) and stand count at first harvest.

Table 4.14 Influence of intercropping systems and foliar pesticides applied on cotton on stand count, days to 75 % physiological maturity and total dry matter (TDM) of cowpea at Bunda College during 2011/2012 season.

Treatments	**Days to 75% physiological maturity**	**Stand count at harvest/m^2**	**Total dry matter (tonnes ha^{-1})**
Sole sprayed	74.75	6.43	2.23
Sole unsprayed	79.00	6.13	1.90
Strip 1:1 same time	78.00	6.03	2.27
Strip 1:1 delayed	86.50	7.60	2.00
Strip 2:2 same time	76.50	6.00	2.45
Strip 2:2 delayed	87.00	7.63	1.59
Within row (Sudan)	82.00	4.03	3.27
Within row (IT82E-16)	78.75	4.17	2.70
Mean	80.13	6.00	2.30
F-pr.	<0.001	<0.001	0.001
LSD (0.05)	4.243	0.696	0.649
CV (%)	3.6	7.9	19.2
Contrasts		**F-pr.**	
Sole cropping vs. intercropping	<0.001	0.578	0.905
	(74.75 vs. 81.35)		
Sole cropping vs. strip cropping	<0.001	0.162	0.542
	(74.25 vs. 82.00)		
Strip 1:1 vs. strip 2:2	0.732	1.00	0.601
Strip same time vs. strip delayed	<0.001	<0.001	0.019
	(82.75 vs. 77.25)	(6.02 vs. 7.62)	(0.2.36 vs.1.80
Strip vs. within row IT82E-16	0.057	<0.001)	0.020
		(6.82 vs.4.17)	(2.08 vs. 2.70)

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

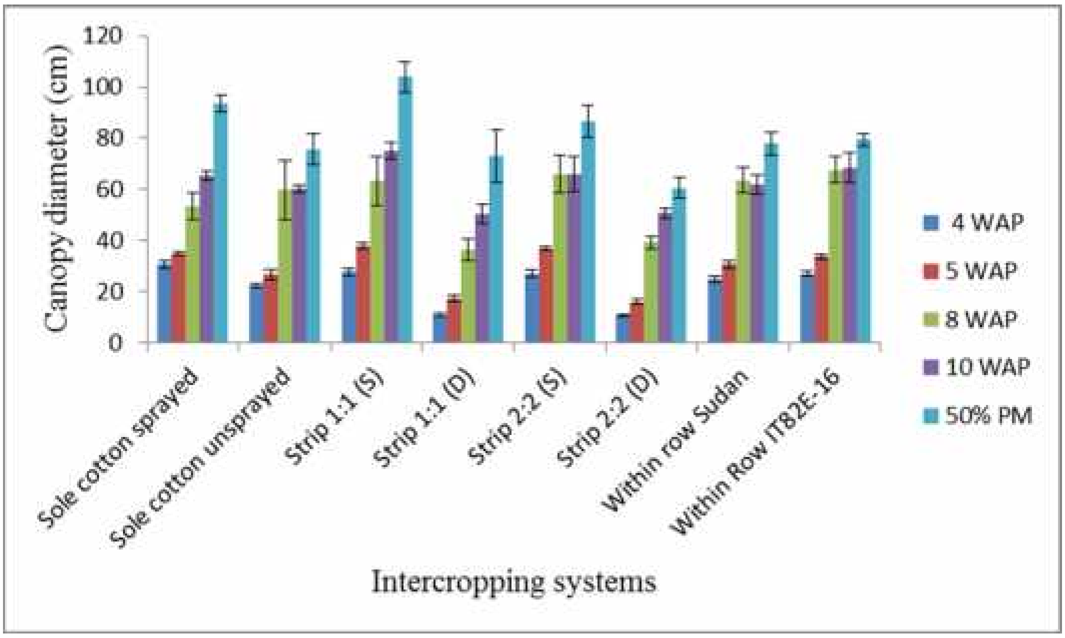

Figure 4.4 Cowpea canopy as affected by intercropping systems at Bunda during 2011/2012 season.

PM = Physiological maturity

Delaying cowpea in 1:1 and 2:2 strip cropping treatments significantly reduced cowpea canopy diameter at Bunda (Fig. 4.4) which can be attributed to suppression of branching resulting from lack of adequate light in late planted intercrops (Terao, et al., 1997). Sole sprayed cowpea matured earlier (74.75 days) though it was not significantly different from number of days taken by 2:2 strip cropping with simultaneous sowing of cowpea and cotton. Delaying cowpea planting in both 1:1 and 2:2 strip cropping increased number of days to reach physiological maturity. Delaying cowpea planting deprived cowpea plants of the favourable soil and environmental factors such as warmer soils and temperatures associated with early periods of the growing season that lead to rapid growth of crop plants (Purseglove, 1986). However it is observed from the results that delaying cowpea planting in intercropping significantly improved crop establishment. Second planting of the cowpea in 1:1 and 2:2 strip cropping treatments coincided with a pickup in rainfall which was otherwise erratic during initial planting (appendix 1a) . This might have contributed to significantly better crop stand for the delayed strip 1:1 and strip 2:2 cropping patterns. The within row intercropping systems had the lowest stand count amongst the treatments. This scenario is not surprising considering that some space in these treatments was taken by cotton and this contributed to highly significant differences amongst the treatments. Total dry matter (TDM) accumulation differed significantly($P< 0.001$) among the treatments with the within row intercropping with Sudan recording the highest TDM followed by within row intercropping with IT82E-16 while 2:2 strip (delayed) cropping registered the least TDM accumulation. Treatments contrasting reveal that overall early planting increased dry matter accumulation over delayed cowpea planting and that within row intercropping had significantly higher TDM accumulation than strip cropping despite within row intercropping having significantly lower stand count. Early planted cowpea could have taken advantage of favourable environmental factors such as higher soil temperatures to induce fast growth and development of plant parts such as leaves and hence increased TDM accumulation. Cowpea plants in the within row intercropping had a direct benefit of pesticides applied on cotton. This reduced pest damage on plant parts such as leaves allowing increased light interception leading to increased rate of photosynthesis and hence higher TDM accumulation (Addo-Quaye, et al., 2011).

4.4.3.2 Pod length, number of seeds per pod, shelling percent and harvest index

The results on pod length, number of seeds per pod, shelling percent and harvest index at Bunda College (Table 4.15) indicate that intercropping systems had significant differences on pod length, number of seeds per pod and harvest index while no significant effects were observed on shelling percent. At Mpingu EPA (Table 4.16) intercropping systems showed statistically significant effects on number of seeds per pod and pod length. While significant differences were observed amongst intercropping systems on number of seeds per pod at Rivirivi EPA (Table 4.16), all intercropping systems had similar pod lengths.

Table 4.15 Effect of intercropping systems and foliar pesticides applied on cotton on pod length, seeds per pod and shelling % of cowpea at Bunda College 2011/2012 season.

Treatments	**pod length (cm)**	**seeds /pod**	**shelling %**	**HI (%)**
Sole sprayed	13.53	11.50	68.59	44.40
Sole unsprayed	13.30	12.00	67.33	32.80
Strip 1:1 same time	13.80	12.75	65.12	40.70
Strip 1:1 delayed	12.80	11.00	70.58	38.90
Strip 2:2 same time	13.73	12.00	66.01	36.60
Strip 2:2 delayed	12.32	10.25	67.90	40.60
Within row (Sudan)	14.48	13.50	67.96	28.10
Within row (IT82E-16)	14.20	12.75	68.19	32.70
Mean	13.52	11.97	67.71	36.80
F-pr.	<0.001	0.002	0.878	0.012
LSD (0.05)	0.801	1.377	7.475	8.39
CV (%)	4.0	7.8	7.5	15.5
Contrasts		**F-pr.**		
Sole cropping vs. intercropping	0.585	0.631	0.715	0.049
				(44.40 vs. 37.90)
Sole cropping vs. strip cropping	0.233	1.00	0.680	0.117
Strip 1:1 vs. strip 2:2	0.324	0.124	0.727	0.679
Strip same time vs. strip delayed	<0.001	0.001	0.163	0.689
	(13.77 vs. 12.56)	(13.75 vs. 10.63)		
Strip vs. within row IT82E-16	0.003	0.026	0.784	0.054
	(13.16 vs. 14.20)	(11.05 vs. 12.75)		

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Table 4.16 Influence of intercropping systems and foliar pesticides applied on cotton on pod length and number of seeds per pod in cowpea at Rivirivi and Mpingu EPAs during the 2011/2012 season.

Treatments	Rivirivi EPA		Mpingu EPA	
	no. of seeds /pod	**pod length (cm)**	**no. seeds / pod**	**pod length (cm)**
Sole sprayed	12.00	15.56	11.75	14.70
Strip 1:1 same time	13.90	16.03	11.00	14.21
Strip 2:2 same time	12.50	16.55	11.25	14.11
Within row (Sudan)	15.75	16.43	14.75	16.43
Within row (IT82E-16)	13.00	16.60	11.50	14.97
Mean	13.35	16.26	12.05	14.88
F-pr.	0.028	0.310	0.002	0.007
LSD (0.05)	2.241	1.245	1.610	1.17
CV (%)	10.9	5.0	8.7	5.1
Contrasts			**F-pr.**	
sole cropping vs. intercropping	0.257	0.100	0.423	0.542
sole cropping vs. strip cropping	0.284	0.167	0.348	0.265
strip vs. within row IT82E-16	1.00	0.540	0.569	0.105

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days.

The within row intercropping with Sudan produced the longest pods at Bunda (Table 4.15) and Mpingu EPA (Table 4.16) compared to all other intercropping systems. The within row intercropping with Sudan cowpea variety also gave significantly higher number of seeds per pod compared to other treatments at all the three sites. This difference can be attributed to genotypic characteristics of Sudan cowpea variety considering that all other treatments planted with IT82E-16 cowpea variety produced pod lengths and number of seeds per pod that were not significantly different from each other.

At Bunda College (Table 4.15) the results show that delaying planting of cowpea in 1:1 and 2:2 strip intercropping systems reduced cowpea pod length and number of seeds per pod compared to simultaneous sown cowpea and cotton in the two strip intercropping systems. Delaying cowpea could have led to reduced leaf area index (LAI) which could not provide assimilates for pod development and grain filling and under such circumstances, flowers abort and/or seeds are partially filled (Adipala, et al., 2002). Treatment contrasts on pod lengths and number of seed per pod at Bunda show that within row intercropping treatments had longer pod lengths and number of seeds per pod compared to strip cropping treatments combined though this difference was none existent at both the on farm sites. Cowpea plants in the within row intercropping system had a more direct benefit from pesticides applied on cotton and this might have reduced the degree of pest damage to cowpea pods hence a higher number of fully developed seeds per pod for the within row intercropping compared to strip cropping system as observed from results from Bunda College.

Harvest index (HI) is the proportion of grain in the total above ground biomass of the crop expressed as a percentage (Singh, et al., 2011). The highest (44.4 %) and lowest (28.1 %) HI values were obtained from sole sprayed cowpea and within row intercropping with Sudan respectively. All intercropping treatments had similar HI values. The HI value range of 28.1% to 44.4% indicates that only 28.1% to 44.4% of the photosynthate was translocated to the grain (Singh, et al., 2011). The HI values obtained in this study are in conformity with most HI values from various studies on cowpea as reported by Dadson, et al. (2005); Chattha, et al., (2007); Singh, et al., (2011); and Kiari, et al., (2011).

4.4.3.3 Number of pods per plant, 100 seed weight and grain yield

Results on number of pods per plant, cowpea grain yield and 100 seed weight (seed size) at Bunda are shown in Table 4.17. There were significant treatment differences on grain yield, number of pods per plant and seed size. Intercropping systems differed significantly on number of pods per plant and grain yield at Riviriviri EPA (Table 4.18). None significant treatment effects on cowpea grain yield were observed at Mpingu EPA (Table 4.18). At both on farm sites, seed size was not different amongst the treatments.

Table 4.17 Influence of intercropping and foliar chemicals applied on cotton on pods per plant, seed size and grain yield of cowpea at Bunda College during 2011/2012 season.

Treatments	**pods / plant**	**seed size (g)**	**Grain yield (kg ha^{-1})**
Sole sprayed	16.25	10.77	2677
Sole unsprayed	12.50	10.53	1914
Strip 1:1 same time	17.50	10.86	2612
Strip 1:1 delayed	15.50	9.66	2136
Strip 2:2 same time	18.75	11.10	2247
Strip 2:2 delayed	14.00	10.12	1802
Within row (Sudan)	15.50	9.23	1635
Within row (IT82E-16)	17.50	10.92	1820
Mean	15.94	10.40	2106
F-pr.	0.045	0.005	0.008
LSD (0.05)	3.727	0.968	579.0
CV (%)	15.9	6.3	18.7
Contrasts		**F-pr.**	
Sole cropping vs. intercropping	0.776	0.509	0.018 (2677 vs. 2123)
Sole cropping vs. strip cropping	0.896	0.367	0.042 (2677 vs. 2197)
Strip 1:1 vs. strip 2:2	0.922	0.295	0.090
Strip same time vs. strip delayed	0.015 (18.13 vs.14.75	0.003 (10.98 vs. 9.89)	0.029 (2430 vs.1969)
Strip vs. within row IT82E-16	0.462		0.100

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Table 4.18 Influence of intercropping systems and foliar pesticides applied on cotton on number of pods per plant, grain yield and seed size of cowpea at Rivirivi and Mpingu EPAs during the 2011/2012 season.

	Rivirivi EPA			**Mpingu EPA**		
Treatments	**pods/ plant**	**grain yield (kg ha^{-1})**	**seed size (g)**	**pods/ plant**	**grain yield (kg ha^{-1})**	**seed size (g)**
Sole sprayed	8.75	1315	11.60	13.75	1982	11.57
Strip 1:1 same time	9.25	2007	12.85	13.75	1454	11.94
Strip 2:2 same time	8.75	2130	11.73	13.00	1745	12.03
Within row (Sudan)	16.50	1502	10.55	18.50	1765	11.12
Within row (IT82E-16)	11.50	1312	12.08	16.00	1770	12.53
Mean	10.95	1652	11.77	15.00	1743	11.84
F-pr.	0.045	0.005	0.333	0.102	0.411	0.143
LSD (0.05)	5.542	467.8	2.282	4.432	558.2	1.122
CV (%)	32.9	18.4	12.5	19.2	20.8	6.2
Contrasts				**F-pr.**		
Sole crop vs. intercropping	0.611	0.014 (1315 vs.1816	0.480	0.769	0.146	0.183
Sole crop vs. strip crop	0.912	0.002 (1315 vs. 2069)	0.460	0.835	0.111	0.373
Strip vs. within row IT82E-16	0.279	0.002 (2068 vs. 1312)	0.823	1.620	0.459	0.245

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Treatment effects at Bunda College (Table 4.17) show that 1:1 and 2:2 strip cropping treatments with same time planting of cowpea and cotton produced number of pods per plant that were significantly higher than the unsprayed sole cowpea treatment. At Rivirivi EPA (Table 4.18) the significantly higher number of pods per plant were produced from the within row intercropping with Sudan otherwise all other treatments had uniform number of pods produced per plant between them. The number of pods from 1:1(same time) and 2:2 (same time) were at par with those obtained from sole sprayed cowpea treatment at all the three sites implying that the chemical sprays applied to control cotton pests effectively reduced both flower and pod drops. Delaying cowpea planting at Bunda College in both strip cropping arrangements resulted in a reduction in number of pods formed per plant. Delayed cowpea sowing also reduced cowpea seed size at Bunda College but no significant differences on seed size were observed from both on farm sites (Table 4.18). Gandebe, et al. (2010) reported that delaying cowpea sowing in maize intercrop reduced number of cowpea pods per plant and the 100 seed weight. The lower number of pods recorded in delayed planted cowpea can be attributed to shading effect of taller component crop (cotton) which obstructed solar radiation from penetrating into lower cowpea canopy. Delaying cowpea could also have led to reduced leaf area index (LAI) which could not provide assimilates for pod development and grain filling and under such circumstances, flowers abort and/or seeds are partially filled (Adipala, et al., 2002). Terao, et al. (1997) indicated that the main reason for a reduction in pod formation and cowpea grain yields in late planted intercropped cowpea is lack of branching or delayed branching. The mechanism of branching suppression results from lack of adequate light in the late planted intercrops. Lack of light changes phytochrome to its inactive form (Pfr) which stimulates apical dominance to escape from a light deficient condition. Seed sizes for all treatments were generally lower than the optimal seed sizes of 13g/100 seeds and 12g/100 seeds for Sudan-1 and IT82E-16 respectively as reported by Kabambe, et al., (2010a).

At Bunda College (Table 4.17) sole sprayed cowpea gave the highest cowpea grain yield (2677 kg ha^{-1}), followed by 1:1 strip (same time) cropping (2612 kg ha^{-1}) and strip 2:2 (D) with 2247 kg ha^{-1}. Within row intercropping with IT82E-16 gave cowpea grain yield of 1820 kg ha^{-1} which was at par with grain yields from 1:1 and 2:2 strip cropping systems. This indicates that cowpea growth was not negatively affected by the presence of cotton plants unlike with cotton which was affected by the presence of cowpea on the same ridge. Higher cowpea grain yields from sole cropping than from intercropping with maize were also reported by Rusinamhodzi, et al. (2006). No significant differences were observed in the performance of Sudan and IT82E-16 cowpea varieties used in the within row intercropping implying that both varieties can be used in intercropping with cotton. While there were no significant effects between within row intercropping with Sudan and IT82E-16 cowpea varieties, within row intercropping with Sudan gave grain yields which were significantly lower than 1:1 and 2:2 strip cropping treatments planted at the same time. Delaying sowing of cowpea in 1:1 and 2:2 strip cropping systems reduced cowpea grain yield by about 19%. This is in agreement with observations made by Blade, et al. (1997) who found out that delaying cowpea planting by 2-3 weeks in cotton and cowpea intercropping reduced cowpea grain yield by 50 % compared to the simultaneous sown cotton and cowpea crops.

At Rivirivi EPA in Balaka (Table 4.18) strip 1:1 (same time) gave the highest grain yield of 2007 kg ha^{-1} followed by strip 2:2 (same time) and the least was intercropping with IT82E-16 which gave 1312 kg ha^{-1}. Treatment contrasts on grain yield at Rivirivi indicate that intercropping significantly ($P \leq 0.05$) increased cowpea grain yields over the pure cowpea treatment while the within row intercropped treatments on average produced significantly lower yields (1312 kg ha^{-1}) compared to the strip cropped treatments (2068 kg ha^{-1}).

Overall cowpea grain yields obtained from the three sites are comparable to average grain yields obtained from other studies. Kabambe, et al. (2010b) reported mean yields of 1631 kg ha^{-1} and 1728 kg ha^{-1} for IT82E-16 and Sudan 1 respectively at Bunda. Cowpea mean grain yields of 2156 kg ha^{-1} for IT82E-16 and 2158 kg ha^{-1}for Sudan 1 have been reported at Rivirivi EPA (Kabambe, et al., 2010b). Cowpea grain yields of 1493 and 1649 kg ha^{-1} at Makoka and Chitala Research Stations respectively were reported by Mkandawire and Likoswe (2002) from intercropping of cotton and cowpea.

4.4.3.4 Correlation analysis of some important quantitative traits in cowpea

Correlations between cowpea grain yield and some important yield related traits show that there were significant and positive associations between cowpea grain yield with number of pods per plant and also between numbers of seeds per pod with pod length at Bunda College (Table 4.19). A negative but none significant correlation existed between pod length and grain yield while the relationship between grain yield with 100 seed weight, number of seeds per pods with cowpea grain yield was positive but not significant. Correlation results at Mpingu (Table 4.20) indicate a positive and significant association of cowpea grain yield with pod length, number of pods per plant and number of seeds per pod. The relationship between pod length and number of seeds per pod was also positive and significant. Results for Rivirivi EPA (Table 4.21) show that there was a positive and significant correlation for pod length with grain yield and also between numbers of seeds per pod with pod length.

A positive but none significant association of 100 seeds weight, pods per plant and number of seeds per pod with grain yield were observed at Rivirivi in Balaka district.

Table 4.19 Correlations coefficient (r), coefficient of determination (r^2) and their significance for cowpea grain yield and other quantitative traits in cowpea at Bunda College.

No.	Character combination (n = 20)	r	r^2	significance
1	100 seed weight vs. cowpea grain yield	-0.3879	0.15	ns
2	pod length vs. cowpea grain yield	0.5400	0.29	**
3	pods per plant vs. cowpea grain yield	0.4903	0.19	*
4	seeds per pod vs. cowpea grain yield	0.5971	0.36	**
5	seeds per pod vs. pod length	0.6210	0.39	**

ns = not significant, **, *** significant at 0.01, 0.001 respectively.

Table 4.20 Correlations coefficient (r), coefficient of determination (r^2) and their significance for cowpea grain yield and other quantitative traits in cowpea at Mpingu EPA in Lilongwe district.

No.	Character combination (n = 20)	R	r^2	significance
1	100 seed weight vs. cowpea grain yield	-0.3879	0.15	ns
2	pod length vs. cowpea grain yield	0.5400	0.29	**
3	pods per plant vs. cowpea grain yield	0.4903	0.19	*
4	seeds per pod vs. cowpea grain yield	0.5971	0.36	**
5	seeds per pod vs. pod length	0.6210	0.39	**
6	seeds per pod vs. pods per plant	0.4087	0.17	ns
7	pod length vs. pods per plant	0.3105	0.10	ns

ns = not significant, *, ** significant at 0.05, 0.01 respectively.

Table 4.21 Correlations coefficient (r), coefficient of determination (r^2) and their significance for cowpea grain yield and other quantitative traits in cowpea at Rivirivi in Balaka district.

No.	Character combination (n = 20)	R	r^2	significance
1	100 seed weight vs. cowpea grain yield	0.2091	0.04	ns
2	pod length vs. cowpea grain yield	0.4555	0.21	*
3	pods per plant vs. cowpea grain yield	0.1895	0.04	ns
4	seeds per pod vs. cowpea grain yield	0.1782	0.03	ns
5	seeds per pod vs. pod length	0.6010	0.36	**
6	seeds per pod vs. pods per plant	0.4484	0.20	ns
7	pod length vs. pods per plant	0.3751	0.14	ns

ns = not significant, *, ** significant at 0.05, 0.01 respectively.

The positive association between number of seeds per pod and cowpea grain yield as observed across three sites (Tables 4.19, 4.20 and 4.21) implies that an increase in number of seeds per pod has a resultant increase in cowpea grain yields. Positive and significant correlation between grain yield and number of seeds per pod were also reported by Nakawuka and Adipala (1999); Nehru, et al. (2009) and Gandebe, et al., (2010). The coefficient of determination (r^2) for number of pods per plant indicates that 26%, 19% and 4% variations in cowpea grain yield at Bunda, Mpingu and Rivirivi respectively are attributed to differences in number of pods per plant amongst the different treatments. Nwofia, et al. (2012) reported positive correlation between number of pods per plant and grain yield. The results of positive and significant association between pod length and grain yield as observed at Mpingu and Rivirivi (Tables 4.20 and 4.21 respectively) suggest that longer pods may lead to increased cowpea grain yield an association also reported by Nakawuka and Adipala, 1999). From the results of this study, this association is cemented by the positive and significant association between number of seeds per pod and the length of the pod at the three sites. The negative association between 100 seed weight and grain yield as observed at Mpingu in Lilongwe district (Table 4.20) was also reported by Nakawuka and Adipala (1999). The negative association between 100 seed weight and grain yield may help extrapolate and explain a negative association between pod length and grain yield at Bunda (Table 4.19) which suggests that sometimes it is possible for longer pods to result in reduced cowpea yields. This would be the case in situations where longer pods may have many seeds at the expense of seed weight. However, Gandebe, et al. (2010) indicated that 100 seed weight was not necessarily the main factor involved in seed yield but the number of seeds per pod which in this study was found to positively correlate with cowpea grain yield.

4.4.4 Biological viability of intercropping

4.4.4.1 Land Equivalent Ratio (LER)

Biological productivity and economic viability of the intercropping systems were only determined for the main experiment at Bunda college. The results indicate that all intercropping systems had total LER values greater than 1(Table 4.22) implying that intercropping was more productive than monocropping.

Table 4.22 Biological indices on the performance of different cotton and cowpea intercropping systems at Bunda College during 2011/2012 season.

Treatments	**PLER (*k,y*) cotton**	**PLER Cowpea**	**LER**	**ATER**	**CPR**
Strip 1:1 same time	0.94[b]	0.98	1.91[b]	1.36[b]	1.92[b]
Strip 1:1 delayed	1.19[b]	0.80	1.99[b]	1.53[b]	1.87[b]
Strip 2:2 same time	1.19[b]	0.84	2.03[b]	1.55[b]	1.94[b]
Strip 2:2 delayed	1.21[b]	0.67	1.88[b]	1.49[b]	1.74[b]
Within row IT82E-16	0.40[a]	0.68	1.08[a]	0.70[a]	1.15[a]
F-test *(z)*	**	**Ns**	**	**	*

k: Partial Land Equivalent Ratio (PLER), Land Equivalent ratio (LER), Area Time Equivalent Ratio (ATER), Crop Performance Ratio (CPR).

z: F-test: *= $p<0.05$, ns = not significant.

y = Means with different superscripts within the same column are significantly different ($p<0.05$) according to Fisher LSD test.

The higher productivity of intercropping over sole cropping can be explained by the underlying principle of better resource use in intercropping (Willey, 1990). Crops differ in the way they utilize environmental resources and that they complement each other and make better combined use of resources when grown together than when grown separately (Willey, 1990, Li, et al., 2006). In this study cowpea and cotton have dissimilar maturity dates and will therefore tend to differ on peak requirements for growth resources and this minimises competition for nutrients, water and light. In addition cotton and cowpea have a varying root depth which means that they tap nutrients and water from different zones resulting into reduced competition (Casper and Jackson, 1997). Except for the within row intercropping which gave significantly lower LER value, all other intercropping treatments had none significant LER values amongst them. Despite none significance though, it is observed that 2:2 strip cropping with simultaneous sowing of cowpea and cotton had an advantage over 1:1 strip cropping with same time sowing of both crops. Rusinamhodzi, et al. (2006) also reported higher LER values for intercropping over sole cropping in a study to evaluate the productivity of cotton and cowpea intercropping and N_2 fixation capacity in improving yield of subsequent maize crop under in Zimbabwe. Partial LER values for cowpea and cotton reveal that cowpea was more productive in the within row intercropping. Cotton was more productive than cowpea in 2:2 strip (Same time) cropping while cowpea was more productive than cotton in 1:1 strip (Same time) cropping. Overall, based on the relatively higher partial LER for cotton over cowpea, it can be suggested that cotton was the main component crop influencing the final productivity of the intercrop systems in this study. This is further evidenced from none significant differences on partial LER for cowpea implying that the effectiveness of cowpea in using available resources in cotton and cowpea intercropping was not affected by the intercropping system which was the case with cotton. The limitations in using LER are that it does not take into account the relative duration of each species within the intercrop or sole crop system (Hiebsch and McCollum, 1987) and that the LER is not able to identify the physiological processes responsible for any differences that may occur between intercrops and sole crops (Azam-Ali, et al., 1990). To correct the time deficiency, LER was modified by Hiebsch and McCollum (1987) to include the duration of crops from sowing to harvest (ATER).

4.4.4.2 Area Time Equivalent Ratio (ATER)

The results at Bunda College (Table 4.22) show that all strip cropping treatments gave higher ATER values compared to the within row intercropping with IT82E-16 ($P<0.01$). The within row intercropping, with ATER value of 0.70, was the least productive than the monoculture. From observations, all ATER values were smaller than LER values indicating overestimation of resource utilisation in LER. Higher ATER values over LER were also reported by Khan and Khaliq (2004), Seran and Brintha (2009). Higher productivity of 1:1 and 2:2 strip cropping (both simultaneous and delayed cowpea planting) over sole and within row intercropping are attributed to efficient utilisation of natural (land and light) and added (fertilizers) resources (Khan and Khaliq, 2004). All strip cropping treatments had values greater than unity suggesting a more superior strip cropping performance compared to monoculture.

4.4.4.3 Crop Performance Ratio (CPR)

Results of the study at Bunda College (Table 4.22) show that all intercropping treatments had CPR values greater than1.0 implying intercropping superiority over mono cropping. Strip 2:2 (Same planting) gave the highest CPR value of 1.94 though this was not significantly different from other strip cropping treatments. Higher CPR values for intercrops over monocrops indicate that intercrops were efficient in using growth resources such as radiation, water, light and nutrients.

4.4.5 Economic viability of cotton and cowpea intercropping

4.4.5.1 Monetary Advantage Index (MAI)

An economic analysis of intercropping is inevitable especially if one of the intercrops is a cash crop (Yahuza, 2011a). All monetary advantage indices (MAI) for different intercropping systems, as shown in Table 4.23, were positive and significantly different.

Table 4.23 Economic viability of different cotton and cowpea intercropping systems at Bunda College during 2011/2012 season**.**

Treatments	**MAI**	**MER**
Strip 1:1 same time	255,879[b]	1.34[b]
Strip 1:1 delayed	249,920[b]	1.36[b]
Strip 2:2 same time	264,866[b]	1.30[b]
Strip 2:2 delayed	211,725[b]	1.14[ab]
Within row IT82E-16	24,454[a]	0.84[a]
F-test (*z*)	**	**

k: Monetary Advantage Index(MAI), Monetary Equivalent Ratio (MER).

z: ns = not significant.

Positive values for MAI as found out in this study show a definite yield and economic advantage for intercrops compared to the sole crops. Higher and positive MAI returns were also reported by Oseni (2010) from intercropping of cowpea with sorghum which were attributed to better utilisation of resources in intercropping than in sole cropping. The MAI results are consistent with results of LER which also show intercropping advantage over monocropping. Ghosh (2004) reported that when LER values are higher there is also an economic benefit expressed with higher MAI values.

The highest MAI value was obtained from 2:2 strip intercropping with simultaneous sowing of cowpea and cotton though this was at par with other intercropping treatments.

4.4.5.2 Monetary equivalent Ratio (MER)

Monetary equivalent ratio (MER) values indicate that there were significant differences ($p<0.01$) on the superiority of intercropping systems. All strip cropping treatments had similar MER values though 1:1 strip cropping (same time) had a slight advantage over other strip cropping treatments. The advantage in performance of 1:1 strip cropping (Same time) over 2:2 strip cropping could have come as a result of higher cowpea yields obtained from this intercropping system compared to 2:2 strip (same time) intercropping system. In general the MER values suggest that cotton and cowpea intercropping would be economically beneficial compared to sole cropping apparently because of crop complementarities an observation also made by Ghosh (2004).

In summary, results of all biological and economic indices indicate that intercropping was more productive than sole cropped cowpea or cotton. No differences in different forms of strip intercropping were observed but strip intercropping was more productive than within row intercropping.

CHAPTER FIVE

EFFECT OF INTERCROPPING SYSTEMS AND FOLIAR CHEMICALS APPLIED ON COTTON ON INCIDENCES OF COTTON AND COWPEA PESTS

5.1 Introduction

Intercropping is an important cultural practice in pest management and it is based on the principle of reducing insect pests by increasing the diversity of an ecosystem (Risch, 2005). The adoption of intercropping by farmers who cannot afford input-intensive plant protection measures, offers an opportunity to protect crops by natural pest management (Rao, et al., 2012). In addition, when other pest management technologies are superimposed on such intercropping systems, it becomes much easier and cheaper for farmers to manage pests rather than in monocultures which are more prone to pest's incidences and require huge investments in pest's management (Rao, et al., 2012). In intercropping, presence of crop-crop diversity reduces populations of different pests and that pulses which are often grown in intercropping situations are mainly beneficial if suitable intercrop is selected (Rao, et al., 2002). Trenbath (1993) indicated that components of intercrops are often less damaged by pests and disease organisms than when grown as sole crops.

In Malawi, cotton and cowpea production are limited by increased production costs due to high costs of insect pests' management especially where cotton and cowpea are grown as sole crops. Intercropping the two crops therefore offers an opportunity for smallholder farmers' to reduce costs of insecticide application on cowpea thereby increasing profit margins.

This chapter examines the effects of foliar chemicals applied on cotton to control cotton pests in a cotton and cowpea intercropping on the incidences of intercropped cowpea pests.

5.2 Specific objectives

- To determine effectiveness of foliar chemical sprays applied to control cotton pests at reducing occurrence and abundance of intercropped cowpea pests in different intercropping systems.

- To determine effect of intercropping systems on occurrence and abundance of cowpea pests.

5.3 Materials and methods

This chapter focuses at addressing the above objectives by looking at the effect of intercropping systems and foliar pesticides applied on cotton on the incidences of intercropped cotton and cowpea pests. Treatments and methods of data analysis are as outlined in sections 3.3 and 3.6 respectively.

5.3.1 Cotton pest assessment and control

Assessment of pests on cotton and cowpea at Bunda College was done every fortnight starting from 4 weeks after planting. Ten (10) plants (Balakrishnan, et al., 2010) each of cotton and cowpea per treatment in each replicate were randomly selected from the net plot and assessed for the presence of major cotton and cowpea pests. Pest assessment was done on leaves, stems, flowers, bolls (cotton) and pods (cowpea) early in the morning when pests were less active (MoAFS, 2005a). On each selected plant, three randomly selected leaves (top, middle and bottom) were monitored for pests presence. Based on scouting results, carbaryl 85 WP (85g in 14 litres of water), and dimethoate 40 EC (34 millilitres in 14 litres of water and cypermethrin (20 millilitres in 14 litres of water) were used to control various cotton pests (MoAFS, 2005b). On farmers' fields, a blanket recommendation of carbaryl 85 WP at the rate of 85g in 14 litres of water was sprayed on cotton from third week to control jassids. From 6 to 10 weeks a mixture of carbaryl 85 WP at 85g in 14 litres of water and dimethoate 40 EC, 34 millilitres in 14 litres of water was used for aphids' control. At flowering and boll formation, cypermethrin at 20 millilitres in 14 litres of water and carbaryl (at the above rates) was used for the control of bollworms and aphids. Pest assessments in on- farm experiments were done once a month using the same procedures as used in the on station experiment. On sole sprayed cowpea treatment for all sites, dimethoate 40 EC, 10 millilitres in 10 litres of water was used for the control of aphids two weeks after planting. After first flowering, cypermethrin at the rate of 4 millilitres in 10 litres of water was used for the control of pod borers, sucking insects and thrips. No pesticides were applied directly to cowpeas on both strip (1:1 and 2:2) and within row intercrops. These treatments only benefited from the chemical drifts applied on cotton. Spraying was done using a Jacto knapsack sprayer and was set to release chemicals at a pressure of 3 bars which is a standard pressure for application of insecticides (Goizper, 2008). This pressure was necessary to ensure a uniform droplet size and accurate application of chemicals thus minimising the risks of pollution to users and environment. Spraying was done during non- windy mornings soon after dew had evaporated and insects were less active. Pests in cotton and cowpea were assessed using the following protocols.

5.3.1.1 Red spider mites *(Tetranychus spp.)* and Aphids *(Aphis gossypii)*

Redspider mites and aphids prevalence were assessed by estimating the population of the pests on the cotton plant using the following scale (MoAFS, 2005a).

Table 5.1 Scoring scale for assessment of red spider mites and aphids in cotton

Score	Estimated number of mites or aphids per plant
1	No mites or aphids present (un infested)
2	1-10 mites or aphids present (light infestation)
3	11-30 mites or aphids present (moderate infestation)
4	Over 30 mites or aphids present (severe infestation)

Mites were monitored from the underside of leaves and the oldest leaves were sampled when cotton plants were relatively young and in the later stages leaves from 3, 4 or 5 nodes below the plant terminal were sampled. (MoAFS, 2005a). Aphid scoring was done on adults and nymphs on the underside of the main stem leaves 3 – 4 nodes below the plant terminal (Farrell, et al., 2010).

5.3.1.2 Bollworms

Assessment of African bollworm (*Helicoverpa armigera*) and red bollworm (*Diparopsis castanea*), spiny bollworm [*Earias insulana* (Boisd.) and *Earias spp*.] and pink bollworm *(Pectinophora gossypiella)* prevalence was done by counting number of larvae found on the plants. Numbers of bolls damaged per treatment were also counted as an indicator of bollworm damage (MoAFS, 2005a).

Very insignificant populations of spiny bollworms were registered in all sites as such analysis of bollworm populations considered African and red bollworms only.

5.3.1.3 Cotton Stainers *(Dysdercus spp)*

Cotton stainers sampling was done by counting numbers of adults and nymphal instars of the pest found on cotton plants. Where lint staining was observed, spraying was done when a threshold of 30 % of bolls damage was registered (Farrell, et al., 2010).

5.3.1.5 Cotton Jassid *(Jacobiella fascialis)* and Cotton psyllid *(Paurocephala gossypii)*

Cotton jassid and psyllids assessment was done by making individual counts of the pests and a mean score was calculated from the scores of 10 plants randomly selected from a net plot.

5.3.2 Cowpea pests and disease assessment

5.3.2.1 Cowpea pod borer *(Maruca testulalis)*

Pod borer ratings on cowpea were recorded using the following visual ratings as described by Jackai and Singh, (1988). The rating was based on damage on flower buds, flowers, pods and on peduncle using a scale of 1-9 as shown in Table 5.2. *Maruca testulalis* damage is characterised by round holes on flowers and leaves, pod distortion and frass production on pods during feeding (Ayodele and Kumar, 1998).

Table 5.2 Scoring scale for assessment of cowpea pod damage by cowpea pod borer.

Score	**Score description (aggregate damage on flower buds, flowers, peduncle and pods**
1	0-10 % damage
2	11-20% damage
3	21-30 % damage
4	31-40 % damage
5	41-50 % damage
6	51-60 % damage
7	61-70 % damage
8	71-80 % damage
9	81-100 % damage

5.3.2.2 Aphids *(Aphis craccivola)*

Levels of aphid infestation in cowpea was assessed by estimating numbers of aphid colonies on plants using a modified Jackai and Singh (1988) scale of 1-9 as depicted below.

Table 5.3 Scale for assessment of aphid damage in cowpea.

Score	**Score description**
1	No infestation
3	Few individual aphids
5	A few isolated colonies
7	Several small colonies
9	Large isolated / continuous colonies

5.3.2.3 Thrips *(Taemothrips sjostedti)* and flower sucking bugs *(Anoplocnemis curvipes)*

Flower damage by thrips is characterized by distortion, malformation and discolouration of floral parts. Thrips also feed on terminal leaf bud and bracts/stipules and cause deformation with a brownish- yellow mottled appearance (Ayode and Kumar, 1998; Mohammed and Yusuf, 2010). Leaf defoliation is also evident under high thrips infestations (Ayodele and Kumar, 1998). Thrips damage rating was done on browning/drying of stipules, leaf or flower buds and abscission using a scale developed by Singh, et al., (1990).

Table 5.4 Scoring guide for assessment of thrips and *A. curvipes* damage in cowpea

Score	Score description
1	Clean and healthy plants.
2	Few flowers with signs of feeding
3	Few plants damaged (less than 50 % flower drop)
4	Moderate plant damage (up to 50 % flower drop)
5	Extensive plant damage (more than 50 % flower drop)

(Singh, et al., 1990).

5.3.4 Data analysis

In addition to general data analysis procedures outlined in section 3.6, data on insect counts were transformed to log(x+1) before being subjected to analysis to normalize it so that it meets the ANOVA assumptions (Zar, 1999). Means presented in tables of results for insect counts were computed from original untransformed data.

5.4 Results and Discussion

Across site analysis results as indicated by a summary of F- probabilities for analysis of variance for cotton pests (Table 5.5) shows that intercropping systems and interaction between site and intercropping systems did not significantly affect incidences of aphids, jassids, whiteflies, African bollworm and cotton stainers. However sites significantly influenced abundance and populations of aphids, jassids, whiteflies, African bollworm and cotton stainers. Site differences in pest populations can be attributed to differences in temperatures, rainfall and relative humidity. Rao, et al. (2013) indicated that higher numbers of nymphs, adults and eggs of whitefly in cotton fields were recorded at higher temperature whereas rainfall amounts were negatively correlated with whitefly adult populations.

Table 5.5 Summary of F-probabilities for analysis of variance across three sites for aphids, jassids, African bollworm and cotton stainers on cotton intercropped with cowpea.

Source of variation	**F-probabilities x pest population and damage levels**				
	DF	**Aphids**	**Jassids**	**African bollworm**	**Cotton stainers**
Intercropping system	4	0.668	0.479	0.478	0.835
Site	2	<0.001	<0.001	<0.001	<0.001
Intercropping x site	8	0.998	0.621	0.780	0.933
Means	-	2.1	4.02	1.38	1.4
CV (%)	-	17.8	27.3	43.7	51.2

5.4.1 Prevalence of pests in cotton

5.4.1.1 Aphids and Jassids prevalence

Results on the status of aphids and jassids infestation in cotton at Bunda (Table 5.6) indicate that there were significant differences among the treatments.

Table 5.6 Effect of intercropping systems on aphids and jassids occurrence in cotton at Bunda during 2011/2012 season.

Treatments	Mean aphid score (1-4) per plant	Jassids counts per plant
Sole sprayed	1.43	2.25
Sole unsprayed	2.48	3.75
Strip 1:1 same time	1.43	2.00
Strip 1:1 delayed	1.33	1.50
Strip 2:2 same time	1.43	2.00
Strip 2:2 delayed	1.33	1.75
Within row (Sudan)	1.43	2.25
Within row (IT82E-16)	1.33	2.50
Mean	1.519	2.25
F-pr.	<0.001	0.002
LSD (0.05)	0.316	0.893
CV (%)	14.1	27.0
Contrasts	**F-pr.**	
Sole cropping vs. intercropping	0.615	0.377
Sole cropping vs. strip cropping	0.681	0.212
Strip 1:1 vs. strip 2:2	0.517	0.685
Strip same time vs. strip delayed	0.362	0.231
Strip vs. within row IT82E-16	0.681	0.056

F-pr. = p-value.

Results for Bunda College (Table 5.6) indicate that unsprayed sole cotton treatment had significantly higher levels of aphids (2.48) and jassids (3.75). All intercropping treatments had similar levels of aphids and jassids populations. Aliyu, et al. (2011) observed that higher populations of pests in unsprayed sole crops indicate that in the absence of alternate hosts under sole cropping arrangement, on which insect pests could feed, the insect pests are left with no option but to continue to feed on the sole crop plant and hence more damage is inflicted on plants. The higher levels of aphids and jassids infestation levels in the unsprayed cotton treatment implies that the unsprayed cotton treatment accounted for the much significant difference status of treatments on aphids and jassids populations at Bunda. All treatment contrasts were not significant on aphids and jassids populations.

5.4.1.2 Psyllids and red spider mites

Results from Rivirivi EPA in Balaka indicate that no significant effects were observed in the treatments on red spider mites (Table 5.7). However significant differences were observed among the treatments on occurrence of psyllids on cotton (Table 5.7).

Table 5.7 Influence of intercropping systems on psyllids and red spider mites abundance in cotton at Rivirivi EPA in Balaka during 2011/2012 season.

Treatments	Pyllids counts per plant	Red spider mites score
Sole sprayed	2.10	2.50
Strip 1:1 same time	2.60	2.50
Strip 2:2 same time	2.40	2.50
Within row (Sudan)	2.40	2.50
Within row (IT82E-16)	2.95	2.25
Mean	2.49	2.45
F-pr.	0.029	0.445
LSD (0.05)	0.487	0.344
CV (%)	12.7	9.1
Contrasts	**F-pr.**	
Sole crop vs. intercropping	0.011	0.531
	(2.10 vs. 2.65)	
Sole crop vs. strip crop	0.061	0.980
Strip vs. within row IT82E-16	0.039	0.039
	(2.10 vs. 2.65)	

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Results in Table 5.7 show that within row intercropping with IT82E-16 and strip 1:1 (same time) had higher psyllids counts than all other treatments. It is also observed from treatments contrast results that overall intercropping increased the abundance of psyllids (2.65) over sole cropped cotton treatment (2.10). Strip cropping treatments had relatively lower psyllids populations compared to within-row intercropped cotton.

5.4.1.3 African, Red bollworms and cotton stainers

Results of African bollworm larvae and cotton stainers counts at Bunda as presented in Table 5.8 show that there were highly significant treatment differences on African bollworm eggs, larvae and cotton stainers ($P<0.001$) counts. No significant treatment differences for African and Red bollworms and cotton stainers counts were observed at Rivirivi EPA in Balaka district (Table 5.9). Significant treatments effects (P 0.022) for African bollworm were obtained at Mpingu EPA in Lilongwe district (Table 5.9).

Table 5.8 Effect of intercropping systems on African bollworm eggs, larvae and cotton stainer occurrence in cotton at Bunda College during 2011/2012 season.

Treatments	African boll worm eggs counts per plant	African bollworm larvae counts per plant	Cotton stainer counts per plant
Sole sprayed	1.38	1.00	1.75
Sole unsprayed	3.00	8.25	10.75
Strip 1:1 same time	1.38	1.50	0.50
Strip 1:1 delayed	1.19	1.25	0.50
Strip 2:2 same time	1.31	1.75	0.50
Strip 2:2 delayed	1.25	1.50	1.00
Within row (Sudan)	1.13	0.75	1.00
Within row (IT82E-16)	1.25	1.00	1.25
Mean	1.484	2.120	2.16
F-pr.	<0.001	<0.001	<0.001
LSD (0.05)	0.056	1.878	1.609
CV (%)	25.5	60.1	50.8
Contrasts		**F-pr.**	
Sole cropping vs. intercropping	0.634	0.573	0.110
Sole cropping vs. strip cropping	0.662	0.491	0.080
Strip 1:1 vs. strip 2:2	1.000	0.669	0.652
Strip same time vs. strip delayed	0.516	0.669	0.652
Strip vs. within row IT82E-16	0.884	0.491	0.319

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days.

Table 5.9 Influence of intercropping systems on African and red bollworms larvae and cotton stainers severity in cotton at Rivirivi and Mpingu EPAs during the 2011/2012 season.

	Rivirivi EPA		Mpingu EPA	
Treatments	**African bollworm larvae counts per plant**	**Red bollworm larvae counts per plant**	**Mean cotton stainer counts per plant**	**African bollworm larvae counts per plant**
Sole sprayed	4.25	2.25	9.50	4.00
Strip 1:1 same time	3.50	1.75	11.50	2.50
Strip 2:2 same time	4.25	1.12	10.00	1.75
Within row (Sudan)	2.50	1.00	10.50	2.25
Within row (IT82E-16)	3.00	1.50	10.50	2.00
Mean	3.50	1.52	10.00	2.50
F-pr.	0.517	0.102	0.923	0.002
LSD (0.05)	-	-	-	1.312
CV (%)	47.6	42.1	3-.6	34.10
Contrasts		**F-pr.**		
Sole crop vs. intercropping	0.501	0.054	0.537	0.022 (4.00 vs. 2.08)
Sole crop vs. strip crop	0.720	0.061	0.533	0.044 (4.00 vs. 2.10)
Strip vs. within row IT82E-16	0.408	0.876	0.900	0.815

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Results of African bollworms eggs, larvae and cotton stainers counts on cotton at Bunda (Table 5.8) show that not spraying cotton significantly increased African bollworm eggs, larvae and cotton stainers abundance in cotton and that the levels of African bollworm eggs, larvae and cotton stainers were not significantly influenced by the intercropping systems. The none significant differences in the abundance of bollworm eggs, larvae and cotton stainers amongst the different intercropping systems and all their contrasts show that the intercropping systems did not have an influence on the occurrence and abundance of cotton pests in intercropping. Results from Mpingu (Table 5.9) indicate that intercropping reduced African bollworm larvae severity over the sole cropped cotton, but no significant differences were observed amongst intercropped cotton treatments. Since all cotton treatments received a uniform pesticide application, the reduction of African bollworm larvae in intercropped treatments on farm in Mpingu may be because of the influence of intercrops. A similar observation was also made by Balakrishnanan, et al. (2010), who reported reduced African bollworm populations in cotton when crops like cowpea, maize, sorghum, blackgram, sunflower and cluster beans were used as bollworm trap crops in intercropping. Balakrishnan, et al. (2010) attributed the reduced African bollworm population to the fact that in polyculture insects such as bollworms are unable to locate host plants as the visual and chemical stimuli get manipulated or altered, and due to disruption of host finding behaviour through aromatic odours of other plants. In addition, depending on crop combinations, intercropping can interfere with the population development and survival of pests because the companion crop blocks their dispersal across the field and it may be more difficult for them to locate and remain in the microhabitat that favours their rapid development (Balakrishnan, et al. 2010).

Figure 5.1 African Bollworm can be a serious pest from the early stage of cotton flower bud development.

In summary, since all cotton plants in all the treatments (except unsprayed control) received uniform and direct pesticides application, the differences in response to pests pressure amongst the treatments can be attributed to the effect of different cropping systems, site effects (environmental conditions) and diversity of insect pests' rather than the effects of pesticides applied. Generally there were no significant differences in pest pressure between pure sprayed and intercropped cotton. This implies that intercropping cowpea in cotton may not have significant effect on the severity of cotton pests.

5.4.2 Prevalence of pests in cowpea

A summary of F- probabilities for analysis of variance of cowpea pests across all sites (Table 5.10) shows that site had significant effects on the abundance of cowpea aphids, *Maruca testulalis*, pod sucking bugs *(Anoplocnemis curvipes)* and thrips.

The abundance of aphids and thrips were not significantly influenced by different intercropping systems and the interaction between intercropping systems and site. This could be attributed to environmental differences in amount of rainfall, temperatures and relative humidity which have influence on different hosts and populations of insect amongst crops.

Table 5.10 Summary of F- probabilities for analysis of variance across three sites for aphids, *Maruca testulalis,* pod sucking bugs and thrips in cowpea intercropped with cotton.

	F-probabilities x pest population and damage levels				
Source of variation	**DF**	**Aphids**	**Jassids**	**African bollworm**	**Cotton strainers**
Intercropping system	4	0.653	<0.001	<0.001	0.156
Site	2	<0.001	<0.001	<0.001	<0.001
Intercropping x site	8	0.280	0.002	<0.001	0.619
Means	-	1.75	2.17	1.5	1.49
CV (%)	-	41.8	21.9	22.4	30.6

F-pr. = p-value.

5.4.2.1 Aphids, *Maruca testulalis,* thrips and *Anoplocnemis curvipes*

The results on pests incidences on cowpea at Bunda (Table 5.11) indicate that significant effects (P<0.001) existed among the treatments on *Maruca testulalis*, thrips and *Anoplocnemis curvipes* damage. Significant differences (P≤0.01) were also observed for aphid abundance. There were no significant differences amongst the treatments for aphids' populations, *Maruca testulalis* and thrips damage in cowpeas at Rivirivi EPA in Balaka (Table not shown). The sole sprayed cowpea registered scores of 2.50, 1.80 and 2.0 for aphids, *Maruca testulalis* and thrips respectively.

Intercropping treatments registered the following mean scores: strip 1:1 (S) 2.0, 1.55, 1.75; strip 2:2 (S) 2.0, 2.20, 1.75; within row (Sudan) 3.0, 1.80, 1.75; and within row (IT82E-16) 2.0, 1.80, 2.0 for aphids, *Maruca testulalis* and thrips respectively. Results from Mpingu EPA (Table 5.12) indicate that there were no significant differences amongst the treatments for aphids abundance and thrips damage while highly significant differences ($P<0.001$) for *Maruca testulalis* damage were observed amongst the treatments.

Table 5.11 Influence of intercropping systems and foliar pesticides applied on cotton on aphids, *M. testulalis*, thrips and *A. curvipes* in cowpea at Bunda College during 2011/2012 season.

Treatments	**Aphid score (1-9) per plant**	***Maruca testulalis* damage score (1-9)**	**Thrips score (1-5)**	***Anoplocnemis curvipes* score (1-5) per plant**
Sole sprayed	1.00	2.25	1.25	1.75
Sole unsprayed	4.50	4.75	2.50	3.75
Strip 1:1 same time	2.00	3.75	1.00	2.50
Strip 1:1 delayed	1.50	1.50	1.88	1.25
Strip 2:2 same time	2.25	4.75	1.75	3.25
Strip 2:2 delayed	2.00	1.68	2.13	1.50
Within row (Sudan)	1.75	3.75	1.00	2.00
Within row (IT82E-16)	1.75	3.00	1.00	1.75
Mean	2.09	3.18	1.562	2.22
F-pr.	0.002	<0.001	<0.001	<0.001
LSD (0.05)	1.358	1.034	0.532	0.858
CV (%)	44.1	22.0	23.2	26.3
Contrasts		**F-pr.**		
Sole cropping vs. intercropping	0.084	0.103	0.042	0.263
			(1.25 vs. 1.69)	
Strip 1:1 vs. strip 2:2	0.426	0.108	0.012	0.101
			(1.44 vs. 1.94)	
Strip same time vs. strip delayed	0.426	<0.001	0.002	<0.001
		(4.25 vs. 1.59)	(1.38 vs. 2.01)	(2.88 vs. 1.38)
Strip vs. within row IT82E-16	0.720	0.840	0.003	0.263
			(1.69 vs. 1.00)	

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after14 days; figures in brackets are means for statistically significant contrasts.

Table 5.12 Aphids, pod borer and thrips occurrence in cowpea as affected by intercropping systems and foliar pesticides applied on cotton in Mpingu EPA in Lilongwe district during 2011/2012 season.

Treatments	**Aphid score (1-9)**	***Maruca testulalis* damage score (1-9)**	**Thrips damage (1-5)**
Sole sprayed	1.18	1.00	1.40
Strip 1:1 same time	1.20	1.05	1.30
Strip 2:2 same time	1.30	1.70	1.80
Within row (Sudan)	1.15	1.05	1.33
Within row (IT82E-16)	1.13	1.02	1.28
Mean	1.19	1.165	1.42
F-pr.	0.879	<0.001	0.452
LSD (0.05)	0.386	0.165	0.676
CV (%)	21.1	9.2	30.9
Contrasts		**F-pr.**	
Sole crop vs. intercropping	0.822	0.001 (1.00 vs. 1.26)	0.822
Sole crop vs. strip crop	0.634	<0.001 (1.0 vs. 1.38)	0.587
Strip vs. within row IT82E-16	0.432	<0.001 (1.34 vs. 1.02)	0.326

F-pr. = p-value; Strip (Same time) = cotton and cowpea sown on same day; strip (Delayed) = cowpea sowing after 14 days; figures in brackets are means for statistically significant contrasts.

At Bunda (Table 5.11) the sole unsprayed cowpea treatment gave significantly higher levels of aphids' population (4.5), *Maruca testulalis* (4.75), thrips (2.50) and *Anoplocnemis curvipes* (4.75) damage compared to the rest of the treatments. For aphids, all intercropping treatments had similar levels of aphid population compared to the sole sprayed cowpea treatment implying that aphids were effectively controlled by the drift pesticides applied on cotton. Strip 1:1 (delayed) and strip 2:2 (delayed) had similar levels of *Maruca testulalis* damage to sole sprayed cowpea treatment but significantly lower compared to all other intercropping treatments. Strip 2:2 (same time) produced *Maruca testulalis* damage score which was at par with the sole unsprayed cowpea treatment. Strip 1:1 (same time) and within row intercropping with either cowpea variety gave lowest levels of thrips damage though not significantly different from the sole sprayed cowpea, but significantly higher than other intercropping treatments. Amongst the intercropping treatments, strip 2:2 (same time) registered the highest *Anoplocnemis cervixes* damage at Bunda. Overall the results indicate that pesticides applied on cotton to control cotton pests were equally effective at reducing the populations of cowpea aphids, *Maruca testulalis*, thrips and *Anoplocnemis curvipes* bugs at Bunda compared to pesticides applied directly on sole cowpea treatment. Early planting of cowpea increased pod borer and sucking bugs infestation, an observation also reported by Nabirye, et al. (2003). The increased *Maruca testulalis* and *Anoplocnemis curvipes* damage observed in the earlier planted cowpea crop was probably due to the vigorous growth of the cowpea crop in the early season due to favourable soil conditions. This might have resulted in plants attaining denser canopy and flowering earlier and this provided conditions that were more favourable to *Maruca testulalis* infestation (Oghiakhe, et al., 1991). In Malawi, cypermethrin is used in cotton from flowering. This meant that flowering and pod formation in delayed planted cowpea coincided with use of cypermethrin in cotton resulting in reduced populations of *Maruca testulalis* and *Anoplocnemis curvipes* populations unlike in the earlier planted cowpea.

The within row intercropping significantly reduced thrips damage over strip cropping, and it is also observed from the results that the within row intercropping and strip 1:1 (same time) had significantly lower levels of thrips than strip 2:2 (same time). Cowpea plants in within row intercropping had a direct benefit of pesticides applied on cotton. In 1:1 strip cropping, cowpea plants were relatively closer to cotton plants, and a cowpea ridge being in between two cotton ridges meant a better access by cowpea plants to the drift pesticides than in 2:2 strip cropping. This explains why the within row intercropping and 1:1 strip cropping treatments had relatively lower pests' pressure than 2:2 strip cropping treatments planted on the same day. Despite the none significant results, it is also observed in Table 5.11 that there was more benefit from the 'drift' pesticides in 1:1 strip cropping than in 2:2 strip cropping both on the simultaneous sown and delayed cowpea planted crops. Myaka and Kabissa (1996) also reported significant benefits of increased cowpea yields and reduced pests populations derived by cowpea from insecticides directly applied on cotton in 1:1 strip cropping compared to 2:2 strip cropping. Delaying cowpea planting by two weeks significantly reduced pod borer and sucking bugs damage but it increased thrips damage. Intercropping with either Sudan or IT82E-16 cowpea varieties did not have a significant effect on aphid, legume pod borer, thrips and pod sucking bugs at Bunda.

Figure 5.2 Aphid colony on unsprayed cowpea plant at Bunda.

The none significant effects among the treatments at both on farm sites imply that pesticides applied on cotton to control cotton pests equally suppressed cowpea pests in intercropping as did pesticides directly applied on sole sprayed cowpea treatment. In Mpingu EPA (Table 5.12), strip 2:2 (same time) had significantly higher (P<0.001) pod borer damage score (1.70) than the rest of the treatments. The sole sprayed cowpea treatment registered the least pod borer damage (1.00) followed by the within row intercropping (1.02). The lower aphids' population and insignificant thrips and *Maruca testulalis* damage on cowpea from all the three sites suggest that either the presence of cotton plants acted as barrier to aphids, *Maruca testulalis* and thrips on intercropped cowpea or cowpea or cotton combination did not provide the required conditions for multiplication of the pests (Mohammed and Yusuf, 2010). Lower thrips populations at all sites agree with assertions by Jackai and Adalla (1997) that population density of flower thrips is consistently lower in intercropped cowpea with such crops as maize, sorghum, cassava and beans. This was attributed to diversified predator effects and changes in field microclimate that affect build-up of thrips populations. The reduced thrips populations in such intercropping systems are attributed to shading, high humidity and lower temperature effects that help keep thrips population low. The higher *Maruca testulalis* damage at a wider 2:2 strip (same time) row arrangement demonstrated the influence of intercrop–barrier effect of relatively taller intercrop component on pest infestation and damage to the companion crop (Mohammed and Yusuf, 2010). Contrasting the performance of intercropping systems at Mpingu shows that there was a more effective management of pod borer damage in sole sprayed cropping than in intercropping treatments. The within row intercropping significantly reduced pod borer damage over the strip cropping (same time) and that 1:1 strip cropping had significantly lower number of pod borer damage than the 2:2 strip (same time) cropping.

In summary, it is noted that intercropping systems did not have significant influence on the abundance of cowpea pests. At Mpingu the results show that overall sole cropping registered fewer pests' populations than all intercropping treatments combined. Amongst intercropping treatments the within row intercropping was more effective compared to strip cropping. Lower pests populations (based on scores) at Bunda and indeed from both on farm sites explain why cowpea grain yields from unsprayed cowpea treatments were unexpectedly higher than it would otherwise have been the case under a severe pest pressure.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

The results of the study indicate that intercropping increased the productivity of cotton and cowpea compared to monoculture as evidenced from more than unity values for LER, ATER and CPR indices. The higher productivity of intercropping is largely due to crop complementarities in the system which is not available in monocropping. Cotton and cowpea mature at different times and also have different canopy architecture and root dispersion which allows better resource use compared to monocropping (Bezerra-Neto and Robichaux, 1997). Increased N fixation in cowpea intercropped with cotton compared to sole cowpea was reported by Rusinamhodzi, et al. (2006). In addition to increased BNF fixation, Rusinamhodzi, et al. (2006) also reported that 78% of cowpea residues were found to decompose within first 4 weeks of growth contributing to increased N levels to the benefit of cotton. Cotton and cowpea pests' populations were largely at par with the levels obtained in sole sprayed treatments meaning that cotton and cowpea intercropping managed to contain pest populations within the acceptable thresholds. Because of this effect, yields of cotton and cowpea were well above the national average yields of between 500-800 and 300-600 kg ha^{-1} respectively as obtained by smallholder farmers, who in most cases, have limited resources to use to increase crop yields and reduce the damaging effects of pests and diseases (MoAFS, 2005b).

6.1.1 Cropping system and crop growth

The study has shown that cotton growth and productivity was more influenced by the intercropping system while cowpea growth and productivity was not significantly influenced by the intercropping system an observation also reported d by Mohammed, et al. (2008). The significant impact of the intercropping system on cotton may have been contributed by the within row intercropping system where cotton plants were overgrown by cowpea plants. This reduced cotton ability to intercept enough solar radiation necessary for the process of the photosynthesis whose by products are required for plant growth. This is evidenced from reduced number of bolls per plant, smaller cotton boll sizes, fewer numbers of sympodial branches, shorter plants and narrower plant canopies all of which resulted into lower seed cotton yields from within row intercropping than those obtained from strip and sole planted cotton. The within row effect factor aside, it was observed that there were slightly higher cotton yields from the strip cropping than from sole cotton. Rusinamhodzi, et al. (2006) reported enhanced nitrogen fixation capacity of cowpea in intercropping compared to sole cropping which was attributed to increased interspecies completion for Nitrogen in intercropping which led to better nodulation by cowpea. The habitat manipulation in sole cotton ecosystem by intercropping is beneficial in maintaining the eco-balance resulting in reduced pests incidences. For instance, crops grown simultaneously enhance the abundance of predators and parasites, which in turn prevent the build-up of pests which may lead to better crop growth and higher yields (Lithourgidis, et al., 2011). Higher yields of intercrops as shown in this study also further emphasize the usefulness of intercropping to resource constrained smallholder farmers in sustaining cotton yields (Shivaprasad, 2008).

Yields of cowpea from strip and within row intercropping were similar with those from sole cowpea indicating that either there was less inter species competition between cotton and cowpea in intercropping or that the 'incidental' pesticides on cowpea were just as effective as pesticides applied directly on sole cowpea in managing cowpea pests. Cowpea took advantage of early growth to minimize competition from cotton. This study results also indicate that 1:1 strip cropping had a slight edge over 2:2 strip cropping in terms of cowpea grain yields. While Adipala, et al. (2002); Mkandawire and Likoswe (2002) and Rusinamhodzi, et al. (2006) reported higher cowpea yields from sole cropping than from intercropping, Singh and Emechebe (1998) found that intercropped cowpea grain yields were generally higher than yields from sole cropping when no pesticides were applied. Myaka and Kabisa (1996) found that alternating single rows of cotton with single row of cowpea was superior to 2:2 strips cropping in terms of crop yields of cowpea when insecticides were applied directly on the cotton component of the intercropping.

6.1.2 Time of sowing and crop growth

The results from this research indicate that cotton growth and productivity was not negatively affected by time of cowpea planting in the intercropping system, but delaying cowpea planting in cotton and cowpea intercropping systems significantly reduced number of cowpea pods per plant, cowpea seed size, pod length, number of seeds per pod and the resultant cowpea grain yield. The reduction of cowpea grain yield and its yield components can be attributed to the shading effect from the relatively taller cotton plants. The shading, as reflected in differences in plant height, canopy diameter and number of pods set, affected the partitioning of the radiation use efficiency amongst component crops in an intercrop (Yahuza, 2011a).

In a study to assess the effect time of sowing on the performance of millet and cowpea in intercropping in Nigeria, reduced cowpea grain yields in delayed cowpea planted crop compared to simultaneous sown crops were also reported by Terao, et al. (1997). The yield reduction was attributed to lack of branching in late planted cowpea. The suppression of branching in cowpea was attributed to lack of access to adequate light and lack of light changes phytochrome to an active form (Pfr) which stimulates apical dominance to escape from light deficient conditions. Terao, et al. (1997) also indicated that the number of branches established in early growth stage decides the plant skeleton. It limits both the number of leaves, which produce the photosynthate (source) and number of pods which become the sink. This hypothesis as indicated by Terao, et al. (1997) is well supported by the results of cowpea at Bunda. The differences in yields between the simultaneous sown cowpea and delayed cowpea in both 1:1 and 2:2 strip cropping are basically explained by the significant differences in number of seeds per pod and pod length. Strip 2:2 (delayed) also registered significantly less total dry matter and number of pods per plant compared to strip 2:2 (same time). Strip 1:1 (delayed) had lower total dry matter and number of pods per plant than strip 1:1 (same time) though not statistically different. Delaying cowpea sowing was nevertheless seen to contribute to good cowpea crop establishment. This situation was expected considering that the delayed cowpea coincided with a peak in rainfall most especially at Bunda that guaranteed a better crop establishment. Overall results imply that a simultaneous sowing of cotton and cowpea in intercropping would be the most favourable option for increased cotton and cowpea production in intercropping.

Similar observation was made by Reddy and Visser (1997) who recommended a simultaneous sowing of cowpea and millet though the study provided a different cropping system from the current study. Blade, et al. (1997), in a study to assess cowpea intercrop growth and yield as affected by time of planting relative to millet, concluded that delaying cowpea sowing by a period of 2 or 3 weeks resulted in a reduction of cowpea grain yield of over 50 % compared to simultaneous sown cowpea and millet.

6.1.3 Effectiveness of pest control

Of great interest in this study was to assess the effectiveness of pesticides applied on cotton to control cotton pests on the management of cowpea pests. Results have shown that the occurrence and abundance of cowpea pests in intercropping was similar with the sole sprayed cowpea but generally higher than the sole unsprayed cowpea. This implies that the 'incidental' pesticides were effective in the management of cowpea pests. An added advantage in the levels of cowpea pest's management was observed in within row intercropping compared to 1:1 and 2:2 intercropping systems. This was the case because in the within row intercropping system cowpea had a direct benefit of pesticides applied on cotton compared to 1:1 and 2:2 strip cropping which just benefited from the chemical drifts. Interspaced between two cotton ridges, the 1:1 strip cropping provided a shorter distance for pesticide drifts to reach cowpea plants than in 2:2 strip cropping and this explains the differences in effectiveness of pests control between the two treatments. Overall pests' populations for both cotton and cowpea crops were generally on the lower side in all the sites. These low pests' populations can be attributed to either the seasonal effects where naturally pests' populations are bound to differ from one season to another or to the deterrence effect of intercropping systems. The deterrence of pest colonization through intra field diversity, as was provided in this study, is probably one of the most promising means of controlling pests (Rao, et al. 2012). Diversity in crop field has profound effect on colonization of pests and any such delay in pests' colonization results in subsequent delays in pest build up. Cotton plants in all but the unsprayed control treatment received uniform pesticide application. The differences in pest pressure for cotton can, therefore, be attributed to effects of the intercropping systems. It is not surprising therefore that similar pest' levels were observed between the sprayed and intercropped cotton. This implies that the cowpea component of the intercropping system did not have significant influence on abundance and levels of cotton pests. It should however also be borne in mind that the results could have possibly been different under high pest population levels, most especially in Rivirivi EPA which is known for serious red bollworm damage on cotton.

6.1.4 Biological and economic viability of intercropping systems

An evaluation was also made to determine the biological and economic benefits of cotton and cowpea intercropping compared to component sole crops. The biological benefits of intercropping were evaluated using land equivalent ratio (Vandermeer, 1989), area time equivalent ratio (Hiebsch and McCollum, 1987) and crop performance ratio (Haris, et al., 1987) while Monetary advantage (Willey, 1985), monetary equivalent ratio (Adetioye and Adekuncle, 1989) were the indices used in evaluating the economic viability of the intercropping systems. The basis for choosing each of these indices is because each one of these has different interpretation (Yahuza, 2011b). The values for all biological indices were more than unity (>1.0) for all strip cropping intercropping systems meaning that land requirement for intercrops was lower than that for monocrops (Rusinamhodzi, et al. (2006). Rusinamhodzi, et al. (2006) indicated that intercropping legumes such as cowpea with cotton help to use growth resources efficiently than pure stands and this was attributed to the advantage of intercropping to different above ground and below ground growth habits, morphological characteristics of the crops and also to the higher efficiency in the utilization of water and radiation (Fukai and Trenbath, 1993). The partial LER of component crops showed that cotton contributed more to the total yield than cowpea except in within row intercropping where cowpea had an advantage. Based on these indices, the study has shown that strip cropping was economically beneficial for cotton and cowpea compared to within row intercropping and sole cropping.

6.2 Conclusions

The following are major conclusions from this research.

- Sowing cowpea two weeks after cotton in cotton and cowpea intercropping does not affect growth and productivity cotton but reduces growth and productivity of cowpea.

- Within row intercropping reduced cotton yields and yield components compared to sole sprayed and strip cropping treatments. Cowpea yields and yield components is similar under sole sprayed, strip and within row intercropping treatments.

- Occurrence and abundance of cotton and cowpea pests is not affected by cotton and cowpea intercropping systems.

- Pesticides applied on cotton to control cotton pests in different intercropping arrangements reduced populations of cowpea pests.
- Determinate and indeterminate cowpea varieties have similar plant growth and yields in within row intercropping with cotton.

6.3 Recommendations

Within the confines of the methods used in this study and the conditions under which the experiment was conducted, the following recommendations are made.

Best bet treatments: Growers should be encouraged to use 1:1 and 2:2 cotton and cowpea intercropping systems for increased cotton and cowpea yields. The choice on the use of 1:1 or 2:2 strip cropping (same time) may be dictated by the main crop of interest or objective of the farmer. Those farmers whose crop interest is cowpea or cotton may opt for 1:1 or 2:2 strip (same time) cropping respectively. Farmers should also continue practising within row intercropping of cowpea and cotton as is the case at the moment in some areas of Malawi provided the population of cowpea is reduced so that cotton is equally competitive.

Time of sowing: Simultaneous cotton and cowpea sowing is recommended for increased cotton and cowpea yields in intercropping.

Future research: In depth investigations on cowpea and cotton intercropping with different genotypic interactions are necessary for future studies in order to identify plant growth habits of either crop that would optimize cowpea and cotton growth and yields. Considering that the results of this study are for one year, further studies for at least two more seasons with additional sites across all the agro-ecological zones would be necessary to validate the effects of other key drivers of productivity such as environmental factors, soil types and management systems on the current results.

The effects of different intercropping systems on N-fixing capacity of cowpea and detailed assessment of population dynamics of beneficial insects in intercropping with cotton will also have to be investigated in future studies.

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APPENDICES

Appendix 1.0 Rainfall (mm) for Bunda College over a six year period

Month	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012
October	0.0	17.6	18.5	0.9	20.5	28.3
November	74.5	67.3	119.2	60.5	18.5	114.8
December	290.5	248.8	177.2	197.3	213.7	42.2
January	281.0	377.6	291.9	125.1	209.1	313.1
February	152.2	125.4	174.0	337.6	204.7	154.9
March	151.0	60.3	218.3	118.4	254.3	182.2
April	32.3	29.1	28.0	5.4	48.7	166.7
May	0.0	0.0	0.0	4.7	0.0	0.0

Appendix 2.0 Rainfall (mm) for Rivirivi EPA in Balaka district over a six year period

Month	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012
October	2.3	81.3	0.0	0.0	3.5	32.5
November	130.3	75.1	201.0	101.0	54.1	64.7
December	113.9	339.0	191.5	191.5	170.9	80.1
January	189.2	166.2	197.3	196.5	140.2	280.8
February	256.9	136.5	120.0	120.0	79.4	99.6
March	67.2	152.9	61.2	61.2	160.9	133.3
April	22.2	0.0	0.0	75.0	45.2	28.0
May	0.0	0.0	0.0	0.0	2.5	0.0

Appendix 3.0 Rainfall (mm) for Chitedze Research Station over a six year period.

Month	2006/ 2007	2007 /2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	RH (%) 2011/2012
October	0.0	1.7	5.5	1.4	0.0	15.6	49
November	123.1	27.7	113.5	61.7	56.6	69.2	56
December	207.2	27.2	119.2	171.6	205.4	76.0	64
January	411.8	360.6	227.8	116.8	181.3	268.5	73
February	196.7	183.6	121.0	322.4	147.2	204.0	76
March	53.5	72.2	223.6	201.3	100.3	154.6	80
April	23.5	13.6	18.1	34.7	31.7	80.9	73
May	0.0	0.0	0.0	0.2	2.6	0.0	65

Appendix 4.0 Initial soil characteristics results for Bunda College experimental site.

Sample no.	Depth (cm)	K (%)	pH	Sand (%)	Silt (%)	Clay (%)	P (ppm)	N (%)	OM (%)
1	0-15	0.061	5.2	40.00	20.00	40.00	14.41	0.097	1.849
2	15-30	0.023	5.0	33.33	13.33	53.33	3.79	0.079	1.513
3	0-15	0.01	4.5	40.00	13.33	46.67	27.56	0.141	2.689
4	15-30	0.0	4.4	33.33	20.00	44.67	4.30	0.088	1.647
5	0-15	0.014	4.6	43.33	13.33	43.33	11.38	0.133	1.849
6	15-30	0.0	4.7	40.00	13.33	46.67	3.16	0.099	2.353
7	0-15	0.023	4.5	43.33	13.33	43.33	29.46	0.133	2.454
8	15-30	0.005	4.5	40.00	13.33	46.67	3.41	0.118	2.252
9	0-15	0.011	4.6	43.33	16.67	40.00	11.88	0.160	3.059
10	15-30	0.002	4.4	40.00	16.67	43.33	2.78	0.127	2.387
11	0-15	0.011	4.5	43.33	13.33	43.33	15.68	0.135	2.555
12	15-30	0.001	4.9	33.33	20.00	46.67	3.67	0.097	1.815