Effect of cowpea planting date and row arrangement on crop growth and yield in maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L. (Walp)) intercrop.

By

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A dissertation submitted to the University of Zambia in partial fulfillment of the requirements for the degree of Master of Science in Agronomy.

CROP SCIENCE DEPARTMENT
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DECLARATION

I, Mwiya Mukungu, hereby declare that this dissertation represents my own work and that it has not previously been submitted at this or any other university.

Signature:.......................................   Date: 17/10/2002

APPROVAL

This dissertation of Mwiya Mukungu is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy by the University of Zambia.

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ABSTRACT

In order to improve the productivity of land in smallholder agriculture, intercropping of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L. (Walp)) has great potential. An experiment was conducted at the University of Zambia School of Agricultural Sciences Field Station in Lusaka, Zambia during the 2000/2001 season to evaluate the effect of cowpea planting date and row arrangement on the growth and yield of maize and cowpea. The objectives arrangement and planting date of cowpea intercropped with maize and to assess the yield advantage and profitability of maize-cowpea intercrop system. Cowpea (Lutembwe) was planted on three planting dates as an intercrop with maize (Pool 16), on the same day, 14 and 28 days after maize. Four row arrangements 1:1=one row of cowpea in between inter-row space of maize 75 cm apart and 1:2=two rows of cowpea 50 cm apart in between inter-row space of maize 75 cm apart. Sole maize and sole cowpea were used as control treatments. The treatments were arranged in a split-plot design with three replications. Planting dates were the main-plots, while row arrangements were sub-plots. Maize yield and yield components were not affected by treatment. Average yield however, was 2735 kg/ha. Cowpea yield and yield components were affected by the treatments. The average yield was 1222 kg/ha. Sole crop cowpea produced the highest grain yield (1934 kg/ha) followed by the 1:1 row arrangement (1019 kg/ha) and least was the 1:2 row arrangement (713 kg/ha). The average number of pods/plant was 6. Sole crop cowpea produced the highest number of pods/plant (9), followed by the 1:1 row arrangement (5) and least was the 1:2 row arrangement (3). The number of pods/plant were highest when the crop was planted 14 days after maize. This produced 8 compared to 5 when planted with maize or 4 when planted 28 days after maize. There was a strong interaction of planting date and row arrangement ($p<0.001$) on number of pods/plant suggesting that planting cowpea in 1:1 row arrangement 14 days after maize is the most optimum. The average harvest index was 0.37. Sole crop cowpea produced the highest harvest index (0.43), followed by the 1:1 row arrangement (0.38) and least was 1:2 (0.29). Harvest

index and number of pods/plant in cowpea were positively correlated with grain yield (r = 0.95 and r = 0.84, respectively). The land equivalent ration (1.51) and financial gross returns (ZMK 278,000/ha) data showed relative yield advantage (51 %) and profitability (37 %) of maize/cowpea intercropping in the 1:1 row arrangement compared to the 1:2 row arrangement. Dry matter production, leaf area and leaf area index of cowpea were affected by planting date 42 days after planting maize. Cowpea dry matter production, leaf area and leaf area index was significantly affected ($p<0.001$) by row arrangement and generally reached their maximum at 63 days after planting maize, and declined thereafter. The tallest plants were observed when cowpea was planted 28 days after maize, and in the 1:2 row arrangements. These results indicate that cowpea in the intercrop, with canopy always below that of maize, suffered from competition for photosynthetically active radiation, nutrients and water resources during vegetative and reproductive stages (nodulation, grain filling). The loss of leaves (leaf senescence, shedding) due to aging in cowpea explains the observed decline in dry matter production, leaf area and leaf area index. The results suggest that the 1:1 row arrangement is a better alternative for growing maize together with cowpea in an intercrop system.

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DEDICATION

To my beloved daughter Dorcas, my sons Mukungu, Imbuwa, Mwiya, Janwa and wife Maureen, may the Almighty God continue guiding and blessing you.

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LIST OF ABBREVIATIONS AND ACRONYMS

DM............................Dry Matter
EC.............................Emulsifiable Concentrate
HI..............................Harvest Index
IAEA.........................International Atomic Energy Association
IITA...........................International Institute of Tropical Agriculture
IRRI...........................International Rice Research Institute
LA.............................Leaf Area
LAI............................Leaf Area Index
LER...........................Land Equivalent Ratio
LSD...........................Least Significant Difference
MAFF........................Ministry of Agriculture, Food and Fisheries
No............................Number
ZAMSEED.................Zambia Seed Company
ZMK.........................Zambian Kwacha

Chapter 1

INTRODUCTION

The combined yields of crops of farmers that practice intercropping in Zambia has been reported to be rather low (Kamona, 1989; MAFF, 1987). Yet the benefits of this cropping system is to diversify production and increase total yields. Because most small-scale farmers only cultivate small parcels of land at any one time, intercropping is commonly used. This system is well adapted to the low level of technology used by these farmers.

Intercropping has been reported to offer great scope for developing energy efficient and sustainable agricultural systems to the farmer (IAEA, 1980). Some of the benefits reported are: increased grain yield (Adiku, et al., 1995), diversity of food and income sources, soil fertility improvement (Agboola and Fayemi, 1972; Willey, 1979), judicious use of land and labor resources (MAFF, 1999) and insurance against total crop failure in cases of unfavourable weather conditions or pest/disease epidemics (De and Singh, 1981).

In Zambia, various forms of intercropping are practiced. However, the intercrops, usually the legumes, vary according to dietary preferences and agro-ecological regions. The common crop combinations are cereals particularly maize (the staple food crop in diets of most people) with low densities of pumpkin, field bean, cowpea, groundnuts, sweet potatoes, cassava and sorghum (Mwaipaya, 1989). The aim of cereal-legume intercropping in Zambia is to produce some additional yield of the intercrop (minor crop) without necessarily reducing the yield of maize (main crop).

Intercropping, or growing two or more crop species simultaneously in the same field (Isom and Worker, 1979; Willey, 1979) is a farming practice that is widely used in tropical Asia, Africa and

Latin America. Crookston (1976) described intercropping as "a new version of an old idea", implying that intercropping is a long standing strategy that farmers have been practising. Intercropping is well adapted to the low level of mechanisation and the limited availability of land of small-sacle tropical farming environments (Okigbo and Greenland, 1976). Much research was directed towards intercropping systems in the 1970's and 1980's following observations of consistently higher land use efficiencies of intercrop systems over sole cropping (Ofori and Stern, 1987a; Willey, 1979). But a recent survey conducted in Kafue and Chongwe Districts of Lusaka Province, Zambia revealed that failure by farmers to adopt crop diversification recommendations was attributable to limited land and labour resources (MAFF, 1994).

Francis (1990) cited component crop densities, relative planting dates and haphazard spatial arrangements of crop components on soils of low fertility status among factors affecting the productivity of cereal-legume intercropping. These factors influence competition between component crops for growth limiting factors (Trenbath, 1976). It has been reported that increasing legume densities in maize-legume intercrops does not affect maize yields, but results in significant increases in legume yields and the intercrop land equivalent ratios (LER) (Ofori and Stern, 1987a). Therefore, although the cereal component usually contributes a greater portion of the intercrop yield, the intercrop advantage tends to be determined by the legume component.

Studies of plant competition to determine the optimum plant population density for maize have shown that there is no single recommendation for all environments. This is due to a variety of unmanageable environmental and management factors that limit yield (Modarres et al., 1998). Even then, it is still worthwhile and incumbent upon researchers to develop appropriate cropping systems that are compatible with farmers' practices. The widespread application of intercropping technologies as a result of their relative simplicity, sustainability, environmental friendliness and limited demand on external inputs has aroused interest among farmers and researchers (Kelly and

Jackobs, 1983).

Although recommendations on planting dates and plant population densities for maize and cowpea exist, they are only for sole crops, but not in intercrops. The usual intercropping practice by farmers has been to plant cowpea at the same time as maize, or a few weeks later. This is done in varying planting patterns, in a haphazard manner with little or no consideration of crop geometry and planting densities of component crops (Mwaipaya, 1989). Therefore, the effect of planting date and row arrangement of maize/cowpea intercrop is of a special interest.

The objectives of the following study were to: (a) identify the optimum row arrangement and planting date of cowpea in an intercropping system (b) assess the yield advantage and profitability of maize-cowpea intercrop system.

Chapter 2

LITERATURE REVIEW

2.1 Maize characteristics and growth requirements

2.1.1 Botany

Maize is a monoecious annual plant and belongs to the grass family, *Graminae*. It has staminate flowers on the terminal branched end of a tall erect stem (the tassel) and pistillate flowers approximately half way up the same plant on the axillary shoots (ear shoots). Maize is a tall plant with a fibrous root system. Some hybrids grow up to 3.5 m while in-breds are smaller and shorter, growing up to 2 m (Tollenaar and Dwyer, 1999).

Maize has a single leaf at each node, and two successive leaves along the stem, that have an approximately opposite azimuthal orientation. Each leaf consists of a sheath surrounding the stem and a leaf blade that is connected to the leaf sheath at the collar or ligule. The number of leaves varies from 7–23 leaves for short season open pollinated, temperate hybrids and 7–30 leaves for tropical cultivars (Tollenaar and Dwyer, 1999).

2.1.2 Climatic requirements

Maize exhibits a wide range of tolerance to environmental conditions. It is best suited to warm weather with adequate moisture, therefore most of the maize is cultivated in the temperate regions and humid subtropics. Maize belongs to the C_4 group of plants. It requires a frost-free growing period. The optimum temperature for germination is 18-21 ^{o}C. Below 13 ^{o}C, germination is greatly reduced, while below 10 ^{o}C, germination completely fails.

Rainfall during the growing period should not fall below 200 mm and 450-600 mm is preferred, with periods of clear warm weather between rainstorms. In the tropics, best results for maize occur with 600-900 mm of rain during the growing season (Purseglove, 1978). The most critical period is the 30 days of maximum growth before pollination, when warm wet weather is required with 100-125 mm of rain. High temperatures and deficient moisture at this time may result in the pollen being shed before the silks are receptive, or in the death of the tassel and drying out of the silks.

Time of flowering is influenced by photoperiod and temperature. Maize can be grown on a wide variety of soils, but performs best on well drained, well aerated, deep, warm loams and silt loams containing adequate organic matter and good supply of nutrients. A pH range from 5.0-8.0, with 6.0-7.0 is optimum and some varieties have been reported to be more tolerant to soil acidity and can grow at lower pH and aluminium saturation greater than 60 % (Purseglove, 1978).

2.2 Cowpea characteristics and growth requirements

2.2.1 Botany

Cowpea is an annual legume and it belongs to the sub-family *Papilionoideae* of the family *Phaseolae.* Cultivated cowpea is an annual herb with great morphological and physiological diversity. Genotypic and environmental interactions influence both the numbers and the lengths of their branches, hence the observed diversity in plant architecture and growth habits. Two different forms of cowpea exist; some cowpea varieties may be bushy, erect with short branches while others may be prostrate, spreading, sometimes twining and climbing.

Cowpea is a self-pollinated crop (Purseglove, 1978; Mulila-Miti, 1995). Each axillary inflorescence is a compound raceme of several simple racemes carried on a grooved peduncle 5-6 cm long. Each simple raceme has between six and twelve flower buds, but only the lower, first formed pair develops while the rest degenerate to form extra floral nectarines between paired flowers.

The leaflets are ovate to lanceolate, sometimes hastate, 5-18 cm long and 3-16 cm wide, entire or lobed and sub-tended by inconspicuous stiples. In the axil of each leaf are three buds. Only the central bud normally expands to produce either a potentially indeterminate, monopodial branch or a racemose inflorescence. Consequently, the number of branches is the complement of the number of inflorescence.

Rare determinates have terminal inflorescence on their main stem and branches. Such types may have more than one inflorescence and a reduced branch at a single node. The cleistogamous flowers are typically papilionaceous and are large, with a standard petal 2-3 cm wide. The standard petal is either white or with anthocyanin pigmentation (tan or straw coloured) or in shade or pale mauve or pink to dark purple, with or without a "V" shaped distribution at the top center of the petal.

Mature fruits vary widely in size, shape, colour and texture. Fruit length vary between 12-20 cm and are straight, curved or coiled. They may lack anthocyanin pigmentation or have varying intensities of anthocyanin pigmentation from pink, purple to almost black. They contain between six and twenty one kidney shaped, oval or rarely almost spherical seeds whose dimensions are within the ranges 5-12 mm and with individual weights between 50 and 340 milligrams. The testa may be smooth or wrinkled and rough. Testas may be white, buff brown, red or black.

2.2.2 Climatic requirements

Cowpea is an annual legume that is adapted to warm conditions and sensitive to chilling. Consequently, it is cultivated either in the tropics or in the subtropics, during the warm season. Cowpea belongs to the C_3 group of plants. It is a short-day species and some cultivars have an obligate or highly sensitive response to photoperiod and do not initiate floral buds when subjected to day lengths that are longer than a critical value (Hall, 1999).

High night temperatures can cause male sterility in cowpea. The stage of floral development most sensitive to high night temperature occurs 9 to 7 days before anthesis. This is after meiosis and involves premature degeneration of the tapetal tissue and lack of endothecial development (Ahmed et. al., 1992). Warrag and Hall (1984b) cited by Hall (1999) reported that high soil temperatures and planting depths have been associated with low emergence rates in the tropics. Average soil temperatures greater than 19 °C are needed for about 3 days after sowing or plant emergence will be delayed and reduced. Onwueme and Adegoroye (1975) cited by Hall (1999) observed reduced emergence under stress for seeds sown deeper in the soil. These seeds of cowpea were most sensitive to heat during the first day after sowing. Pandey (1987) reported best temperatures for cowpea growth to be 20-35 °C while flowering is best when days are 8-14 hours long. Hall (1999) reported that grain yield of cowpea is strongly dependent upon the water supply during the reproductive stage, with relatively little influence of drought on vegetative stage and grain yield.

While cowpea can grow in both low and high rainfall areas, Pandey (1987) reported that standing water may kill the crop while drought during early growth stages may reduce yields. Excessive rains during pod ripening results in poor seed quality. However, water requirement for cowpea is most critical from flowering to pod filling (30-50 days after planting).

2.3 Cropping systems

Palaniappan (1985) defined cropping system as 'the yearly sequence and spatial arrangement of crops, or of crops and fallow, on a given area of a farm and their interaction with farm resources, other farm enterprises and available technology which determine their make up'. Intercropping on the other hand is a cropping system and has been described as the growing of two or more crops in the same field during the same growing season (Willey, 1979; Ofori and Stern, 1987a). In this arrangement, two crops growing simultaneously experience intercrop competition apart from intra crop competition that already exists in sole crops. The degree of intercrop competition depends on the type of intercropping. Intercropping forms such as sequential, strip and relay may exhibit less competition, compared to mixed and row intercropping. While mixed and row-intercropping forms are commonly practiced by majority of small-scale farmers, there is a lack of agronomic recommendation of appropriate plant densities and times of planting intercrops.

In Zambia, several diagnostic surveys conducted have revealed that intercropping is an old farming practice in the subsistence farming sector (Mwaipaya, 1989). Local open pollinated varieties of maize have always been and still continue to be planted together with local legumes that have varied according to dietary preferences and ecological conditions. The Intercropping Research Team based at Mount Makulu Central Research Station started working with hybrid cereal and better yielding legume cultivars, paying special attention to improved intercropping management techniques as far back as the 1980/81 season. Out of a wide range of research studies on legume cultivars carried out in Zambia, studies on maize/field bean (*Phaseolus vulgaris*), maize/soyabean (*Glycine max* L. Merr.) and maize/groundnut (*Arachis hypogaea*) are the most significant. These experiments were carried out in the regional research stations of the country (Mwaipaya, 1989).

2.4 Effect of intercropping on crop growth and yield

Nutrient requirements for maize and cowpea differ at different growth stages. Bridgemoham (1995) reported that when there is adequate water, nutrients and favourable temperature, the productivity of and photosynthesis by plants is controlled by the amount of light available. Therefore, any reduction in incident light due to canopy shading will reduce rates of growth and lower maximum photosynthetic rates. Kandel et al. (1997) observed that intercropping would cause component crops to compete for water, nutrients, light and carbon dioxide. Isom and Worker (1979) suggested that in order to prevent the main crop from dominating the intercrop, it is necessary to understand the geometry of these crops. When the crops are compatible, competition for light will be reduced and solar radiation will be used more efficiently. Lesoing and Francis (1999) reported that higher intercrop yields are attributable to better utilization of environmental resources with greater light interception believed to be the most important factor.

Water is an essential requirement for plant growth. Pandey (1987) reported that maximum dry matter is produced when the plants get right amount of moisture. He stated that inadequate water results in closure of the leaf pores thereby reducing the amount of photosynthates produced by the leaves, while excess water leads to poor nutrient absorption by the roots of plants.

The genetic make-up of a crop species sets the limit for its maximum yield potential and can only be realized when favourable conditions for crop growth and development are provided. Mwala (1980) and Modarres (1998) stated that yield is a dependent variable that varies according to genetic, environmental and management conditions under which the crop is grown. In a study conducted by Adiku et al. (1995), it was reported that intercropping maize (Zea mays L.) with cowpea (Vigna unguiculata L. (Walp)) resulted into considerable reduction in the yield of cowpea while the yield of maize was not affected. In crop plants, particularly maize, the amount of photosynthates produced and translocated to the kernels after anthesis determines the yield. In a field experiment conducted at Mochipapa Regional Research Station in Choma, Zambia, MAFF (1991) reported that grain yield in maize increased linearly with increase in population from 22,220 – 53,330 plants/ha until competition effects became apparent at high plant densities. It was further observed that yields of bean or soyabean, intercropped with maize decreased when planted at the same time.

When the main crop progresses much faster than the intercrop, the latter may become shaded. Shading results in lower respiration rates, light compensation point, decreased activity of ribulose biphosphate (RuBP), phosphoenol pyruvate (PEP), leaf chlorophyll content and reduced electron transport (Bridgemohan 1995). He stated that shade reduces the amount of dry matter accumulated by the plant as a result of a decline in photosynthetic activities. Ultimately, the amount of carbohydrates produced will be inadequate to provide for crop requirements to perform its functions for both reproduction and maintenance.

2.5 Effect of planting date on intercrop performance

The choice of planting dates can be critical in determining yields of the intercrop. Fordham (1983) reported yield advantages ranging from 10 % to 60 % that varied according to the relative planting dates of the two crop species on maize/bean system. Maize agronomy studies carried out at Mochipapa Regional Research Station revealed that optimum plant population and growth of maize was greatly affected by planting date (MAFF, 1991). It was observed that increase in plant population resulted into increase in lodging in maize while silking was delayed more than taselling. It was also established that delayed silking was one of the reasons for increased barren ears at high population stands.

Willey (1979) reported that staggering planting dates of component crops maximizes productivity of intercrops by minimizing inter-species competition for growth limiting factors. He however reported that planting bean four weeks after maize resulted into 20 percent loss in potential yield of a maize-bean intercrop. Francis, et al., (1982) observed maximum productivity of maize-bean intercrops at near simultaneous planting of the component crops. In another study conducted in Zimbabwe, Natarajan and Shumba (1990) observed that planting cowpea one month after maize did not affect maize yield, but resulted in low cowpea yield while simultaneous planting drastically reduced maize yields in a dry year.

2.6 Effect of row arrangement on grain yield

Research conducted in Nigeria (IITA, 1975) as cited by Isom and Worker (1979) found that single alternate rows of maize and a grain legume produced more grain than double or quadruple row plantings of the same crops. They further observed that except for pigeon pea, the single alternate rows of maize and a grain legume had adverse effect on yield of other grain legumes. It was further observed that the combined yields of maize and grain legumes were greater than sole crops of either of the component intercrops. Row intercropping has been identified as one of the methods of maximising yield advantage in intercropping systems by minimising intercrop competition for and enhancing complementary utilisation of limited growth factors (Adetiloye and adekunle, 1988). MAFF (1999) reported that grain yield of maize was increased by 78% for 1:2, 69% for 2:2 and 73% for 3:2 plant densities in an intercrop with cowpea. A mean yield of 3.2 tonnes/ha of maize was recorded. Intercrop advantage for cowpea was however low giving means of 11% for 1:2, 18% for 2:2 and 16% for 3:2 maize/cowpea cropping system. It was deduced from this study that when plant population per unit area increases, competition for nutrient resources also increases, and ultimately render a cropping system less productive.

2.7 Economic advantages of intercropping

2.7.1 Land Equivalent ratio

Various methods of assessing yield advantage of intercropping over sole cropping have been developed. To evaluate biological efficiency on account of land use in intercropping systems, IRRI (1974), Fordham (1983) and Mead (1990) reported a procedure called the Land Equivalent Ratio (LER). The LER describes the relative land area required under sole crops to produce the same yields as intercropping under the same management. Willey (1979) observed that the LER was the preferable index for any intercropping situation. Mathematically, Land Equivalent Ratio is the sum of two or more quotients, depending on the number of crops in association and is calculated using the formula below;

$$LER = L_a + L_b = (Y_a/S_a) + (Y_b/S_b)$$

where; L_a and L_b are the LERs for individual crops, Y_a and Y_b are the individual crop yields in intercropping system and S_a, S_b are their yields as sole crops. Land equivalent ration assessment is usually based on land area, but also reflects relative yields.

2.7.2 Gross margin returns

To assess the benefits of alternative intercropping technologies, gross margin analysis is one of the measures of profitability that is usually used. Barnard and Nix (1984) defined gross margin as the enterprise output less the variable costs attributable to it and helps to facilitate comparisons of returns obtained from different methods of farming practices. Considering the size of plots, gross values were chosen to evaluate the monetary returns.

Adetiloye and Adekunle (1988) observed that assessing monetary returns based on gross values was more realistic than the net monetary returns when small size plots were considered. This is so because of the difficulty associated with estimation of costs of production in small size plots. They further observed that although maize gave higher grain yields than cowpea in sole crop, the selling price of cowpea was twice the price of maize, per kilogram. Conversely, the monetary returns of cowpea in the intercrop was low because cowpea yield was much reduced by competition relative to maize yield.

Chapter 3

MATERIALS AND METHODS

3.1 Experimental site and soil data

The field experiment was carried out at the University of Zambia School of Agricultural Sciences Field Station, Lusaka, during the 2000/2001 agricultural season. The site is located 15^0 23'S, 28^0 E and is about 1140m above sea level. It is found in Region II of the agro-ecological regions of Zambia. The soil is described according to FAO classification as Ferric Luvisol with fine clay loam. Twenty seven soil samples were randomly obtained from each of the 27 sub-plots measuring 3 m x 6 m from which a composite soil sample was taken to the laboratory for chemical analysis. Soil pH, nitrogen, phosphorus and potassium content were determined and the soil chemical characteristics are presented in Table 1. The site was under vegetable (cabbage, tomato, spinach) production for the previous three years. A soil pH ($CaCl_2$), of 7.66 was considered suitable for growth of both crops.

Table 1. Soil analysis results for experimental site

Parameter	Value
pH ($CaCl_2$) [z]	7.66
Nitrogen (%) [y]	0.05
Phosphorus (mg/kg) [x]	22.19
Potassium (cmol/kg) [w]	0.41

[z] pH was determined in 0.01 M Calcium Chloride ($CaCl_2$).

[y] Nitrogen = mineral nitrogen (%) (NH_4^+ and NO_3^-) in 2 M KCl extract, distilled in boric acid indicator and titrated with 0.05 N H_2SO_4.

[x] Phosphorus = available phosphorus in milligrams per kilogram of soil (mg/kg) by resin extract method.

[w] Potassium = available potassium in centimoles per kilogram of soil (cmol/kg). Neutral ammonium acetate solution read on atomic absorption spectrophotometer (AAS).

3.2 Experimental treatments and design

Maize and cowpea crops were used to compare planting dates and row arrangements in intercropping systems. Three planting dates of cowpea and one planting date of maize were selected. The first planting date was 20th December when maize and cowpea were planted simultaneously. The second planting date for cowpea was 4th January (14 days after first planting) while the third planting date for cowpea was 18th January (28 days after first planting). Four row arrangements were used. These were: (a) maize sole crop at 75 cm inter-row spacing, (b) cowpea sole crop at 50 cm inter-row spacing, (c) a 1:1 intercrop of single maize rows 75 cm apart with one row of cowpea at the centre and (d) a 1:2 intercrop of single maize rows 75 cm apart with two rows of cowpea in between (Figures 1 and 2). Each of the 27 sub-plots comprised four rows of maize 6 m long. In the 1:1 row arrangement, there were three rows of cowpea while in the 1:2 row arrangement, there were six rows of cowpea in each of the intercrop sub-plots. The 9 sole cowpea sub-plots had six rows excluding two border rows on each edge.

The experiment was arranged in a split-plot design with planting date (First, second and third) as main-plots and row arrangement (sole maize, sole cowpea, 1:1 and 1:2 intercrop) as sub-plots. The experiment was replicated three times. The gross plot measured 36 m width x 18 m length, the main-plot was 2 m width x 6 m length while the sub-plot was 3 m width x 6 m length.

Pool 16, an open pollinated, semi-dent, early maturing variety of maize (ZAMSEED, 1994) was used as the major crop. According to crop production guidelines, it requires an optimum plant population of about 40,000–55,000/ha. The crop can grow to a height of 1.9 m. It takes 55 days to tassel emergence, matures in 100 days. Pool 16 maize exhibits a recurved ear attitude at maturity, which can be 18.5 cm in length. The variety has strong tolerance to drought and a potential yield of 3.0 mt/ha has been recorded. In case of cowpea which was the minor crop, Lutembwe, one of the released varieties was used in this study. It is a medium maturing (75-80 days) variety providing dual benefits (leaf and grain) to the farmers. The variety is tolerant to cowpea aphid mosaic virus (CAMV) and has a yield potential of about 1.0-1.8 mt/ha.

The treatments were randomly allocated to the plots.

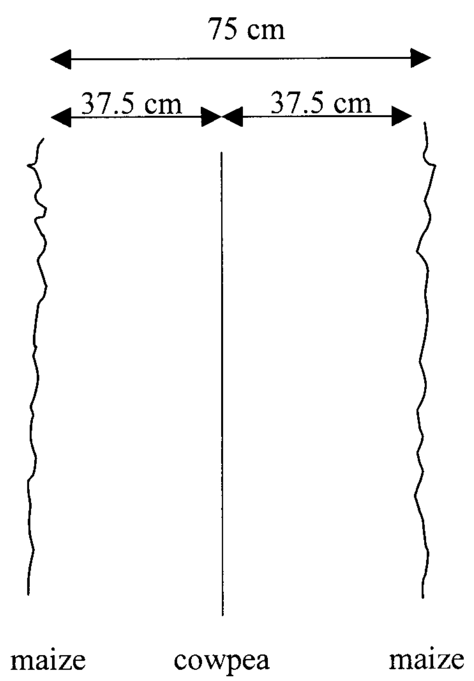

Figure 1. Illustration of a 1:1 row arrangement of maize/cowpea intercropping.

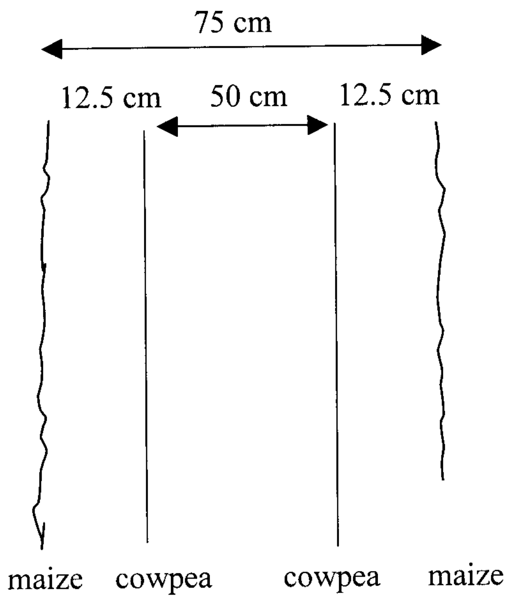

Figure 2. Illustration of a 1:2 row arrangement of maize/cowpea intercropping.

3.3 Crop management

Two weeks after emergence, when the crops were well established, the crops were thinned to the recommended intra–row spacing of one plant per station. Compound D (10 N, 20 P_2O_5, 10 K_2O, 8 S) basal dressing fertiliser was applied in furrows at planting. Each sub-plot received 0.55 kg of the basal fertiliser that supplied 0.10 kg N/sub-plot, 0.30 kg P_2O_5/sub-plot and 0.10 kg K_2O/sub-plot. Urea (46 N) top dressing fertiliser was applied to maize plots only and each sub-plot receiving 0.59 kg of the Urea which supplied 0.27 kg nitrogen per sub-plot at 14 and 55 days after emergence. Plots were kept weed free as much as it was necessary. Occurrence of aphids in cowpea was controlled by foliar application of Monokill 40% (EC) insecticide that had monochrotophos as active ingredient and was applied at 15-20 mls/10 litres of water. Two sprays were carried out, 30 and 60 days after planting maize. Fungal diseases in cowpea such as ascochyta blight, anthracnose and cercospora leafspot were controlled by foliar application of Benlate WP fungicide that comprised benzimidazole (500 g/kg) as active ingredient. The fungicide was applied at a rate of 5 g/10 litres of water. The fungicide was applied once to the crop at 60 days after planting maize.

3.4 Data collection and parameters measured

3.4.1 Weather data

Data on rainfall, temperature and sunshine hours for the 2000/2001 season were collected from the University of Zambia meteorological station shown in Appendix 1a-c.

3.4.2 Growth parameters

All growth parameters (i.e. plant height, leaf area and dry matter production) were measured through out the growth of the crops, beginning when the crop was 21 days after planting. Data for these parameters were collected at 21 day intervals on one set of 5 randomly selected plants per plot, per sampling stage. Due to the limited size of plots, plants marked for destructive sampling were randomly selected from the border rows *prior* to their harvest, an approach suggested by Pearce, et. al. (1988).

Plant height was taken to be the distance from the soil surface to the apex of the central growing point. The mean values were taken as the plant height for that plot.

Dry matter production was taken from 5 randomly selected plants. This parameter was measured from the shoot of selected border plants. The plants were cut at ground level and oven dried at 105 ^{o}C for 24 hours. Samples were taken 4 times at 21 day intervals. Leaf area measurement was taken from the same sample above.

Leaf area normally considered to be the upper surface area of the leaf was determined from fresh green leaves only. A grid method was used for measuring leaf area in cowpea while for maize, length and breadth for all the leaves were measured and multiplied by a factor, 0.75.

Leaf area index was derived from leaf area and was obtained by dividing leaf area by the ground area (spacing) of each crop.

3.4.3 Yield components

These were determined at harvesting. Harvesting for final yield and partitioning of yield components was done when the crop in the field was sufficiently dry. The parameters were obtained from 10 randomly selected plants per plot taken from the 2 middle rows leaving out one metre on each edge. In the case of maize, the 2 middle rows were taken from a total of 4 rows while in cowpea, a total of 3 and 6 rows per plot in the 1:1 and 1:2 row arrangements, respectively were considered. In the sole treatments, there was a total 4 rows of maize and 6 rows of cowpea per plot.

Harvest index, an integrated measure of assimilate partitioning within the whole plant, was determined as the total grain dry weight over the total biomass dry weight. The number of plants and cobs/pods per plant from the sample area were counted before they were harvested.

Cob and pod length were determined from a sample of cobs and pods taken from 10 randomly selected plants, a week before final harvesting. Measurements were taken from the base up to the tip of the fruit. A measuring tape was used to take measurements and the sample average figure was considered for analysis.

Number of cobs and pods per plant were measured from a selected random sample of 10 plants. The number of cobs and pods per plant for maize and cowpea, respectively were physically counted and the average figure was considered for analysis.

Number of grains/cob and seeds/pod were determined by counting the number of seeds from 10% of the cobs and pods of the 10 randomly selected sample plants. This parameter was taken a week before harvesting.

Shelling percentage was determined from the same sample of plants above. Ten percent of the cobs and pods per plot were shelled by hand. The weight of the seed and that of the whole cob and pod before shelling were recorded. The shelling percentage was obtained for each plot by dividing the total weight of the seed by the weight of the whole cob and pod before shelling and multiplying the figure obtained by 100.

100-grain weight was obtained from each of the shelled grain from each plot. One hundred grains were randomly sampled and weighed using an electronic scale and was done at harvesting.

Grain yield per plot was obtained from an area of 12 m^2 taken from two middle rows after leaving out one metre from each edge. Yield data was later expressed on a hectare basis.

3.5 Data analysis

Analyses of variance was performed on growth, yield components and combined variables (i.e. land equivalent ratios, gross margins) using the Genstat 5 Release 3.22 statistical computer programme. Differences amongst treatments and interactions were tested by a *prior* single degree of freedom contrast comparisons. Separation of means of treatments and interactions was done using the LSD ($p<0.001$). Correlation analysis of yield on harvest index and number of pods per plant was also performed using simple linear regression to determine the type and degree of association between the parameters.

Chapter 4

RESULTS

4.1 Environmental conditions

The weather was favourable for crop growth and development. Critical growth stages for both maize and cowpea (seedling, flowering and grain filling) occurred between the 70th and 170th day after the start of the season in October 2000 during which period favourable moisture, temperature and sunshine duration prevailed as shown in Appendices 1a, 1b and 1c. Total rainfall during the season was 1272.3 mm and the highest amounts were received during the month of March 2001. Daily average air temperature was 22.1 ^{0}C while the minimum and maximum temperatures were 17.1^{0}C and 27.1 ^{0}C respectively. Daily average sunshine declined from 10.9 hours in October to 3.4 hours in April 2001 after which it started to increase again. Rains sufficient for planting however only started around mid December. Crop emergence was generally good and the intended planting populations were achieved. Crop condition was generally good throughout the growing season except for a few cases of anthracnose in cowpea. There was water logging of some parts of the field, especially during the month of March 2001, and this affected crop growth. Heavy rains at crop maturity also induced some fungal disease in both maize and cowpea.

4.2 Effect of planting date and row arrangement on plant height (cm) of cowpea *(Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

The effect of planting date on plant height is presented in Table 2a. Plant height was significantly affected ($p<0.001$) by planting date when the crop was 21 and 63 days after planting. Cowpea planted on the third planting date had taller plants compared to those of the first and second planting dates. Plant height was similar for all planting dates when the crop was 42 and 84 days after planting.

The effect of row arrangement on plant height is presented in Table 2b. Plant height was significantly affected ($p<0.001$) by row arrangement 42 days after planting and the 1:2 row arrangement gave taller cowpea plants compared to 1:1 and sole row arrangements. Plant height did not differ between 1:1 and 1:2 row arrangements 21, 63 and 84 days after planting. However, plant height differed between the 1:2 and sole row arrangements 63 and 84 days after planting. The 1:2 row arrangement treatments had the tallest cowpea plants at maturity compared to those of 1:1 and sole row arrangements.

Table 2a. Effect of planting date on plant height (cm) of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	8.6b [Z]	27.7a	61.8b	86.6a
Second	7.2b	29.6a	77.5a	87.0a
Third	12.6a	34.9a	81.5a	89.4a
Mean	9.4	30.7	73.6	87.7
CV (%)	6.6	19.7	9.0	4.0

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

Table 2b. Effect of row arrangement on plant height (cm) of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

Row	Sampling stage (days after planting)			
Arrangement[$]	21	42	63	84
1:1	10.2a [Z]	31.2b	72.9ab	89.3a
1:2	9.3a	37.2a	80.2a	93.8a
Sole crop	8.8a	23.8c	67.7b	79.9b
Mean	9.4	30.7	73.6	87.7
CV (%)	20.1	16.3	11.9	6.9

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea

4.3. Effect of planting date and row arrangement on dry matter production (g/plant) of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

Dry matter production was not affected by planting date when the crop was 21 and 63 days after planting. Dry matter production was however significantly affected ($p<0.001$) by planting date when the crop was 42 days after planting. At this stage, dry matter production was highest (7.08 g/plant) in the first planting date treatment and least (3.08 g/plant) in the third planting date treatment. When the crop was 84 days after planting, dry matter production was significantly different ($p<0.001$) between the Second and Third planting dates (Table 3a). The second planting date produced 7.17 g/plant as compared to the third planting date that produced 3.45 g/plant of dry matter.

The effect of row arrangement on dry matter production was observed between the intercrop and sole crop treatments when the crop was 63 and 84 days after planting. The sole crop treatments gave higher dry matter yield; 19.33 and 8.78 g/plant at 63 and 84 days after planting, respectively (Table 3b).

Table 3a. Effect of planting date on dry matter production (g/plant) for cowpea (*Vigna unguiculata* L. Walp) at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	0.458a[Z]	7.08a	17.05a	8.25ab
Second	0.464a	4.50b	16.89a	7.17a
Third	0.431a	3.08c	11.02a	3.45b
Mean	0.451	4.89	14.98	6.29
CV (%)	19.0	6.5	28.4	17.0

[Z] Means in a column followed by the same letter are not significantly different at p<0.001.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

Table 3b. Effect of row arrangement on dry matter production (g/plant) for cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

Row	Sampling stage (days after planting)			
arrangement[$]	21	42	63	84
1:1	0.430a[Z]	4.22a	12.97b	5.63b
1:2	0.450a	4.97a	12.65b	4.45b
Sole	0.472a	5.48a	19.33a	8.78a
Mean	0.451	4.89	14.98	6.29
CV (%)	15.5	27	21.6	17

[Z] Means in a column followed by the same letter are not significantly different at p<0.001.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea

4.4 Effect of planting date and row arrangement on leaf area (cm^2/plant) of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

The response of leaf area to planting date is shown in Table 4a. Leaf area per plant was significantly influenced ($p<0.001$) by planting date when the crop was 42 days after planting with the first planting date giving the highest (1036 cm^2) and the third planting date the least (566 cm^2) leaf area per plant. Leaf area per plant was also significantly different ($p<0.001$) between the first (721 cm^2) and the third (447 cm^2) planting date when the crop was 84 days after planting. The highest leaf area per plant (1138 cm^2), although not significantly different from the first and third planting dates, was observed in the second planting date when the crop was 63 days after planting. A reduction in leaf area per plant of 12.2 %, 51.1 % and 50.4 % for the first, second and third planting dates, respectively was recorded when the crop was 84 days after planting. There were no differences in leaf area per plant between the different planting dates when the crop was 21 and 63 days after planting.

The response of leaf area per plant to row arrangement was similar in all treatments at all growth stages (Table 4b). However, the highest leaf area per plant for all treatments was observed when the crop was 63 days after planting. A reduction in leaf area per plant values of 46.7 %, 36.5 % and 35.6 % for 1:1, 1:2 and sole row arrangements, respectively were recorded when the crop was 84 days after planting.

Table 4a. Effect of planting date on leaf area (cm^2/plant) of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	74.5a[Z]	1036a	821a	721a
Second	82.4a	753b	1138a	556ab
Third	111.3a	566c	903a	447b
Mean	89.4	785	954	575
CV (%)	19.1	7.1	12.4	15.1

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

Table 4b. Effect of row arrangement on leaf area (cm^2/plant) of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Row arrangement[$]	21	42	63	84
1:1	86.0a[Z]	714.0a	986.0a	525.0a
1:2	93.2a	813.0a	920.0a	584.0a
Sole	89.1a	827.0a	955.0a	615.0a
Mean	89.4	785.0	954.0	575.0
CV (%)	13.8	25.3	25.9	31.9

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea

4.5. Effect of planting date and row arrangement on leaf area index of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

Leaf area index (LAI) was significantly ($p<0.001$) influenced by planting date as shown in Table 5a when determined at 42 and 84 days after planting. In both cases, the highest LAI was obtained in the first planting date and the third planting date had the least. At 42 days after planting, the first planting date gave a LAI value of 1.72, while the second and third planting dates recorded LAI values of 1.25 and 0.94, respectively. A similar tendency was observed when the crop was 84 days after planting although the differences observed were between the first (1.19) and the third (0.74) planting dates. A reduction in leaf area index values of 12.5 %, 51.3 % and 50.7 % for the first, second and third planting dates, respectively were recorded when the crop was 84 days after planting. Leaf area index however, did not appear to be influenced by the row arrangement (Table 5b).

Table 5a. Effect of planting date on leaf area index for cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	0.123a[Z]	1.72a	1.36a	1.19a
Second	0.137a	1.25b	1.89a	0.92ab
Third	0.185a	0.94c	1.50a	0.74b
Mean	0.149	1.30	1.58	0.953
CV (%)	19.1	7.2	12.4	15.0

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

4.6 Effect of planting date and row arrangement on plant height of maize (*Zea mays* L.)

Maize plant height was not affected by time of introducing cowpea or the row arrangement (Tables 6a and 6b). The average plant height increased up to 176.4 cm in either case.

Table 5b. Effect of row arrangement on leaf area index of cowpea (*Vigna unguiculata* L. (Walp)) at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Row arrangement[$]	21	42	63	84
1:1	0.14a[z]	1.18a	1.64a	0.87a
1:2	0.15a	1.35a	1.53a	0.97a
Sole	0.14a	1.37a	1.59a	1.02a
Mean	0.15	1.30	1.58	0.95
CV (%)	13.9	25.3	26.0	15.0

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea

Table 6a. Effect of planting date on plant height (cm) of maize (*Zea mays L.)* at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	10.5a[z]	54.5a	150.8a	179.4a
Second	9.0a	47.6a	142.4a	173.8a
Third	9.0a	49.9a	149.1a	176.1a
Mean	9.5	50.7	147.4	176.4
CV (%)	16.4	31.1	30.6	13.3

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

Table 6b. Effect of row arrangement on plant height (cm) of maize (*Zea mays L.)* at different sampling stages (days after planting).

Row arrangement[$]	Sampling stage (days after planting)			
	21	42	63	84
1:1	9.6a[z]	51.8a	153.4a	178.7a
1:2	9.8a	53.7a	149.6a	181.3a
Sole	9.1a	46.5a	139.3a	169.2a
Mean	9.5	50.7	147.4	176.4
CV (%)	16.3	20.6	23.6	13.2

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of maize

4.7 Effect of planting date and row arrangement on dry matter production (g/plant) of maize (*Zea mays* L.)

Maize dry matter production was not affected by time of introducing cowpea or the row arrangement (Tables 7a and 7b). The average dry matter production increased up to 130.60 g/plant in either case.

Table 7a. Effect of planting date on dry matter production (g/plant) of maize (*Zea mays L.)* at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	0.73a[z]	18.00a	52.90a	119.80a
Second	0.60a	15.40a	48.00a	135.10a
Third	0.63a	18.50a	65.50a	137.00a
Mean	0.65	17.30	55.50	130.60
CV (%)	27.6	50.70	52.00	35.2

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

Table 7b. Effect of row arrangement on dry matter production (g/plant) of maize (*Zea mays L.)* at different sampling stages (days after planting).

Row arrangement	Sampling stage (days after planting)			
	21	42	63	84
1:1	0.67a[z]	18.2a	53.9a	124.2a
1:2	0.65a	18.6a	61.8a	133.2a
Sole	0.63a	15.0a	50.7a	134.5a
Mean	0.65	17.3	55.5	130.6
CV (%)	38.2	34.8	19.7	28.0

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of maize

4.8 Effect of planting date and row arrangement on leaf area (cm^2/plant) of maize (*Zea mays* L.)

Maize leaf area was not affected by time of introducing cowpea or the row arrangement (Tables 8a and 8b). The average leaf area increased up to 2819 cm^2/plant in either case.

Table 8a. Effect of planting date on leaf area (cm^2/plant) of maize (*Zea mays L.)* at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	175a[z]	2478a	4298a	2568a
Second	132a	2140a	3890a	2883a
Third	140a	2585a	5200a	3007a
Mean	149	2401	4463	2819
CV (%)	35.4	45.7	40.2	28.6

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

4.9 Effect of planting date and row arrangement on leaf area index of maize (*Zea mays* L.)

Maize leaf area index was not affected by time of introducing cowpea or the row arrangement (Tables 9a and 9b). The average leaf area index increased up to 1.50 in either case.

Table 8b. Effect of row arrangement on leaf area (cm^2/plant) of maize (*Zea mays L.)* at different sampling stages (days after planting).

Row arrangement[$]	Sampling stage (days after planting)			
	21	42	63	84
1:1	154a[z]	2535a	4367a	2725a
1:2	152a	2565a	4600a	2872a
Sole	141a	2102a	4421a	2862a
Mean	149	2401	4463	2819
CV (%)	39.8	30.4	16.7	24.4

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of maize

Table 9a. Effect of planting date on leaf area index of maize (*Zea mays L.)* at different sampling stages (days after planting).

	Sampling stage (days after planting)			
Planting date*	21	42	63	84
First	0.08a[z]	1.32a	2.29a	1.36a
Second	0.06a	1.14a	2.07a	1.53a
Third	0.07a	1.37a	2.77a	1.59a
Mean	0.07	1.28	2.38	1.50
CV (%)	35.8	45.8	40.3	28.7

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

Table 9b. Effect of row arrangement on leaf area index of maize (*Zea mays L.)* at different sampling stages (days after planting).

Row arrangement[$]	Sampling stage (days after planting)			
	21	42	63	84
1:1	0.08a[Z]	1.35a	2.32a	1.45a
1:2	0.07a	1.36a	2.45a	1.53a
Sole	0.07a	1.12a	2.35a	1.52a
Mean	0.07	1.28	2.38	1.50
CV (%)	41.2	30.4	16.7	24.5

[Z] Means in a column followed by the same letter are not significantly different at p<0.001.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of maize

4.10 Effect of planting date and row arrangement on yield components of cowpea (*Vigna unguiculata* L. (Walp)).

Data on the response of yield and yield components of cowpea to planting date are shown in Table 10a. Clearly, planting date had no influence on grain yield, number of pods per plant, harvest index, pod length, number of seeds per pod and shelling percentage. The only difference observed was in number of pods per plant between the second and third planting dates. The highest number of pods per plant was observed in the second planting date (8), followed by the first planting date (5) and the third planting date (4) had the least number of pods per plant (Table 10a).

On the other hand, the response of grain yield, number of pods/plant and harvest index was significantly different (p<0.001) between row arrangements as presented in Table 10b. The highest cowpea grain yields were obtained in the sole plot 1934 kg/ha), followed by the 1:1 intercrop (1019 kg/ha) while the lowest yield was from the 1:2 intercrop (713 kg/ha). The highest number of pods per plant was obtained in the sole treatment (9), followed by the 1:1 intercrop (5) while the 1:2 intercrop (3) had the least number of pods per plant. Harvest index was highest in the sole treatment (0.43), followed by 1:1 intercrop (0.38) and lowest in the 1:2 row arrangement treatment (0.29). Pod length, number of seeds/pod and shelling percentage did not differ between row arrangements.

Table 10a. Effect of planting date on yield components of cowpea (*Vigna unguiculata* L. Walp).

Planting date*	Grain yield (kg/ha)	No. of pods/ plant[y]	Harvest index	Pod length (cm)	No. of seeds/pod[x]	Shelling percentage
First	1118a[z]	5ab	0.29a	18.0a	14a	59.3a
Second	1439a	8a	0.44a	18.3a	15a	62.9a
Third	1109a	4b	0.37a	18.4a	13a	62.1a
Mean	1222	6	0.37	18.2	14	61.4
CV (%)	20.8	27.6	21.6	1.8	11.9	5.9

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[y] Total number of pods per plant; [x] Total number of seeds per pod

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

4.11 Effect of planting date and row arrangement on 100-grain weight (g) of cowpea *(Vigna unguiculata* L. (Walp)*)*

The response of 100-grain weight (g) of cowpea to planting date and row arrangement is shown in Table 11. The 100-grain weight of cowpea tended to increase significantly ($p<0.001$) in both the 1:1 and 1:2 row arrangements as planting date changed from the first to the second and third planting dates while that of cowpea sole treatment remained the same. The highest 100-grain weight of cowpea was observed in the third planting date treatment; 13.2 g and 12.4 g, in the 1:1 and 1:2

intercrops, respectively. The lowest 100-grain weight was observed in the first planting date treatment; 10.4 g and 9.8 g in 1:1 and 1:2 intercrops, respectively.

Table 10b. Effect of row arrangement on yield components of cowpea (*Vigna unguiculata* L. Walp))

Row arrangement	Grain yield (kg/ha)	No.of pods/plant[y]	Harvest index	Pod length (cm)	No. of seeds/ pod[x]	Shelling percentage
1:1	1019b[z]	5b	0.38b	18.2a	15a	61.7a
1:2	713c	3c	0.29c	18.0a	15a	59.8a
Sole	1934a	9a	0.43a	18.4a	13a	62.8a
Mean	1222	6	0.37	18.2	14	61.4
CV (%)	27.3	32.2	20.0	2.3	24.1	7.1

[Z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[y] Total number of pods per plant, [x] Total number of seeds per pod,

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea

4.12 Effect of planting date and row arrangement on yield components of maize (*Zea mays* L.).

Neither planting date nor row arrangement had any effect on yield components of maize (Tables 12a and 12b).

Table 11. Effect of planting date and row arrangement on the 100-grain weight (g) for cowpea (*Vigna unguiculata* L. (Walp)) and maize (*Zea mays* L.).

Planting date	Row arrangement 1:1	1:2	sole	Mean
First	10.4b[z]	9.8b	12.1a	10.8a
Second	12.5a	11.5a	11.7a	11.9a
Third	13.2a	12.4a	11.1a	12.2a
Mean	12.0	11.2	11.7	11.6
CV (%)	5.3	5.3	5.3	5.3

[z] Means in a column followed by the same letter are not significantly different at p<0.001.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later, Third planting date = cowpea planted 28 days later.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea or maize

Table 12a. Effect of planting date on yield components of maize (*Zea mays* L.)

Planting date*	Harvest index	Coblength (cm)	No.of cobs/plant	No. of grains/cob	Shelling %	Grain yield (kg/ha)
First	0.71a[z]	12.9a	1a	403a	53.3a	2952a
Second	0.55a	12.0a	1a	375a	85.3a	2659a
Third	0.51a	12.4a	1a	383a	85.5a	2594a
Mean	0.59	12.5	1	387	84.7	2735
CV (%)	24.1	16.1	11.0	22.2	2.9	34.8

[z] Means in a column followed by the same letter are not significantly different at p<0.001.

* First planting date = maize/cowpea planted simultaneously, Second planting date = cowpea planted 14 days later,

Third planting date = cowpea planted 28 days later.

Table 12b. Effect of row arrangement on yield components of maize (*Zea mays* L.)

Row arrangement[$]	Harvest index	Coblength (cm)	No. of cobs/plant	No. of grains/cob	Shelling %	Grain yield (kg/ha)
1:1	0.66a[z]	12.6a	1a	391a	84.9a	2494a
1:2	0.63a	12.9a	1a	402a	86.3a	2932a
Sole	0.47a	11.8a	1a	368a	83.0a	2779a
Mean	0.59	12.5	1	387	84.7	2735
CV (%)	44.7	14.0	12.6	19.1	4.7	13.6

[z] Means in a column followed by the same letter are not significantly different at p<0.001.

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand

4.13 Effect of row arrangement on land use efficiency and financial gross returns of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L. Walp).

The LERs for the 1:1 intercrop was 1.51 while that for the 1:2 intercrop was 1.47 and were both significantly different (p<0.001) from 1.00 (sole treatment) as presented in Table 13. Although the land equivalent ratios did not differ among the intercrop row arrangements, significant differences (p<0.001) were observed when the intercrops were compared to the sole crop treatments. The LERs for the intercrops were greater than unity, while the sole treatments had LER equal to one.

When gross returns were calculated for the systems, there were significant differences (p<0.001) between row arrangements. The sole plot treatment gave the highest financial returns (K777,000/ha) followed by the 1:1 (K278,000/ha) while the lowest (K174,000/ha) financial returns were from the 1:2 intercrop treatment. The 1:1 row arrangement returned 37.4 % more financial gains per hectare compared to the 1:2 row arrangement although sole treatment was better than both intercrops. There is financial advantage to intercrop following the 1:1 row arrangement treatment. Land equivalent ratios and financial gross returns in maize were not affected by row arrangement (Table 13).

Table 13. Effect of row arrangement on land use efficiency and financial gross returns ('000 zmk) of cowpea and maize intercrop.

	Gross returns ('000) zmk[x] /ha		LER[y]
Row arrangement[$]	Cowpea	Maize	
1:1	278b[z]	228a	1.51a
1:2	174c	370a	1.47a
Sole	777a	323a	1.00b
Mean	410	307	1.325
CV (%)	47.5	40.1	14.5

[z] Means in a column followed by the same letter are not significantly different at $p<0.001$.

[x] Input prices of variable costs were obtained from MAFF-Lusaka District Office; Farm Budgeting Handbook for October 2000. Producer prices per kilogram were those of the prevailing market as at October 2001. Producer prices: maize = 333 zmk/kg, cowpea = 600 zmk/kg. Variable costs for maize was 602,050 zmk/ha and cowpea was 270,360 zmk/ha.

[y] Combined land equivalent ration for maize and cowpea

[$] 1:1 row arrangement = 1 row cowpea in between 2 rows of maize; 1:2 row arrangement = 2 rows cowpea in between 2 rows of maize; sole row arrangement = pure stand of cowpea or maize.

Chapter 5

DISCUSSION

5.1 Effect of planting date and row arrangement on plant height of cowpea

The results of this study show that plant height of cowpea was affected by both planting date and row arrangement. The tallest cowpea plants were observed in the third planting date and the shortest in the first planting date. It is likely that cowpea planted on the third planting date was subjected to shading much earlier than cowpea planted on the first and second planting dates. Prolonged shading of cowpea tended to promote taller plants due to competition for light resource.

The 1:2 row arrangement had taller plants compared to the 1:1 row arrangement and sole crop and clear differences were observed when the crop was 42 days after planting. In the 1:2 row arrangement, the number of plants per unit area was higher than in the 1:1 or sole crops row arrangement while the source of nutrient supply remained the same. The observed pattern in plant height at 42 days after planting suggests an increase in competition for growth resources. It is likely that at this stage of cowpea, demand a lot of energy demanding activities such as nodulation may have occurred. Pandey (1987), working with cowpea/rice cropping systems found that maximum nodulation in cowpea occur 40 days after emergence and that demand for light, moisture and nutrient resources at this stage is highest.

The findings in a study on the effect of plant population and nitrogen rate on growth and yield with sesame *(Sesamum indicum* L. landrace Matsai) by Mujaya (1997) supports the observations made in this experiment. He reported that increased plant height was a result of competition for both phototropic effects and inadequate nutrient.

5.2 Effect of planting date and row arrangement on dry matter production of cowpea

Dry matter production in cowpea was significantly affected by planting date and row arrangements. Dry matter production differed significantly between planting dates when the crop was 42 days after planting. It is arguable that the activities of nodulation, coupled with differences in the micro-environment of the crop may have had an influence on the observed differences in dry matter production 42 days after planting. As expected, the first planting date produced higher amounts of dry matter than the second and third planting dates. Delayed planting of cowpea exposed the crop to more shading, hence increased competition for radiation, moisture and nutrient resources. The results also reveal that dry matter production tended to increase with time reaching a peak 63 days after planting and declined thereafter as observed by Adiku et al. (1995). This was expected, as the crop approached physiological maturity at about 75 days, leaf senescence due to old age, occurred and leaf functions for photosynthetic activities became less apparent.

The 1:1 and 1:2 row arrangements produced similar amounts of dry matter. It is likely that at the 63 days after planting, the crop had almost completed and accumulated sufficient assimilates for grain filling, hence the tendency for reduction in dry matter production. The highest dry matter production obtained at 63 days after planting coincided with maximum leaf area indices of 1.89 and 1.50 for the second and third planting dates of cowpea, respectively. The results are in agreement with the findings of Pandey (1987) who working with cowpea in rice reported high dry matter production at high LAIs due to increased leaf production. The reduction in dry matter production in 1:1 and 1:2 row arrangements compared to sole cowpea may be attributed to intra and inter species competition for growth factors. These results are close to those reported by Adiku et al., (1995). While studying maize-cowpea intercrop, he obtained dry matter production value of 15 g/plant at 63 days after planting. They observed that leaf production rate per plant decreases as plant population increases because of increased mutual shading which in turn lead to reduced biomass per plant. Inter-species competition for radiation in crop mixtures was also reported to reduce biomass per plant thereby reducing leaf production rates. The findings of this study are similar to those obtained by Reddy and Visser (1997) who, while working with millet observed a reduction in the growth period of cowpea by the same number of days as the planting was delayed. They further observed that delaying planting from the first planting date with millet to 7 weeks after millet led to significantly lower dry matter yields of cowpea.

5.3 Effect of planting date and row arrangement on leaf area and leaf area index of cowpea

Whereas row arrangement of cowpea had no significant effect on leaf area and leaf area index, these parameters were affected by planting date. Cowpea planted on the first planting date reached maximum leaf area index value of 1.72 about 42 days after planting while that for the second and third planting dates were 1.89 and 1.50, respectively reached at 63 days after planting. The drop in leaf area and leaf area index due to planting date observed between 63 and 84 days after planting can be attributed to leaf senescence and shedding. As the crop advanced towards maturity, the demand for photosynthates declined and the primary function of food manufacture by the leaves became less important. The differences observed in leaf area and leaf area index 42 days after planting, due to planting date coincides with the stage of nodulation in cowpea. The effect of shading coupled with variations in the micro-environment also increased competition (for light, nutrients) associated with increase in leaf area of cowpea. It is most likely that shading induced a reduction in leaf number and size per plant that consequently lead to a decline in total leaf area per plant. Hay and Walker (1989) also reported acceleration or telescoping of crop development resulting in a tendency for lower maximum leaf area index with delayed sowing of cowpea. Leaf area index ratios obtainable in this study although lower (1.6 average) than those reported by Adiku et al., (1995), occurred at a similar sampling stage of 63 days after planting. He reported a maximum leaf area index ratio of 2.5 at 63 days after planting and attributed the reduction in the development of intercrop cowpea leaf area after this stage, to radiation limitation. The differences in the leaf area index ratios may be accounted for by variations in environmental conditions of the crops.

5.4 Effect of planting date and row arrangement on harvest index of cowpea

Harvest index of cowpea was significantly affected by row arrangement, but not planting date. The highest harvest index was observed in the sole crop, followed by the 1:1 while the 1:2 row arrangement gave the least amount of dry matter produced. In the 1:1 row arrangement, although subjected to intra and inter species competition, the crop had a higher competitive advantage compared to those under the 1:2 row arrangement. Consequently, the crop in 1:1 row arrangement was able to invest some its energy towards grain formation and storage. In the 1:2 row arrangement, the crop invested most of its energy (carbohydrates) in production of vegetative material (i.e.'tall' plants) at the expense of building up food reserves necessary for reproduction and maintenance. The low plant population of cowpea in the 1:1 row arrangement had compensatory influence on the observed higher harvest index. It is likely that the high dry matter observed in the 1:1 row arrangement compared to 1:2 row arrangement affected the harvest index of cowpea. Regression analysis of yield of cowpea on harvest index was significant and positively correlated (r = 0.95). The findings of the study seem to agree with those reported by Hall (1999) who observed that cowpea grain yield was positively correlated with harvest index under either well irrigated or dry conditions.

5.5 Effect of planting date and row arrangement on number of pods per plant of cowpea

Both planting date and row arrangement had significant effect on the number of pods per plant of cowpea. Apart from sole plots, the second planting date of cowpea in 1:1 row arrangement favoured pod formation and development more than any other treatment. The high number of pods per plant observed in the 1:1 row arrangement compared to 1:2 row arrangements were expected. In the 1:1 row arrangement, the low plant population per unit area had less competition for moisture and nutrients and greater light interception resulting in greater photosynthetic rates and development of more pods/plant compared to the 1:2 row arrangement. Contrary to these findings, MAFF (1999) reported an average of 10 pods per plant and the number of pods per plant did not differ between row arrangements. Planting date seem to have had an indirect effect on the number of pods per plant by influencing the development of leaf area index. Hay and Walker (1989) working with cereals observed reduced maximum leaf area index due to telescoping of crop development resulting from delayed sowing. Mariga (1990) working with maize-cowpea intercrop observed that the number of pods per plant was significantly affected by cropping pattern, planting date and in-row spacing. Pandey (1987) working with rice-cowpea intercrop reported that the number of pods per plant of cowpea is the most important yield component. He stated that the number of pods per plant as determined from flowering to podding, is most affected by growing conditions such as plant density, soil moisture and weather . A regression of yield on number of pods per plant in this study showed a significant and positive correlation ($r = 0.849$) between the variables.

5.6 Effect of planting date and row arrangement on number of seeds/pod of cowpea

The results obtained indicate that planting date and row arrangement did not affect the number of seeds per pod of cowpea. However, an average of 14 seeds/pod was observed. These observations, although higher, are contrary to the findings by Mariga (1990) in Zimbabwe that the number of seeds per pod in cowpea were significantly affected by planting date. Cowpea planted at the same time with maize produced more (10) seeds per pod compared to the one planted 5 weeks later (4). These differences are expected considering variations in environments and nature of treatments applied.

5.7 Effect of planting date and row arrangement on shelling percentage of cowpea

This study found that shelling percentage for cowpea was not affected by planting date or row arrangement. Shelling percentage varied from 59.3 – 62.9 % and 83.0 – 86.3 % of cowpea. MAFF (1999) in a field experiment conducted at Msekera reported similar values of 62.5 %. Contrary to these observations, Mariga (1990) observed differences in shelling percentage due to planting date, and not cropping pattern. He observed values of 76 % and 79 % for simultaneous and planting cowpea after 5 weeks, respectively.

5.8 Effect of planting date and row arrangement on 100-grain weight of cowpea

The results obtained show that planting date and row arrangement had significant interaction on 100-seed weight of cowpea. Delayed planting tended to increase 100-grain weight of cowpea. The 100-grain weight of cowpea was significantly increased for 1:1 and 1:2 row arrangements when planting date increased from the first to the second, and the third planting dates. In the 1:1 row arrangement, a change in planting date from the first to the second planting date increased 100-grain weight by 25 % while it increased by 32 % at the third planting date. In the 1:2 row arrangement, a change from the first to the second planting date increasing 100-grain weight by 17 % while it increased by 27 % at the third planting date. These findings are however contrary to what was the expected. The differences may be explained by the fact that delayed planting of cowpea (low canopy crop) subjected the crop to competition for light, moisture and nutrient resources. The increase in 100-grain weight between the second and third planting dates was nevertheless not different and indicates that there was less competition for nutrient resources. In sole cowpea, the increase in planting date had no significant effect on 100-grain weight of cowpea.

5.9 Effect of planting date and row arrangement on grain yield of cowpea

Grain yield of cowpea was not significantly affected by planting date probably due to the nature of crop variety used and the favourable growing conditions that prevailed during the season. Grain yield on the other hand was affected by row arrangement on the other hand showed significant effect on yield. The observed differences may be due to the degree of intra and inter species competition for light, nutrients and moisture resulting from differences in plant densities per unit area for each row arrangement treatment.

The findings of this study reveal that intercropping had significant effect on cowpea grain yield. The 1:1 row arrangement produced 30 % more grain yield compared to the 1:2 row arrangement, although the highest grain yield was observed in the sole crop treatment. Cowpea on the other hand suffered competition for light and other growth resources. The differences in cowpea yield obtained in the 1:1 compared to the 1:2 row arrangements is substantiated by the differences in plant populations between the two treatments. Hay and Walker (1989) while working with wheat demonstrated that the effect of increasing plant population resulted into increasing competition between adjacent plants. The resultant shading of plant tissue ultimately had profound effect upon the balance of plant growth regulators. The shading of cowpea by maize influenced the course of leaf area index development of cowpea, which consequently affected dry matter production and ultimate yield. Cowpea being a C_3 crop was expected to exhibit varying responses to yield as the amount and quality of solar radiation changed over time at each planting date. The results of this study also agree with the observations by Egli and Yu (1991) who observed significant reduction of seed yield in soybean due to shading. Rensburg (1998) obtained about 60 % higher cowpea grain yields when planting was delayed for 4 weeks. In contrast, Sesay (1999) reported significantly higher cowpea seed yield in simultaneous intercropping than in staggered intercropping in which yields were depressed consistently as sowing after maize was delayed. Further, Reddy and Visser (1997) working with millet also found that delaying sowing from simultaneous sowing with millet to 7 weeks after millet led to significantly lower grain yield of cowpea while grain yield of millet did not vary significantly with cowpea inter planting time.

The higher grain yield obtained in the 1:1 as compared to the 1:2 row arrangement is consistent with the findings of IITA (1975) as cited by Isom and Worker (1979) in which single alternate rows of maize and legume produced more yield than double or quadruple row plantings of the same crops.

5.10 Effect of planting date and row arrangement on growth and yield components of maize

The results of the study shows that growth and yield components of maize were not affected by either planting date or row arrangement. These observations are expected and agree with Adiku et al., (1995). He found that maize grain yield was not statistically different and attributed these observations to the fact that maize canopy was always above that of cowpea, and hence had a higher advantage over cowpea in terms of capturing solar radiation. Maize, being a more vigorous crop, had an advantage over cowpea in terms of moisture and nutrient capture since it was established earlier than cowpea. Similarly, Mate (1997), while working with forage legumes, reported that maize/forage legume combinations and their row arrangements did not increase maize grain yield.

5.11 Effect of planting date and row arrangement on land use efficiency and gross financial returns of maize/cowpea intercropping system

While the 1:1 row arrangement gave higher grain yield compared to 1:2 row arrangement, this study has also showed that land use efficiency measured by land equivalent ratio was higher in the 1:1 row arrangement compared to 1:2 row arrangement or sole crop treatment. The agronomic yield advantage of intercropping maize with cowpea ranged from 47% (LER = 1.47) in the 1:2 row arrangement to 51% (LER = 1.51) in the 1:1 row arrangement. This means that 47% and 51% more land is needed under sole crops to produce the same yield as in the intercrop. These findings are comparable to those reported by Fordham (1983), who observed a yield advantage of 44 % (LER = 1.44) when maize was intercropped with cowpea in Nigeria. Financial returns based on gross values show that 1:1 is better than 1:2 row arrangement. The study further shows that 37.4 % more financial gross returns are attainable when maize is intercropped with cowpea in a 1:1 row arrangement compared to the 1:2 row arrangement. Mwania, et al., (1989) found that gross margins for maize/bean intercropping were 14 % higher in the 2:1 maize/bean intercrop compared to sole maize. This means that intercropping, especially in the low input systems where availability of good arable land is scarce, intercropping is a more efficient farming practice.

Chapter 6

CONCLUSION

When cowpea was intercropped with maize on different planting dates and under three row arrangements, the growth parameters were variable. Leaf area, leaf area index and dry matter yield, were reduced while plant height increased when cowpea was planted late. Yield components of cowpea; harvest index, number of pods per plant and grain yield were affected by row arrangement. The 1:1 row arrangement gave 46 % more cowpea grain yield than 1:2 row arrangements in the intercrop without affecting growth, yield and yield components of maize (main crop). The 1:1 row arrangement produced 37.4 % more financial gross returns than the 1:2 row arrangement. The 1:1 row arrangement is therefore a better option towards meeting domestic cowpea requirements for consumption and sale. Intercropping maize with cowpea gave relative higher yield advantage (51 % and 47 % in 1:1 and, 1:2 respectively) than sole cropping. This study has demonstrated that planting cowpea in a 1:1 row arrangement two weeks after maize provides a better understanding and alternative to the present intercropping practices.

However, since the data for this study was for one season, further studies in this area should be conducted in future in order to generate long-term conclusive results.

Chapter 7

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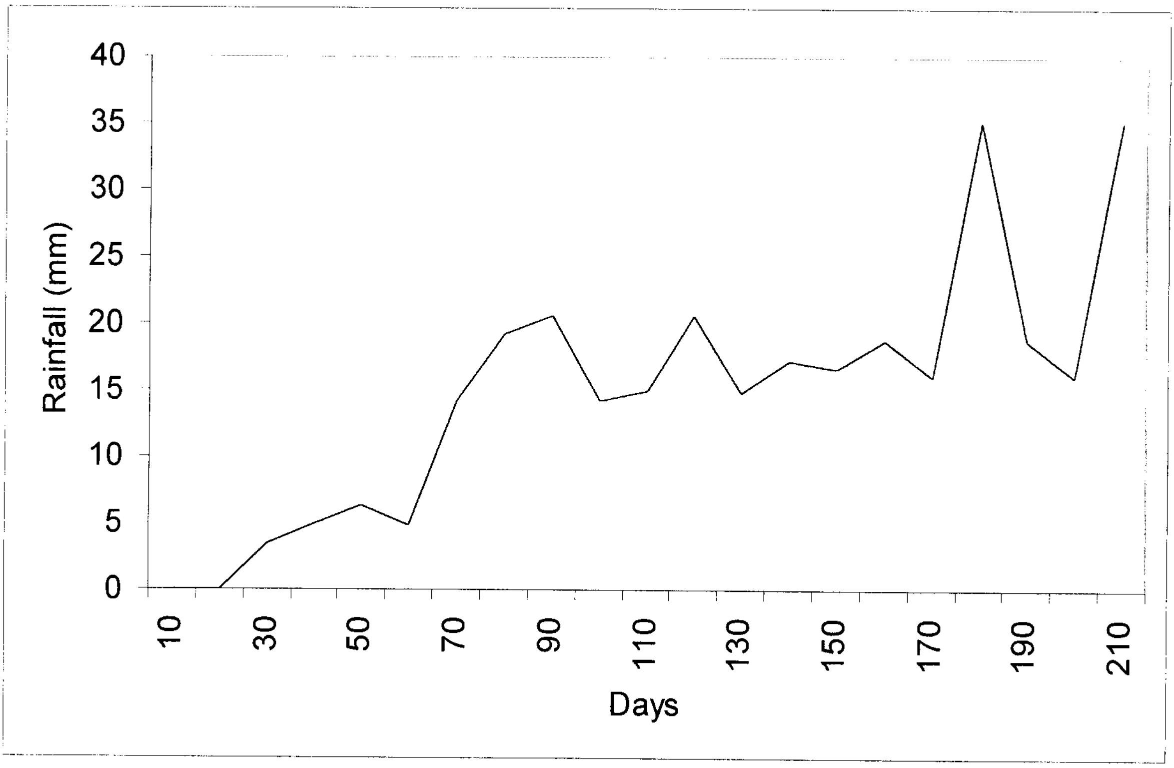
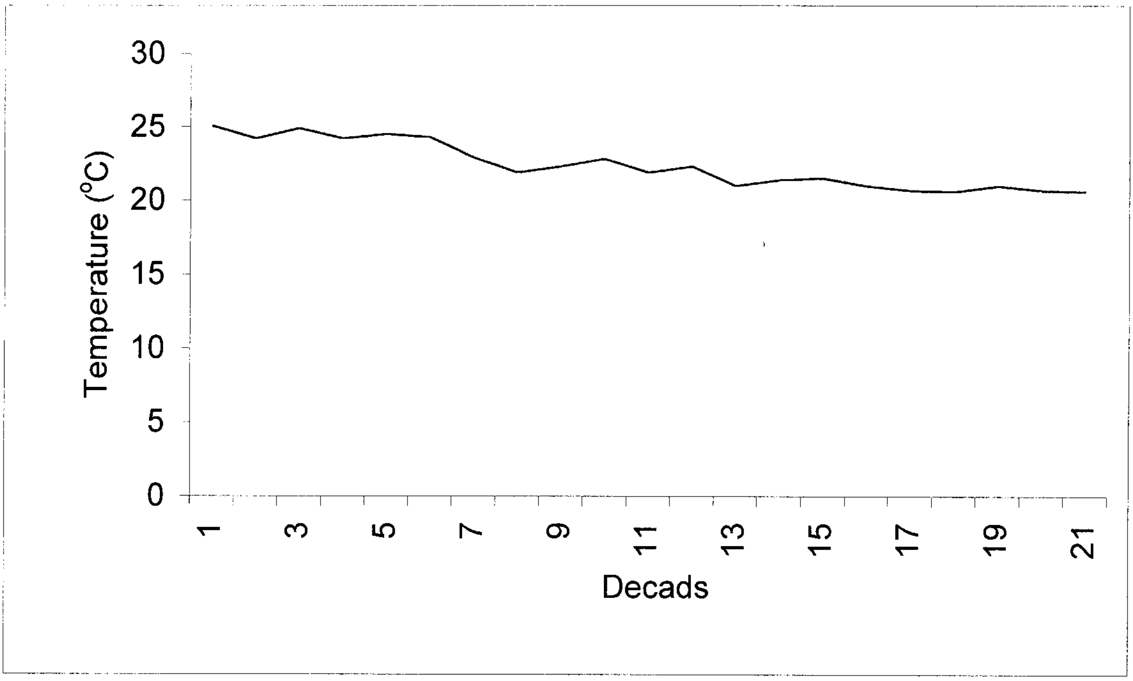
APPENDICES

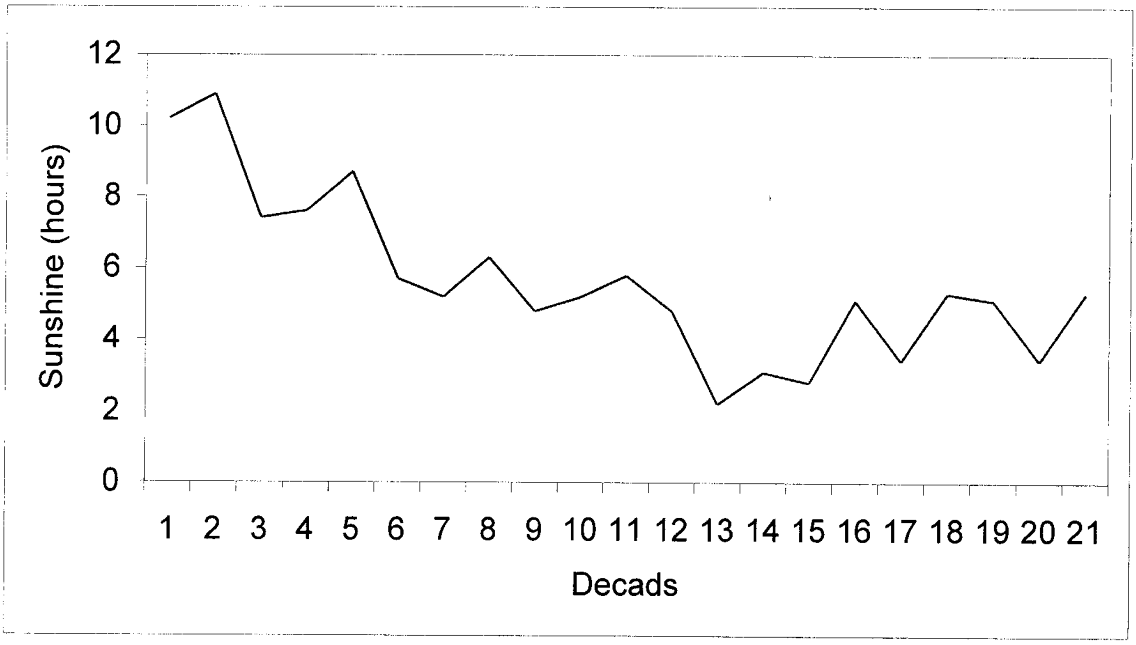
Appendix 1a. Average daily rainfall (mm) for the period October 2000-April 2001 at the University of Zambia School of Agricultural Sciences Field Station.



Appendix 1b. Average daily air temperature (°C) for the period October 2000-April 2001 at the University of Zambia School of Agricultural Sciences Field Station.



Appendix 1c. Average daily sunshine (hours) for the period October 2000-April 2001 at the University of Zambia School of Agricultural Sciences Field Station.



Appendix 2: Combined Analysis of variance and trend analysis for dry matter production (grammes) per plant for cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	53.15	26.58	0.62	
rep.plantdat stratum					
plantdat	2	562.31	281.16	6.59	0.054
Lin	1	213.42	213.42	5.00	0.089
Quad	1	348.89	348.89	8.18	0.046
Residual	4	170.65	42.66	2.31	
rep.plantdat.rowarrangt stratum					
rowarrangt	2	672.07	336.04	18.18	<.001
Lin	1	486.46	486.46	26.32	<.001
Quad	1	185.61	185.61	10.04	0.008
plantdat.row arrangt	4	150.95	37.74	2.04	0.152
Lin.Lin	1	3.39	3.39	0.18	0.676
Quad.Lin	1	76.02	76.02	4.11	0.065
Lin.Quad	1	58.79	58.79	3.18	0.100
Quad.Quad	1	12.75	12.75	0.69	0.423
Residual	12	221.83	18.49	1.46	
rep.plantdat.rowarrangt.*Units* stratum					
Crop stage	3	13564.23	4521.41	356.76	<.001
Lin	1	12860.65	12860.65	1014.76	<.001
Quad	1	701.91	701.91	55.38	<.001
Cub	1	1.66	1.66	0.13	0.719
plantdat.Crop stage	6	791.71	131.95	10.41	<.001
Lin.Lin	1	38.69	38.69	3.05	0.086
Quad.Lin	1	534.34	534.34	42.16	<.001
Lin.Quad	1	44.37	44.37	3.50	0.067
Quad.Quad	1	170.95	170.95	13.49	<.001
Lin.Cub	1	1.30	1.30	0.10	0.750
Deviations	1	2.06	2.06	0.16	0.688
rowarragt.Crop stage	6	728.44	121.41	9.58	<.001
Lin.Lin	1	443.84	443.84	35.02	<.001
Quad.Lin	1	216.73	216.73	17.10	<.001
Lin.Quad	1	35.10	35.10	2.77	0.102
Quad.Quad	1	28.77	28.77	2.27	0.138
Lin.Cub	1	1.08	1.08	0.08	0.772
Deviations	1	2.92	2.92	0.23	0.633
plantdat.rowarragt.c/stge	12	353.66	29.47	2.33	0.018
Lin.Lin.Lin	1	25.07	25.07	1.98	0.165
Quad.Lin.Lin	1	55.87	55.87	4.41	0.040
Lin.Quad.Lin	1	67.00	67.00	5.29	0.025
Lin.Lin.Quad	1	40.87	40.87	3.22	0.078
Deviations	8	164.86	20.61	1.63	0.139
Residual	54	684.37	12.67		
Total	107	17953.39			

CV (a) = 15.1% **CV (b) = 17.2%**

Appendix 3: Combined analysis of variance and trend analysis for leaf area (cm^2) per plant for cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	112746.	56373.	44.37	
rep.plantdat stratum					
plantdat	2	492769.	246385.	193.94	<.001
Lin	1	439292.	439292.	345.78	<.001
Quad	1	53477.	53477.	42.09	0.003
Residual	4	5082.	1270.	0.03	
rep.plantdat.rowarragt stratum					
rowarragt	2	35001.	17501.	0.35	0.711
Lin	1	34798.	34798.	0.70	0.420
Quad	1	203.	203.	0.00	0.950
plantdat.rowarragt	4	98986.	24747.	0.50	0.739
Lin.Lin	1	24076.	24076.	0.48	0.501
Quad.Lin	1	3.	3.	0.00	0.994
Lin.Quad	1	28204.	28204.	0.57	0.467
Quad.Quad	1	46703.	46703.	0.94	0.352
Residual	12	598903.	49909.	1.84	
rep.plantdat.rowarragt.*Units* stratum					
Crop stage	3	11360937.	3786979.	139.91	<.001
Lin	1	3564585.	3564585.	131.69	<.001
Quad	1	7795680.	7795680.	288.01	<.001
Cub	1	672.	672.	0.02	0.875
plantdat.Crop stage	6	1349693.	224949.	8.31	<.001
Lin.Lin	1	32342.	32342.	1.19	0.279
Quad.Lin	1	21857.	21857.	0.81	0.373
Lin.Quad	1	25802.	25802.	0.95	0.333
Quad.Quad	1	106855.	106855.	3.95	0.052
Lin.Cub	1	869510.	869510.	32.12	<.001
Deviations	1	293327.	293327.	10.84	0.002
rowarragt.Crop stage	6	91736.	15289.	0.56	0.756
Lin.Lin	1	3079.	3079.	0.11	0.737
Quad.Lin	1	1450.	1450.	0.05	0.818
Lin.Quad	1	134.	134.	0.00	0.944
Quad.Quad	1	1084.	1084.	0.04	0.842
Lin.Cub	1	61060.	61060.	2.26	0.139
Deviations	1	24929.	24929.	0.92	0.341
plantdat.rowarragt.C/stge	12	496332.	41361.	1.53	0.143
Lin.Lin.Lin	1	115695.	115695.	4.27	0.043
Quad.Lin.Lin	1	30756.	30756.	1.14	0.291
Lin.Quad.Lin	1	32846.	32846.	1.21	0.276
Lin.Lin.Quad	1	51044.	51044.	1.89	0.175
Deviations	8	265992.	33249.	1.23	0.301
Residual	54	1461637.	27067.		
Total	107	16103823.			

CV (a) = 1.7% **CV (b) = 18.6%**

Appendix 4: Combined analysis of variance and trend analysis for leaf area index per plant for cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.30530	0.15265	44.47	
rep.plantdat stratum					
plantdat	2	1.36625	0.68313	199.02	<.001
Lin	1	1.21862	1.21862	355.03	<.001
Quad	1	0.14763	0.14763	43.01	0.003
Residual	4	0.01373	0.00343	0.02	
rep.plantdat.rowarragt stratum					
rowarragt	2	0.09769	0.04884	0.35	0.710
Lin	1	0.09724	0.09724	0.70	0.419
Quad	1	0.00044	0.00044	0.00	0.956
plantdat.rowarragt	4	0.27437	0.06859	0.49	0.741
Lin.Lin	1	0.06690	0.06690	0.48	0.501
Quad.Lin	1	0.00000	0.00000	0.00	0.999
Lin.Quad	1	0.07803	0.07803	0.56	0.468
Quad.Quad	1	0.12945	0.12945	0.93	0.353
Residual	12	1.66640	0.13887	1.84	
rep.plantdat.rowarragt.*Units* stratum					
Crop stage	3	31.36710	10.45570	138.72	<.001
Lin	1	9.81020	9.81020	130.16	<.001
Quad	1	21.55435	21.55435	285.98	<.001
Cub	1	0.00254	0.00254	0.03	0.855
plantdat.Crop stage	6	3.76372	0.62729	8.32	<.001
Lin.Lin	1	0.08896	0.08896	1.18	0.282
Quad.Lin	1	0.06074	0.06074	0.81	0.373
Lin.Quad	1	0.07176	0.07176	0.95	0.334
Quad.Quad	1	0.29578	0.29578	3.92	0.053
Lin.Cub	1	2.42606	2.42606	32.19	<.001
Deviations	1	0.82044	0.82044	10.89	0.002
rowarragt.Crop stage	6	0.25523	0.04254	0.56	0.757
Lin.Lin	1	0.00922	0.00922	0.12	0.728
Quad.Lin	1	0.00389	0.00389	0.05	0.821
Lin.Quad	1	0.00059	0.00059	0.01	0.930
Quad.Quad	1	0.00319	0.00319	0.04	0.838
Lin.Cub	1	0.17222	0.17222	2.29	0.136
Deviations	1	0.06611	0.06611	0.88	0.353
plantdat.rowarragt.C/stge	12	1.38234	0.11520	1.53	0.143
Lin.Lin.Lin	1	0.32296	0.32296	4.28	0.043
Quad.Lin.Lin	1	0.08629	0.08629	1.14	0.289
Lin.Quad.Lin	1	0.08987	0.08987	1.19	0.280
Lin.Lin.Quad	1	0.14432	0.14432	1.91	0.172
Deviations	8	0.73891	0.09236	1.23	0.302
Residual	54	4.06999	0.07537		
Total	107	44.56212			

CV (a) = 1.7% **CV (b) = 18.6%**

Appendix 5: Combined analysis of variance and trend analysis for plant height (cm) per plant for cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	148.26	74.13	0.21	
rep.plantdat stratum					
plantdat	2	508.07	254.03	0.72	0.542
Lin	1	5.12	5.12	0.01	0.910
Quad	1	502.95	502.95	1.42	0.300
Residual	4	1419.96	354.99	5.65	
rep.plantdat.rowarragt stratum					
rowarragt	2	1965.92	982.96	15.66	<.001
Lin	1	536.28	536.28	8.54	0.013
Quad	1	1429.64	1429.64	22.77	<.001
plantdat.rowarragt	4	332.44	83.11	1.32	0.317
Lin.Lin	1	293.54	293.54	4.68	0.052
Quad.Lin	1	17.43	17.43	0.28	0.608
Lin.Quad	1	1.76	1.76	0.03	0.870
Quad.Quad	1	19.72	19.72	0.31	0.585
Residual	12	753.43	62.79	1.01	
rep.plantdat.rowarragt.*Units* stratum					
Crop stage	3	134838.48	44946.16	723.88	<.001
Lin	1	132690.44	132690.44	2137.04	<.001
Quad	1	151.23	151.23	2.44	0.124
Cub	1	1996.80	1996.80	32.16	<.001
plantdat.Crop stage	6	8931.13	1488.52	23.97	<.001
Lin.Lin	1	2188.43	2188.43	35.25	<.001
Quad.Lin	1	456.30	456.30	7.35	0.009
Lin.Quad	1	3550.44	3550.44	57.18	<.001
Quad.Quad	1	1056.03	1056.03	17.01	<.001
Lin.Cub	1	1236.54	1236.54	19.92	<.001
Deviations	1	443.39	443.39	7.14	0.010
rowarragt.Crop stage	6	633.89	105.65	1.70	0.138
Lin.Lin	1	63.59	63.59	1.02	0.316
Quad.Lin	1	377.01	377.01	6.07	0.017
Lin.Quad	1	12.75	12.75	0.21	0.652
Quad.Quad	1	104.58	104.58	1.68	0.200
Lin.Cub	1	39.40	39.40	0.63	0.429
Deviations	1	36.56	36.56	0.59	0.446
plantdat.rowarragt.C/stge	12	234.54	19.55	0.31	0.984
Lin.Lin.Lin	1	113.85	113.85	1.83	0.181
Quad.Lin.Lin	1	9.36	9.36	0.15	0.699
Lin.Quad.Lin	1	3.98	3.98	0.06	0.801
Lin.Lin.Quad	1	7.13	7.13	0.11	0.736
Deviations	8	100.22	12.53	0.20	0.989
Residual	54	3352.89	62.09		
Total	107	153119.01			

CV (a) = 6.6% **CV (b) = 8.1%**

Appendix 6: Analysis of variance and trend analysis for cowpea harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.017474	0.008737	0.47	
rep.plantdat stratum					
rowarragt	2	0.101252	0.050626	2.72	0.180
Lin	1	0.025689	0.025689	1.38	0.305
Quad	1	0.075563	0.075563	4.06	0.114
Residual	4	0.074481	0.018620	3.49	
rep.plantdat.rowarragt stratum					
rowarragt	2	0.086874	0.043437	8.13	0.006
Lin	1	0.012800	0.012800	2.40	0.148
Quad	1	0.074074	0.074074	13.86	0.003
plantdat.rowarragt	4	0.044681	0.011170	2.09	0.145
Lin.Lin	1	0.014700	0.014700	2.75	0.123
Quad.Lin	1	0.000900	0.000900	0.17	0.689
Lin.Quad	1	0.018678	0.018678	3.50	0.086
Quad.Quad	1	0.010404	0.010404	1.95	0.188
Residual	12	0.064111	0.005343		
Total	26	0.388874			

CV (a) = 21.6% **CV (b) = 20.0%**

Appendix 7: Analysis of variance and trend analysis for cowpea number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	6.770	3.385	0.45	
rep.plantdat stratum					
plantdat	2	101.370	50.685	6.76	0.052
Lin	1	14.222	14.222	1.90	0.241
Quad	1	87.147	87.147	11.62	0.027
Residual	4	29.997	7.499	2.19	
rep.plantdat.rowarragt stratum					
rowarragt	2	151.570	75.785	22.15	<.001
Lin	1	61.605	61.605	18.01	0.001
Quad	1	89.965	89.965	26.30	<.001
plantdat.rowarragt	4	13.144	3.286	0.96	0.464
Lin.Lin	1	2.341	2.341	0.68	0.424
Quad.Lin	1	2.103	2.103	0.61	0.448
Lin.Quad	1	3.674	3.674	1.07	0.321
Quad.Quad	1	5.027	5.027	1.47	0.249
Residual	12	41.053	3.421		
Total	26	343.903			

CV (a) = 27.6% CV (b) = 32.2%

Appendix 8: Analysis of variance and trend analysis for cowpea 100-grain weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	4.3657	2.1829	2.53	
rep.plantdat stratum					
plantdat	2	10.6865	5.3432	6.20	0.060
Lin	1	9.2880	9.2880	10.77	0.030
Quad	1	1.3984	1.3984	1.62	0.272
Residual	4	3.4487	0.8622	2.25	
rep.plantdat.rowarragt stratum					
rowarragt	2	2.6387	1.3193	3.45	0.066
Lin	1	0.4020	0.4020	1.05	0.326
Quad	1	2.2367	2.2367	5.85	0.032
plantdat.rowarragt	4	14.3605	3.5901	9.38	0.001
Lin.Lin	1	11.1169	11.1169	29.06	<.001
Quad.Lin	1	0.1534	0.1534	0.40	0.538
Lin.Quad	1	3.0450	3.0450	7.96	0.015
Quad.Quad	1	0.0452	0.0452	0.12	0.737
Residual	12	4.5905	0.3825		
Total	26	40.0906			

CV (a) = 4.6% **CV (b) = 5.3%**

Appendix 9: Analysis of variance and trend analysis for cowpea grain yield per hectare

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	83158.	41579.	0.31	
rep.plantdat stratum					
plantdat	2	404296.	202148.	1.52	0.323
Lin	1	12447.	12447.	0.09	0.775
Quad	1	391848.	391848.	2.94	0.161
Residual	4	532375.	133094.	1.16	
rep.plantdat.rowarragt stratum					
rowarragt	2	8921241.	4460621.	38.87	<.001
Lin	1	3775157.	3775157.	32.90	<.001
Quad	1	5146085.	5146085.	44.84	<.001
plantdat.rowarragt	4	1013367.	253342.	2.21	0.130
Lin.Lin	1	280089.	280089.	2.44	0.144
Quad.Lin	1	132819.	132819.	1.16	0.303
Lin.Quad	1	271556.	271556.	2.37	0.150
Quad.Quad	1	328904.	328904.	2.87	0.116
Residual	12	1377077.	114756.		
Total	26	12331513.			

CV (a) = 18.0% **CV (b) = 29.0%**

Appendix 10: Analysis of variance and trend analysis for maize number of cobs per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.03556	0.01778	0.47	
rep.plantdat stratum					
plantdat	2	0.04667	0.02333	0.62	0.584
Lin	1	0.00500	0.00500	0.13	0.734
Quad	1	0.04167	0.04167	1.10	0.353
Residual	4	0.15111	0.03778	2.27	
rep.plantdat.rowarragt stratum					
rowarragt	2	0.08667	0.04333	2.60	0.115
Lin	1	0.08000	0.08000	4.80	0.049
Quad	1	0.00667	0.00667	0.40	0.539
plantdat.rowarragt	4	0.22667	0.05667	3.40	0.044
Lin.Lin	1	0.01333	0.01333	0.80	0.389
Quad.Lin	1	0.01000	0.01000	0.60	0.454
Lin.Quad	1	0.04000	0.04000	2.40	0.147
Quad.Quad	1	0.16333	0.16333	9.80	0.009
Residual	12	0.20000	0.01667		
Total	26	0.74667			

CV (a) = 34.8% **CV (b) = 13.6%**

Appendix 11: Analysis of variance and trend analysis for maize 100-grain weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	9.852	4.926	0.23	
rep.plantdat stratum					
plantdat	2	37.852	18.926	0.90	0.477
Lin	1	2.000	2.000	0.09	0.774
Quad	1	35.852	35.852	1.70	0.262
Residual	4	84.370	21.093	4.54	
rep.plantdat.rowarragt stratum					
rowarragt	2	48.296	24.148	5.20	0.024
Lin	1	26.889	26.889	5.78	0.033
Quad	1	21.407	21.407	4.61	0.053
plantdat.rowarragt	4	75.926	18.981	4.08	0.026
Lin.Lin	1	0.083	0.083	0.02	0.896
Quad.Lin	1	14.694	14.694	3.16	0.101
Lin.Quad	1	56.250	56.250	12.10	0.005
Quad.Quad	1	4.898	4.898	1.05	0.325
Residual	12	55.778	4.648		
Total	26	312.074			

CV (a) = 12.5% **CV (b) = 10.2%**

Appendix 12: Analysis of variance and trend analysis for maize grain yield per hectare

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	1764695.	882347.	0.32	
rep.plantdat stratum					
plantdat	2	653879.	326939.	0.12	0.890
Lin	1	576112.	576112.	0.21	0.669
Quad	1	77767.	77767.	0.03	0.874
Residual	4	10887169.	2721792.	19.55	
rep.plantdat.rowarragt stratum					
rowarragt	2	885966.	442983.	3.18	0.078
Lin	1	365062.	365062.	2.62	0.131
Quad	1	520904.	520904.	3.74	0.077
plantdat.rowarragt	4	609834.	152458.	1.09	0.403
Lin.Lin	1	13444.	13444.	0.10	0.761
Quad.Lin	1	114.	114.	0.00	0.978
Lin.Quad	1	317298.	317298.	2.28	0.157
Quad.Quad	1	278978.	278978.	2.00	0.182
Residual	12	1671028.	139252.		
Total	26	16472570.			

CV (a) = 34.8% **CV (b) = 13.6%**