

**EFFECT OF PLANT POPULATION ON YIELD OF MAIZE AND
CLIMBING BEANS GROWN IN AN INTERCROPPING SYSTEM**

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DECLARATION

This thesis is my original work, and has not been presented for a degree in any other university.

Signed-----

Date-----

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This thesis has been submitted for examination with our approval, as the University supervisors.

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DR. SAMUEL KYAMANYWA

DEDICATION

This work is dedicated, with affection, to my wife Mary J. Kemigisha and our children
Patience, Denis, Annette, Beth, and Winnie.

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Abstract

Climbing beans (*Phaseolus vulgaris* L.) outyield bush types by more than 100 % are grown at medium to high altitude (approx. 1600 - 2300 m) on fertile soils. Staking materials has limited the adoption of climbing beans in suitable areas, such as Kabale district of Uganda. Production costs for the beans are normally high with dead support systems such as trellises (e.g., one made of wooden poles and sisal twine) and stakes. Therefore, there is a need to find ways of solving the scarcity of supports for climbing beans. Exploring the possibility of using cheaper alternatives, such as maize acting as live support for beans grown in a mixture, even though maize may be more competitive than beans for land and other factors. Although studies of maize+bean mixtures in which maize is the preferred support have been conducted elsewhere, intercropping with climbing beans as the main crop, has not been investigated. Therefore, a field experiment was conducted at Kachwekano, near Kabale town, with the objective of determining the compatibility of maize and climbing beans. The specific objective was to determine the appropriate plant population density (PPD) of the component species in the mixture that maximises bean yield because beans is the preferred crop in Kabale district.

Maize in the mixtures was planted in single rows spaced 1.0 m apart. Two rows of beans separated by 0.40 m were planted in the space between maize rows, at 0.30 m from each maize row. Within-row spacing for maize in mixtures was 0.40 m (25,000 plants ha⁻¹), 0.35 m (28,571 plants ha⁻¹), 0.30 m (33,333 plants ha⁻¹), and 0.25 m (40,000 plants ha⁻¹). For beans in mixtures, the within-row spacing was 0.50 m (57,142 plants ha⁻¹), 0.45 m (63,492 plants ha⁻¹), 0.40 m (71,428 plants ha⁻¹), 0.35 m (81,632 plants ha⁻¹), and 0.30 m (95,238 plants ha⁻¹). Pure stands of maize were planted at the recommended spacing of 0.75 m by

0.30 m giving a plant population of 44,444 plants ha⁻¹. Beans in pure stand was planted in paired rows separated by 0.60 m, with 0.30 m width between rows within-the-pair, and 0.20 m within-the-row spacing, giving a recommended population of 111,111 plants ha⁻¹. The treatments (twelve combinations for intercrops, and two sole crop treatments) were arranged in a randomized complete block design, and were replicated three times. Beans in intercrops was planted 10 days after emergence (DAE) of maize to ensure that maize plants would be ready to support those of beans. Maize genotype POOL 9A, and two climbing bean genotypes Umubano (G2333) and Gisenyi of varying seed size and yield potential, were used in the study. Umubano was used only in 1996b but not in 1997a due to its susceptibility to leaf rust (*Uromyces appendiculatus*) under dry spells, especially during the first rains season.

Maize population significantly affected bean leaf area (LA) and total dry matter (TDM), but had no significant effect on plant height, yield, and pods plant⁻¹ in both seasons. On the other hand, the effect of bean PPD on maize yield was significant only in 1997A, presumably due to drought stress. In 1996B, bean PPD had no significant effect on maize growth, yield and yield components, presumably because climbing beans were dominated by maize. Maize yield in intercrop was significantly lower (32 %) than the yield of sole maize in 1997A. The reduction in maize yield was associated with reduced grains cob⁻¹ and mean grain weight. A significant reduction in bean yield of 63 % and 71 % due to mixing with maize in 1996B and 1997A respectively, was associated with a significant reduction in pods plant⁻¹ by 39 % and 33 % in 1996B and 1997A, respectively. The highest bean yield of 1.075 t ha⁻¹ realised in 1996B was from a mixture of 24,576 and 66,666 plants ha⁻¹ of maize and beans, respectively.

A mean land equivalent ratio (LER) value of 1.26 was achieved, representing a yield advantage of 26 % over mean sole crop yield of both component species. Mean total income (TI) from the mixture was 32 % and 14 % higher than TI realised from sole crops of maize and beans respectively, in 1996B. The yield advantage was achieved presumably due to complementary resource use, with differences in maturity periods and rooting systems enhancing temporal differences in peak demand for resources. However, in 1997A, both yield and economic advantages from mixing maize and the beans were less, i.e., the system was superior to only maize monoculture.

In order to improve the competitiveness and hence intercrop yield of climbing beans, it is suggested that intercrop population should not exceed 25,000 maize plants ha^{-1} and 75,000 bean plants ha^{-1} , during seasons with ample rainfall. However, when drought stress is anticipated, then a 50:50 mixture (i.e., 22,222 maize plants ha^{-1} : 55,556 bean plants ha^{-1}) could be used. For sustainability of intercrop yields, a study on the response of the system to fertilizer needs to be undertaken, and net benefits determined using partial budgeting procedures. The effect of relative planting dates on performance of the mixture also deserves investigation, in order to fully exploit differences in maturity periods of the component species, thereby improving on their ability to maximise utilisation of available resources. Sorghum is more drought tolerant than maize and could, therefore, replace maize during seasons with unreliable rainfall, if compatible sorghum and climbing bean genotypes can be identified.

CHAPTER ONE

INTRODUCTION

Common beans (*Phaseolus vulgaris* L.) is a major source of protein for many farm families in Kabale district. It provides about 45 % of the total protein and 25 % of the total calories intake. Average per capita bean consumption is estimated to be 53 kg yr⁻¹ compared to a national average of 17 kg yr⁻¹ (Sengooba, 1990). However, farmers in Kabale realise very low bush bean yields ranging from 500 to 700 kg ha⁻¹ (UNBP, 1988), which cannot meet the demands of the rapidly growing human population of 246 persons km⁻² (MOFEP, 1992). Given the above situation, research is needed to increase bean yields. One way of increasing bean yields in Kabale would be the integration of climbing bean types in the cropping systems of the area, because the climbing bean types yield more than bush types (Graf *et al.*, 1991).

Climbing beans outyield bush types by more than 100 % when both are grown at high altitude (approx. 1800 to 2300 m) on fertile soils in Kisoro district (UNBP, 1990, 1991). The higher yield of climbing beans is associated with a longer growth cycle during which the crop is able to accumulate more total dry matter. Another reason for high productivity of climbing beans is ability to exhibit some tolerance to bacterial and fungal diseases (Kisakye and Niringiye, 1991). Graf *et al.* (1991) noted that climbing beans are generally less affected by diseases because the climbing growth habit is a disease escape mechanism, which allows better ventilation and limits the development of foliar pathogens. However, the high yield potential of climbing beans can be fully exploited only when the crop is adequately staked.

The Uganda National Beans Programme (UNBP) introduced promising climbing bean lines to farmers in Kabale district and involved the clientele in variety evaluation and production system development beginning in 1989. Although the difference in performance between climbing and bush beans was appreciated, interviews and discussions with the participating farmers revealed several production constraints, notably, scarcity of staking materials, and damage due to speckled "mouse-tail" birds, and rats (UNBP, 1990; 1991). Scarcity of suitable staking materials, such as Napier grass (*Pennisetum purpureum*), blackwattle, eucalyptus, bamboo (*Arundinaria alpina*), and other tree species which coppice easily), was ranked the main factor limiting the acceptance of climbing beans in Kabale district. Labour to cut, transport and place the stakes, further constrains expansion of climbing bean production. Therefore, alternative methods of supporting climbing beans, such as trellises, and maize or sorghum as live stakes for beans grown as intercrops with the cereal species, need to be investigated.

An appropriate maize + climbing bean intercropping system in which maize serves as a live support for the beans is a potential alternative for overcoming the production bottle-neck posed by scarcity of staking materials in Kabale district. One advantage of such a system is that a farmer harvests two crops, i.e., maize in addition to the beans, and it is cheaper to produce maize compared to producing or buying wooden staking materials. Mixed intercropping is common in Kabale. Bush beans are intercropped with either maize, sorghum, *Solanum* potatoes, sweet potatoes, field peas or bananas. Maize and beans are simultaneously planted (after mixing seed in the desired proportions) on the same land. Very low populations of maize are used because beans is the "main" crop and maize is a "bonus" crop. When beans

reach maturity, they are harvested and sorghum is sown into the maize. Sometimes sorghum is sown a few weeks before bean harvest. Bush beans are earlier maturing than climbing beans and, require higher density and different spatial arrangements. Therefore, a change of growth habit from bush to climbing bean is likely to create changes in both the temporal and spatial arrangements of the cropping system (Woolley and Davis, 1991).

Research has been done on maize+climbing bean association mainly in Central and Latin America (Davis *et al.*, 1984; Francis *et al.*, 1982 a & b) but, in all cases, it was assumed that farmers were willing to accept relatively low bean yields provided maize yield was not significantly reduced. However, in Kabale district, beans are of greater importance to farmers than maize. Therefore, Kabale farmers may not sacrifice much bean yield in favour of maize.

It is, therefore, important to identify maize plant densities which do not compromise the yield of climbing beans, when the two species are intercropped.

Research on maize+climbing bean intercropping in Uganda was initiated by Wortmann and Ugen (1988). However, the study was conducted in a mid-altitude environment (1200 m) at Kawanda Research Station, as opposed to cool highlands (1800 to 2300 m) in the Kabale highlands. To-date, the UNBP does not have a recommendation on maximizing bean production in a maize+climbing bean intercropping system. Therefore, this study was undertaken to determine the compatibility of climbing beans and maize when intercropped in Kabale district.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. General Aspects

No other human challenge is more critical than that of providing food for an ever-growing human population. Traditionally, increased food production has come from putting more land under cultivation. But in many areas of the world, for example in Asia, most of the land that can be economically cultivated is already in use (Francis, 1986). In the future, most of the extra food the world needs must come from higher productivity of land already being farmed.

A major share of this increase will likely come from improved crop cultivars, irrigation, fertilizers and pesticide use, which will support higher yields per unit area. Although intensive modern cultivation techniques and high inputs are required, these are not affordable by small farmers in many developing countries. However, multiple cropping or intercropping in the tropics and subtropics provides a suitable mechanism for increased crop production per unit area and time (Rao, 1986). Multiple cropping offers potential not only to increase food production but also to reduce soil erosion by keeping vegetation on the land for a longer duration of the year (Francis, 1986).

Multiple cropping as defined by Andrews and Kassam (1976) involves the intensification of cropping in time and space dimensions by growing two or more crops on the same field in a year. Multiple cropping may be achieved with sole crops and intercrops. Sole cropping represents crop intensification in time dimension only (Papendick *et al.*, 1976), whereas intercropping, which involves growing two or more crops simultaneously on the same field,

represents crop intensification in both the time and space dimensions (Andrews and Kassam, 1976).

Andrews and Kassam (1976) identified four variants of intercropping: (i) mixed intercropping or growing two or more crops simultaneously with no distinct row arrangement, (ii) row intercropping or growing two or more crops simultaneously where one or more crops are planted in rows, (iii) strip intercropping whereby two or more crops are grown simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically and, (iv) relay intercropping in which two crops are grown on the same piece of land but the second crop is normally planted between flowering and physiological maturity of the first crop (CIAT, 1986). Relay intercropping is practiced in central and south America for maize and beans, in Bangladesh for sugarcane relay planted in rice, and in temperate zones where farmers oversow legume species into cereals, such as maize, for nitrogen production and soil conservation (Francis, 1986).

Mixed intercropping is practised by the majority of subsistence farmers in the developing world. In Uganda, farmers mix seeds of species such as maize and beans in the desired proportions, and then sow the mixture by broadcasting. Relay intercropping is only feasible in regions where the growing season is long enough to avoid the effect of end-of-season drought on the second crop.

2.2. Importance of Intercropping

The importance of intercropping in African agriculture can be illustrated by the following proportions of crops grown in association with other crops, in Nigeria: cowpeas (99 %), groundnuts (95 %), melon (93 %), millet (90 %), cocoyam (86 %), cotton (80 %) and maize (76 %) (Francis, 1986). Patterns of crop culture are similar in Uganda, as reported by Jameson (1970): maize (84 %), beans (81 %), pigeonpeas (76 %), coffee (63 %), cowpeas (62 %), groundnuts (56 %), sorghum (46 %), and fingermillet (48 %). In Kenya, 94 % of beans are intercropped mainly with maize, whereas in Malawi, the proportions are: maize (94 %), groundnuts (90 %), cassava (89 %), millet and sorghum (97 %) (CIAT, 1986). Diversity is a common characteristic of these cropping systems, with more than one variety of each crop appearing on the farm. Specific intercropping systems vary widely among countries, among diverse climatic regions within countries, and with food habits of the people (Francis, 1986).

Intercropping systems have several advantages over sole cropping systems, and these include higher yield and efficient resource use. For instance, maize + bush beans had a yield advantage of 38 % (Willey and Osiru, 1972), whereas sorghum + bush beans had a yield advantage of 55 % (Osiru and Willey, 1972), compared to sole crop yields of the component species. A significant reduction in pest damage, such as Japanese and Mexican bean beetles in the maize + bean intercrops, contributed to land equivalent ratio (LER) values that were up to 30 % higher for intercrops compared to those for sole crops (Ugen and Wien, 1996). Yield and income from intercrops tends to be more stable than from sole cropping (Osiru, 1974; Francis and Sanders, 1978; 1986; Ugen and Wien, 1996).

2.3. Biological basis of yield advantages from intercropping

Yield advantages from intercropping systems are generally attributed to complementary utilization of environmental resources in time and space (Willey, 1979a; Barker and Francis, 1986). This increased productivity has been demonstrated for maize+beans and sorghum+beans (Willey and Osiru; Osiru and Willey, 1972); sorghum+pigeonpea and fingermillet+groundnut (Osiru and Kibira, 1981; Rao and Willey, 1983); sorghum+millet (Ssekabembe, 1983); and pearlmillet+groundnut (Willey and Reddy, 1981). The higher productivity of intercrops is attributed to better utilization of growth resources, particularly light because of marked differences in the heights of component crops (Osiru, 1974; Ssekabembe, 1983). Differences in maturity periods of the component crops is also a major factor contributing to yield advantages from crop mixtures. For example, Osiru (1974) reported that maturity difference was the major factor accounting yield advantages from mixtures of maize+beans, and maize+soybean; maize is later maturing while the legumes are earlier maturing. Similarly, in a study of intercropping sorghum and finger millet of different maturity periods, Ssekabembe (1983) reported higher total LER values (and hence yield advantages) from combinations of millet genotype Engenyi (earlier maturing, 120 days) with the taller sorghum genotypes of long maturity (125 cm, 140 days).

Although relatively little information is available on rooting systems, intercrop species with distinct rooting patterns should have the potential to more completely exploit available water and nutrients than either species grown alone (Snaydon and Harris, 1981; Smith and Francis, 1986). Intercropping has led to more effective use of limiting resources, such as inadequate

supplies of mineral nutrients and water in many tropical and subtropical areas where intercropping is practiced (Willey, 1979a; Davis *et al.*, 1986). Ugen and Wien (1996) reported that yield advantages of intercropping maize and bush beans was more expressed under low nitrogen level (no N applied) than under high nitrogen (160 kg N ha^{-1}). It seems that the more effective use of soil resources by root zonation (e.g., cereal + legume mixture) is at least as likely to lead to intercropping advantage as is more efficient capture of light (Smith and Francis, 1986). On the other hand, species vary in their temporal needs for water and nutrients and these variations may turn out to be more important than variations in root morphology (Smith and Francis, 1986).

Higher total yields from intercrops can also be due to better interception of light in a stratified crop canopy, consisting of the cereal above and the legume filling the gaps below (Davis *et al.*, 1986). Light use efficiency is improved when a C_4 plant such as maize, which has a high light requirement, is intercropped with a C_3 plant such as beans, with a lower light requirement (Woolley and Davis, 1991). The photosynthetic energy which is transmitted to the ground in the interval between planting and attainment of full cover in a row-crop monocrop represents a wasted resource (Clark and Francis, 1986). The utilisation of this resource by an interplanted crop may increase total resource use by the intercrop (De Wit, 1960).

Yield advantages from intercropping are also attributed to a reduction in damage due to insect pests, diseases and weeds (Altieri and Liebman, 1986). For example, incidences of Japanese beetles (*Popillia japonica*) and Mexican bean beetles (*Epilachna varivestis* Mulchant.) (Ugen and Wien, 1996), and bean stem maggot (*Ophiomyia phaseoli*) (Mvula and Nyirenda, 1995).

were reduced by intercropping maize and beans. In both cases, the incidence of the pests decreased as the proportion of beans in the mixture decreased. A reduced insect pest incidence in crop mixtures may be the result of increased parasitoid and predator population, availability of alternative food for natural enemies, decreased colonization and reproduction of pests, chemical repellency, masking and/or feeding inhibition from non-host plants, prevention of pest movement and/or emigration and optimum synchrony between pests and natural enemies (Altieri and Liebman, 1986).

The dispersion of host plants among other plant species also restricts the spread of pathogens. The presence of immune or resistant plants in the mixture impedes pathogen spread and increases the separation between susceptible plants. Documented evidence of disease buffering in various tropical intercropping systems includes less prevalence of *Ascochyta phaseolerum* and cowpea mosaic virus (CPMV) in cowpea interplanted with maize; decreased spread of rosette disease of groundnuts in a groundnut/bean mixture; and minimal viral attack on pigeonpea in sorghum/pigeonpea mixture (Altieri and Liebman, 1986). Altieri and Liebman (1986) reported that mixtures of different crop species buffer against disease losses by delaying the onset of disease, reducing spore dissemination, or modifying microenvironment conditions such as humidity, light, temperature, and air movement.

Weeds not only compete with crops for light, water and nutrients, but they can also act as alternate hosts to pests and pathogens that cause damage to crops. Intercropping has potential in weed control because a mixture of crops can capture a greater share of available resources than sole crops, pre-empting their use by weeds (Altieri and Liebman, 1986). The weed-

suppressing ability of intercrops will depend on the component crops, the cultivars selected, and spatial arrangements of the crops. For instance, Wortmann (1993) reported that bean genotypes of Types II and III (spreading types), generally suppressed weed growth better than Type I genotypes (erect type); weed suppression (lower plant weight, leaf weight and leaf size of weeds) was most often related to high bean LAI.

2.4. Methods of assessing yield advantages from crop mixtures

It is essential to determine whether a given intercropping combination is better than sole cropping and whether one intercropping practice is better than another (Mead and Willey, 1980). There are two different objectives for which indices such as land equivalent ratio (LER), income equivalent ratio (IER) or monetary advantage (MA) have been proposed. The first is the assessment of the benefit, or overall advantage of intercropping. The second is the assessment of the relative performance of the various intercrops, including the concept of dominance or competitiveness (Mead, 1986). Mead points out that these two objectives are conceptually different.

Land equivalent ratio (LER) is the area needed under sole cropping to give the same amount of yield as one hectare of intercropping, at the same management level (Andrews and Kassam, 1976). It can be obtained by summing up the fractions of the yields of the intercrops relative to their sole crop yields. Land equivalent ratio is a common way of evaluating the relative yield advantage of an intercropping system compared to sole cropping. For instance, LER value of 1.2 indicates a yield advantage of 20 % over sole crops. Mead and Willey (1980) and

Willey (1985) all indicated that LER is a useful measure in providing a standardized basis so that crops can be added to form "combined" yields, and the LERs can be compared between different situations and even different crop combinations (Mead, 1986). Willey (1979a) also noted that comparisons between individual partial LERs (LA and LB) can be a very useful indicator of the competitiveness of the component crops.

Although LER is a very useful measure of intercrop advantage, it may give a wrong impression of yield advantages from intercropping systems. Large values may be obtained due to lower yields of corresponding sole crops (Mead and Willey, 1980) as a result of insect pest, disease and weed infestation (Altieri and Liebman, 1986). It is, therefore, important to understand the nature of the experiment being carried out and use the most appropriate method to analyze the results. For example, Huxley and Maingu (1979) indicated that all intercrop yields should be compared with the sole crop at its optimum population and spacing. This is to avoid over- and under-estimating the advantages of the intercrop systems compared to sole crops.

Income equivalent ratio (IER) or monetary advantage (MA), is the amount of land under sole cropping required to produce the same gross income as one hectare of intercropping at the same management level (Andrews and Kassam, 1976). It is the conversion of LER into economic terms, i.e., the product of yield multiplied by the price of product is used in the computation of IER values. Since prices of produce tend to vary with seasons, a range of price ratios for the component species in maize+bean mixtures is employed to determine whether intercropping is superior to sole cropping of either component crop (Osiru, 1974;

Francis and Sanders, 1978).

One of the main indices of dominance, is the competition ratio, C.R. (Willey and Rao, 1986) and defined as:

$$C.R. = \frac{L_A}{L_B}$$

where L_A and L_B are the partial LERs of the intercrop components. A partial LER value of 0.5 for both species gives a C.R. of 1:1 indicating lack of dominance of one species over another. On the other hand, a value of C.R. lower than 1:1 indicates that species A is dominated by species B, whereas a value higher than 1:1 indicates that species B is dominated by species A.

The theoretical basis for studying yield stability was set forth in two papers (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966). Yield stability is measured in terms of variance. Hence, systems showing less variation of yield are considered to be more stable (Mead, 1986). Statistically the description of relative variability, which does seem much more appropriate than absolute variability (measured by sample variance or standard deviation) for most biological variations, is much better achieved through the use of a logarithmic scale (Mead, 1986). Mead suggested the standard deviation of the sample of log-transformed yields as the best simple statistic of stability based on variation.

It is desirable when comparing intercropping and solecropping systems that yield data from the same set of location/years should be used in pairs for both systems (Mead, 1986). Regression

analyses of genotype response to an environmental index has been used frequently by plant breeders to evaluate stability (Eberhart and Russell, 1966; Smith and Francis, 1986; Peterson *et al.*, 1992). A genotype (or cropping system) is said to be stable across environments (or seasons) if it has a low mean value, a *b*-value from regression as close to zero as possible, and has minimal deviations from regression (Eberhart and Russell, 1966). In other words, a genotype (or cropping system) with optimal stability should show small deviations from mean performance across environments (or seasons) with a low *b*-value (Peterson *et al.*, 1992).

Little work has been done on the stability of crop mixtures. The underlying assumption on the stability of crop mixtures is that when one crop in a complex mixture suffers short-term stress from drought or temperature, or from an insect or disease problem specific to that crop, then another crop will compensate by using available growth resources and yield proportionally more (Smith and Francis, 1986). Two studies, one conducted in Colombia on maize and beans (Francis and Sanders, 1978) and another in India on sorghum and pigeon pea (Rao and Willey, 1980), have shown that intercrops were more stable than the monocultures. Francis and Sanders (1978) noted that the bean monoculture system involved higher risks, which was reflected in a greater standard deviation.

Net returns from mixtures depend on the prices of the component crops and the proportions of the crops in the mixture. For example, when intercrop and monocrop systems of climbing beans and maize were evaluated over a range of prices, Francis and Sanders (1978) found sole beans to be more profitable over a wide range of price-ratios if the farmer used an intensive package of technology. When net income (NI) was plotted against price ratio, the

maize+bean intercrop system was more profitable below a 4:1 bean:maize price ratio, whereas the monoculture climbing bean system was found to be more profitable above this ratio. However, risk was higher in the monoculture beans than in the mixtures. Therefore, the probability of maintaining a consistent income with relatively lower investment was highest for maize/bean mixture depending on the relative prices and cost of production of the component crops (Francis and Sanders, (1978). A range of price ratio indices is used because prices fluctuate from season-to-season, year-to-year; it is almost invariably found that the ratio of the LER values is well in the centre of the price ratio range (Mead, 1986).

In intercropping systems, net income advantages appear to be secondary to risk reduction, particularly in farming systems where subsistence is an important objective of the farmer. The sources of reduced risk in intercropping as compared to sole cropping are usually attributed to both a reduced variance in output and/or net income from year-to-year, and location-to-location and a higher probability of avoiding complete crop failure (Lynam *et al.*, 1986). Land equivalent ratio and MA enable a researcher trying to improve on traditional intercropping systems, to draw meaningful conclusions and, therefore, make appropriate recommendations on intervention (Ugen and Wien, 1996).

2.5. Agronomic factors influencing performance of intercropping systems.

2.5.1. Plant population and spatial arrangement

The response of intercrops to plant population and spatial arrangement is as important as for sole crops. For sole crops, plant population defines the number of plants per unit area which

determines the size of the area available to the individual plant, whereas spatial arrangement defines the pattern of distribution of plants over the ground which determines the shape of the area available to the individual plant (Willey, 1981).

For intercropping, both total population (sum of all components) and component population have to be distinguished. In terms of plant population "pressure" on resources, a single plant of one crop is seldom directly comparable with a single plant of another crop (Willey and Osiru, 1972). This issue can be overcome by regarding optimum populations of sole crops as comparable and calculating an equivalence factor according to the ratio of their optimum populations in pure stand (Willey and Osiru, 1972). If they are taken as 100%, component populations can then be expressed on a relative basis, e.g., a 50:50 % mixture proportion indicates that each component species occupies one-half of the total land area available for sole cropping (Willey, 1981).

With regard to spatial arrangement of intercrops, two factors have to be distinguished. The first factor is the proportional areas allocated to each component crop at sowing time.

Often proportional areas are directly related to component populations: thus, if a 50:50 component population is achieved by having equidistant alternate rows, proportional areas will also be 50:50. However, this direct relationship does not have to apply, and component populations and proportional areas can be varied independently (Willey, 1981). An example of this is where a "main" crop is grown at full sole crop population, but its spatial arrangement is manipulated to create space for an additional intercrop – a "bonus" crop. This is sometimes achieved by "pairing" the rows of the dominant component species. For instance, a

sorghum/soybean intercrop with sorghum sown in paired rows (30 cm within-pair) 90 cm apart with two rows of soybean in the 90-cm space, had relatively higher yields of intercrops than did other planting geometries (Singh, 1981). This was attributed to better plant growth and more pods plant⁻¹ of intercropped soybean as a result of penetration of more solar radiation. The sorghum/soybean intercropping system also had appreciably higher gross income than from a solid stand of either crop.

The second factor is how proportional areas are arranged with respect to each other. This is usually a matter of how "intimately" the crops are mixed. Thus, an intercrop with a proportional area of 50:50 can be arranged as (1) alternate plants within the row, (2) alternate rows, (3) alternate "double" rows, and so on (Willey, 1981).

Contrasting results from several studies on plant population and spatial arrangement have been reported in the literature. For instance, by maintaining a constant plant population for maize in a maize+bean intercropping system, and using different plant geometries, Rajat De and Singh (1981) noted no significant difference in maize yield whether the rows were spaced 60 cm or 120 cm apart. In the intervening space, soybean was planted, which increased the LER by 54 percent. Osiru and Kibira (1981) reported no striking difference in seed yield between the within-row and the alternate-row arrangements for sorghum+pigeonpea and millet + groundnut mixtures. Similar findings were reported by Evans (1960), and cited by Osiru and Kibira (1981), for groundnut intercropped with either maize or sorghum. In all these cases, plant population rather than planting geometry had a determinant role on the yielding ability of the crops. On the other hand, Bodade (1964, cited by Osiru and Kibira 1981), reported

more yield advantage from mixing groundnuts with sorghum in the same row than when planted in alternate rows.

Maize+climbing bean, or maize+bush bean with seed planted in the same hill had higher yield advantage than planting in alternate hills in the same row, or alternate rows (Francis *et al.*, 1982a, 1982b; Rweyemamu, 1989; Chemining'wa and Nyabundi, 1994). Ssekabembe (1983) also reported that it was more beneficial to intercrop sorghum + finger millet species in a 50:50 mixture proportion by using a "1 row sorghum : 2 rows millet" spatial arrangement.

Using all combinations of three sorghum genotypes of differing heights, the yield of a short genotype in its mixture with a taller genotype was considerably improved by a change in the planting pattern from the single alternate row to double and triple alternate row arrangements (Osiru, 1974). Another example of spatial arrangement manipulation is from Colombia, where results from an Experiment Station in Antioquia showed that a change from four maize plants and two bean plants per hill spaced 1 m x 1 m (a typical farmers' planting arrangement), to two maize plants and two bean plants spaced 0.5 m between hills (row width and maize density unchanged; bean density doubled) increased the yield of new early maturing bean cultivars without affecting maize yield or causing lodging (Woolley and Davis, 1991).

Balance of the species in the final yield may be determined by the dietary requirements of the grower's family in the case of subsistence foodcrops, or it may be determined by the prevailing economic situations in the case of the more commercially-oriented farmers. In either case, the optimum mixture can be described as that which gives maximum total yield and, at the same time, maintains the required yield balance of the two species (Osiru, 1974). Using price ratios

of 1:1, 1:2, 1:3, and 1:4 for the relative values of cereal:legume, Osiru (1974) showed that as the legume becomes of relatively higher value, the optimum mixture contains an increasing proportion of this species.

2.5.2. Relative planting dates and differences in maturity periods

Early maturity for monoculture systems is sometimes desirable, as it allows intensification of cropping over time, whereas a combination of early and late maturing crop species is desirable in intercropping systems (Smith and Francis, 1986). However, farmers face difficult decisions on when to plant component crops in a mixed intercrop with several species having overlapping cycles and different cultural requirements. Adjusting planting time is an important criterion for avoiding competition between crops with the same growth habit, i.e. similar growth rates in time and space. Staggering planting time so that peak periods of growth do not coincide helps to realize the yield potential of both crops (Rajat De and Singh, 1981).

The effects of temporal differences in planting and crop life cycles were reviewed by Willey (1979b) who described the concept of "temporal complementarity." His description may be interpreted as "the greater the difference in maturity and growth factor demands of the crop components, either because of genetic differences or manipulation of planting dates, the more opportunity for greater total exploitation of growth factors and overyielding" (i.e., a total production greater than that of monoculture of each crop).

In areas of central and south America where the rainfall pattern permits, bush or climbing beans are planted between tasselling and physiological maturity of maize, in order to avoid end

of-season drought stress on beans (Davis, 1989). When maize was simultaneously intercropped with beans, maize yield was reduced by 15 to 30 %, whereas there was no yield reduction with relay cropping (Davis and Garcia, 1983). Using a maize hybrid, ICA H-207, and four bean cultivars of contrasting plant types (Type I, determinate bush habit with erect stem and branches; Type II, indeterminate bush habit with erect stem and branches; Type III, indeterminate bush habit with weak and prostrate stems and branches, and ability to climb; and Type IV, indeterminate climbing habit). Francis *et al.* (1982) reported that, compared to simultaneous intercrop planting, beans planted 10 days after maize were reduced in yield by 21 - 31 %. The lowest and highest yield reduction occurred in Types I and III, respectively. On the other hand, planting beans 10 days before maize increased bean yields significantly by 60 - 89 % in Types I - III compared to the simultaneous date. However, bean yields were significantly reduced by 56 % in the early planting of Type IV beans with maize; the vigorous-climbing bean (P589) shaded and retarded the growth of maize, destroyed its own support system, and produced lower yields. Maize yields were significantly reduced by an advance intercrop planting of beans either 5 or 10 days, with the exception of Type I beans. Simultaneous intercrop planting of bean Types I, II and III did not affect maize yield, whereas a similar planting of Type IV significantly reduced maize yield by 22 percent.

Francis *et al.* (1982) recommended simultaneous planting of maize and climbing beans to keep maize yields near monoculture levels under Colombia's environment. However, in Uganda, maize was not ready to support the beans when both were planted simultaneously or beans planted 10-14 days after planting (DAP) of maize, and this resulted in significant reduction in yield of both components (Wortmann and Ugen, 1991). When planted at the same time with

maize, lower bean yields were obtained due to competition for growth factors (light, water and nutrients) compared to relay intercropping in which plants only compete for light (Thung and Erazo, 1991). On the other hand, advanced maize planting causes an even greater proportionate reduction in bean yield, due to early competition and shading of the beans (Barker and Francis, 1986).

From the above contrasting results, it would appear more appropriate if climbing beans are planted between one to two weeks after maize emergence, in order to avoid a situation whereby maize is overwhelmed (pulled over) by the beans. The presence of a support such as maize stimulates climbing in beans, thus exposing the latter to more sunlight than is the case with bush beans. Thus, Davis *et al.* (1986) reported that genotypes that were able to climb suffered less reduction in yield and harvest index due to competition from maize.

2.5.3. Choice of crop combinations

Several combinations of species may be grown in mixtures depending on climate, local preferences, and other site-specific factors. For instance, cereal+pulse mixtures such as those of maize+beans are common in Latin America and Eastern Africa; maize+soybean mixtures are found in Latin America and India; while sorghum+pigeonpea mixtures are prevalent in India (Francis, 1986).

The degree of competition or complementarity of associated crops is determined by the morphological and physiological characteristics of the cultivars, and by their agronomic

management (CIAT, 1986). These characteristics operate at both species and varietal levels.

Canopy properties such as plant height, leaf area index and leaf area density may influence the micro-climate by altering light interception and distribution (Evans and Wardlaw, 1976; Otuman and Welch, 1989).

Plant height is a morphological trait for which considerable within-species variability exists.

One intuitively expects plant height to affect crop performance in crop mixtures. The shading of a legume in an intercrop is affected by the height of the associated crop, time of planting and harvesting of the taller cereal crop, and by the density and spatial arrangements of the intercrops (Calavan and Weil, 1988). Reducing the height and thus the shading or competitive effect of a dominant crop generally allows increased productivity of the lower story crops (Andrews, 1972a; Davis and Garcia, 1983; Davis *et al.*, 1984:). For example, soybeans yielded more in association with short maize than with tall maize (Smith and Francis, 1986); intercrops of sorghum variety Namateera (tall, late maturing) and millet variety Engenyi (short, early maturing), and sorghum variety SB65 (short, early maturing) with millet variety WC30 (tall, late maturing), gave higher total LER and hence yield advantages than mixtures with other combinations (Ssekabembe, 1983).

Maize genotypes with short internodes and broad leaves tend to shade beans more than genotypes with long internodes and narrow leaves (Davis, 1989). For example, Woolley and Rodriguez (1987) and cited by Woolley and Davis (1991), found that the very tall (2.5 - 3.0 m), late maturing maize cultivars that farmers in Latin America use for bush bean associations allowed good yields. This was partly due to better light penetration (such maize cultivars have

many leaves, but they are still well spaced on the stalk), and the possibility that late-maturing maize allows beans to enter pod-filling before starting to compete seriously with them for soil nutrients and water (Woolley and Davis, 1991). Smith and Francis (1986) noted that a later and leafier cowpea cultivar reduced maize yield in association more than an earlier cowpea with lower leaf area index. Vertical separation of leaves is a feature that affects not only light penetration into the crop, but also its supply with CO₂ (Evans and Wardlaw, 1976). When other environmental factors (e.g., water supply or irrigation, fertilizer, herbicide and pesticide application) are favourable, radiation availability to a crop may limit productivity (Otuman and Welch, 1989).

When beans are intercropped with maize, growth habit or climbing ability plus reduced branching of the main stem, are important attributes which enable climbing beans to compete favourably with maize (Davis *et al.*, 1984). Climbing ability is found to be the most important character determining competitive ability, and this is in turn correlated to plant height and biomass production (vigour) (Woolley and Davis, 1991). In an economic analysis of combinations of 3 genotypes of maize (short, medium, and tall stature), and 10 genotypes of beans (semi-climbing, medium climbing, and aggressive climbing types), the best net income was obtained with the medium-stature maize (Suwan-1) associated with the aggressive climbing beans (Davis and Garcia, 1983). Climbing bean genotypes 2.3 to 2.7 m tall caused 16 to 24 % stem lodging and only 4 to 6 % root lodging, resulting in 16 to 33 % reduction in maize yield (Davis *et al.*, 1986). The competitive relationship between maize and beans is reflected in a strong negative correlation between biomass and grain yield production of the two crops. Maize yield reduction was found to be positively associated with bean yield, when the two

were intercropped. Therefore, reduction in maize yield can be used as an independent measure of bean competitive ability (Davis *et al.*, 1986). Osiru (1974) also noted that certain tropical legumes, e.g., cowpeas (*Vigna sinensis*) and Calopo (*Calopogonium mucunoides*), did not affect the yield of maize whereas climbing legumes such as Mucuna (*Mucuna utilis*) and Popondo (*Phaseolus lunatus*) were found to be detrimental to the maize. It was suggested that the climbing habit of the legumes was the cause of the significant reduction in maize yield.

According to Osiru (1974), differences in maturity periods of the component crops is probably the major factor contributing to the yield advantages in crop mixtures, and is probably more important in the maize+bean mixtures than in the sorghum+bean mixtures, simply because the factor accounted for the greater proportion of the yield advantages of the mixtures of maize and beans. Similarly, the millet in the mixture of equal proportion (50:50) of sorghum and millet was able to develop larger grains than the pure stand probably because after removal of competition from the sorghum (variety SB65) when the latter was harvested, the millet was able to compensate in the remaining growth period and have a better grain fill than the pure stand (Ssekabembe, 1983). Osiru (1974) also reported large advantages of mixing maize and early soybean and very little advantages from mixing maize and late soybean.

2.5.4. Soil fertility management in intercrops

Mkandawire *et al.* (1989) noted more recent definitions of intercropping which have incorporated a measure of intercrop competition, whereby two crops growing simultaneously in the same field experience intercrop competition apart from the intracrop competition that already exists in sole crops. The degree of competition is influenced by

crop species, crop density, weed species and density, insect pests, diseases, soil moisture and fertility (Francis, 1986). Decisions that influence the capacity of the soils to provide plant nutrients are not limited to fertility inputs; climate, soil properties (physical, chemical and biological), tillage methods and timing, species selection, spatial and temporal planting patterns, pest and weed control practices - all have a bearing on the fertility status of soil and management decisions (Francis, 1986). Farmers combine species with different above-ground and below-ground morphologies, varying maturation dates, and varying nutrient uptake patterns in order to more completely utilize the plant growth environment (Francis, 1986). These morphological or physiological differences that are the basis for benefits from intercropping also pose difficulties in soil fertility management (Francis, 1986).

The amounts of fertilizers recommended for application depend largely on the total nutrient requirement of the crop and how much is applied by the soil, whereas time of fertilizer application depends a great deal on the pattern of growth of crops in intercropping. The rate of nutrient uptake varies with component crops as well as with plant age, and the period of maximum nutrient demand of one component crop may not necessarily coincide with that of the other crop (Mkandawire *et al.*, 1989). Sole crop data on nutrient requirements and accumulation patterns though applicable to less intensive forms of intercropping (e.g., sequential, strip and relay intercropping), may be irrelevant in intensive intercropping systems because the total nutrient uptake in harvestable products must be greater under intercropping if combined yields are to be significantly increased (Mkandawire *et al.*, 1989). Mkandawire *et al.* (1989) noted evidence of greater nutrient uptake by intercrops for N, P, K, Ca, and Mg, which suggests that intercropping systems

remove more nutrients than comparable sole crops. This leads to more rapid depletion of natural soil fertility or the need for higher fertilizer application rates. Francis (1986) observed that in most cases, basic nutrient uptake patterns are similar for either sole or intercropped situations (e.g., N response curve shape was the same for sole versus intercropped maize in a maize/soybean mixture). However, he noted contradicting reports which suggest that total uptake of nutrients and yield is decreased for each individual crop in an intercrop system, although the total combined uptake may be greater than in monoculture. This suggests that there is competition for nutrients among component species grown in a mixture.

The extent of plant interactions, and therefore competition for nutrients, increases with intensity of the intercropping system. The most intense intercropping situation where competition would be most acute is in mixed intercropping where root systems and leaf canopies of unlike species are in immediate proximity on all sides such as in intercrop systems involving maize and climbing beans in Latin America (Francis, 1986). Fertilizer management may influence the balance between crops, overall biomass production, total grain yields, total energy production, and many other parameters.

Woolley and Davis (1991) noted that the most soil nutrient liable to competition in intercrops is N, because NO_3^- is mobile and depletion zones around roots can extend as far as for water. Only at the highest plant densities will there be competition for the other macronutrients, which are adsorbed onto soil particles and move by diffusion. In the nitrogen nutrition of legume/cereal intercropping systems, nitrogenous fertilizer

applications may seriously decrease legume yield and be less economical in the long term than fertilizing the secondary crop (grain legume) to provide maximum return of biologically fixed N via residues to subsequent primary crops (Francis, 1986). When maize is grown with an associated legume crop, fertilizer N applications increase the yield of maize and usually the legume (e.g., beans) does not respond or yield is significantly reduced (Baguma *et al.*, 1993; Chemining'wa and Nyabundi, 1994; Ugen and Wien, 1996). Chemining'wa and Nyabundi (1994) attributed the increase in maize yield at low N (0 and 50 kg N ha⁻¹) to N excretion by the legume during growth or to N released during decomposition of dead legume roots and nodules. They noted that the extent to which a crop may benefit from beans may be influenced by the life span of the maize crop compared to that of beans. The reduction in yield of the legume is ascribed to greater competition for light from improved maize growth; there is increased shading by maize leaves which grow better under fertilization (Baguma *et al.*, 1993). Watson (1952) noted that increase in leaf area (LA) produced by application of a nitrogenous fertilizer results from increase in both leaf number and leaf size. Nitrogen supply affects both cell division and cell extension in the leaf and, because of this multiplicity of effects, application of nitrogenous fertilizer tends to increase LA throughout the whole growth period (Watson, 1952). The legume also depends on the applied fertilizer or nitrogen released by the soil because its N-fixing capacity is inhibited by high levels of applied N (Ingram and Swift, 1989; Chemining'wa and Nyabundi, 1994). Woolley and Davis (1991) noted that application of N inhibits N-fixation in the bean even when maize and beans are planted in separate rows. Chemining'wa and Nyabundi (1994) observed that depression of N-fixation under high soil N is accomplished through inhibition of attachment of rhizobia to root hair.

abortion of infection thread, slowing of nodule growth, inhibition of fixation within the established nodules, and more rapid senescence of nodules when either NO_3^- or NH_4^+ is added. Woolley and Davis (1991) noted that although more rapid nodule development may occur in beans associated with those of maize, post-flowering fixation may be curtailed because of competition for light. They also observed that lower soil temperatures under maize may also account for improved nodulation. Neither maize nor beans responded to N application or inoculation (with efficient strains of *Rhizobia phaseoli*) alone, but responded to inoculation combined with N application (Woolley and Davis, 1991). By achieving the correct balance of N application and inoculation, it may be possible to increase yields of both maize and beans despite interspecies competition (Woolley and Davis, 1991).

Mkandawire *et al.* (1989) reported that across fertilizer levels (low – high) there was no significant difference in P uptake between intercropped and sole maize, and that intercropped cowpeas uptake of P was linear up to 40 days after planting (DAP), indicating that competition for P between maize and cowpeas begun at cowpea flowering stage. Results from on-farm studies on fertilizer of a maize/climbing bean association in Colombia indicated that maize did not respond to P, but bean yields increased steadily with 11.3 – 56.7 kg ha⁻¹ elemental P applied (Woolley and Davis, 1991). Watson (1952) reported that P_2O_5 application increased LA of cereal crops mainly by increasing tillering, and its effect was greatest near the time of maximum shoot number. Subsequently it declined, falling to zero at about the time of maximum LA. This suggests that leaf size in cereals is not increased by increase in P supply; however, P is essential for development of the root system (Watson, 1952). Watson also noted that dry matter yield does depend

more on variation in LA than in net assimilation rate (NAR, or the rate of increase of dry matter per unit leaf area, also referred to as relative growth rate).

Woolley and Davis (1991) reported that application of K to maize/climbing bean intercrop was economical. Watson (1952) reported that K had little effect on LA of wheat or barley during tillering phase, but increased LA during the subsequent phase of shoot extension, presumably by increasing leaf size or by delaying senescence. Two ways of varying leaf area index (LAI) are by varying plant population and improving nutrient supply. However, yield declines at higher plant population due to mutual shading of leaves and interplant competition (Watson, 1952).

2.6. Research approaches, experimental designs and data analysis for intercropping experiments

Agricultural research seeks to answer key questions in agricultural production whose resolution could lead to significant changes and improvements in existing agricultural practices. Scientific research must be designed precisely and rigorously to answer key questions, which are generally expressed as a statement of hypothesis that has to be verified or disproved through experimentation. These hypotheses are usually suggested by past experiences, observations and, at times, by theoretical considerations (Gomez and Gomez, 1984). Once a hypothesis is framed, the next step is to design a procedure for its verification. The procedures regarding how measurements of characters are to be made and how these measurements can be used to prove or disprove a hypothesis depend heavily on techniques developed by statisticians. These two tasks constitute much of what is

maximized. Because only the variation within a block becomes part of the experimental error, blocking is most effective when the experimental area has a predictable pattern of variability. Treatments are assigned to each block separately and independently. Proper plot technique ensures that all the other factors aside from those considered as treatments be maintained uniformly for all experimental units. For field experiments with crops, the important sources of variability among plots treated alike are soil heterogeneity, competition effects, and mechanical errors (Gomez and Gomez, 1984).

2.6.1. Experimental designs

In certain agricultural cropping systems, interest centres on growing a particular crop, the main crop; it may be that the yield of this crop is unaffected, or is affected to a small degree if another crop, a supplemental (or "bonus") crop, is grown either simultaneously with or sometime after the establishment of the main crop. In such cases, it is necessary to determine the effects of growing the supplemental crop on the main crop yields. In other situations, two crops in a mixture are considered to be of equal (or specified) importance, that is, the farmer grows both crops as main crops. The two crops need to be evaluated relative to their response in monoculture and in a mixture. The responses of each crop are to be evaluated as is some measure of their joint response. When response to the factor of interest is expected to differ under different levels of the other factor(s), a factorial experiment is used to handle simultaneously two or more variable factors. An experiment in which the treatments consist of all possible combinations of the selected levels in two or more factors is referred to as a factorial experiment (Gomez and Gomez, 1984).

Experimental designs used for factorial experiments include randomized complete block, split-plot and systematic designs (Mead, 1989).

2.6.1.1. Randomized complete block designs

The randomized complete block (RCB) design is one of the most widely used experimental designs in agricultural research. The design is especially suited for field experiments where the number of treatments is not large and the experimental area has a predictable productivity gradient. The primary distinguishing feature of the RCB design is the presence of blocks of equal size, each of which contains all the treatments. The importance of random allocation of treatments to plot in all blocks cannot be overemphasized.

Randomization provides the justification for the analysis of variance because it ensures that the data are genuinely a random sample (Mead, 1989). For the analysis of variance, the computations for designs for single-factor experiments are also directly applicable.

However, additional computational steps are required to partition the treatment sum of squares into factorial components corresponding to the main effects of individual factors and their interactions. An outline of the analysis of variance is as follows:

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	<u>Tabular F</u> 5 % 1 %	
Replication	$r-1$					
Treatment	$b-1$					
Factor A	$a-1$					
Factor B	$b-1$					
A X B	$(a-1)(b-1)$					
Error	$(r-1)(a-1)(b-1)$					
Total	$rab-1$					

2.6.1.2. Split-plot designs

Many existing experiments on intercropping, which include two or more factors, use a split-plot design, but Mead (1989) believes that there are relatively few occasions when such a design is appropriate. In a split-plot design, one of the factors is assigned to the main plot. The main plot is divided into subplots to which the second factor is assigned. Thus each main plot becomes a block for the subplot treatments (i.e., the levels of the subplot factor). The only good reason for using split-plots is that some treatments can only be applied to large plots whereas a large plot is not necessary or desirable for others (Mead, 1989). Because, with the split-plot design, plot size and precision of measurement of the effects are not the same for both factors, the assignment of a particular factor to either the main plot or the subplot is extremely important. To make such a choice depends on: i) the degree of precision, ii) the relative size of the main effects, and iii) management practices (Gomez and Gomez, 1984).

Mead (1989) cautions that split-plot designs should be avoided because they are generally inefficient. The inefficiency results from the splitting of information into two levels at one of which (the main plots) the precision of comparisons is usually very poor with few degrees of freedom. The loss of information on main effect is much greater than the gain on the interaction sum of squares (Mead, 1989).

The analysis of variance of a split-plot design is divided into main-plot analysis and the subplot analysis. An outline of the analysis of variance for a split-plot design is as follows:

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F	
					5 %	1 %
Replication	r-1					
Main-plot factor A	a-1					
Error(a)	(r-1)(a-1)					
Subplot factor B	b-1					
A X B	(a-1)(b-1)					
Error(b)	a(r-1)(b-1)					
Total	rab-1					

2.6.1.3. Systematic designs

Systematic designs are increasingly being used in experiments on the spatial arrangement of intercrops. The fundamental idea of the systematic design is that crop density (or spatial arrangement) changes consistently from row to row across a plot in such a way that each density change is small (usually 15 % or less) (Mead, 1989). Since each row is surrounded by others at nearly the same density the usual requirement for guard or discard areas round each plot can be avoided. The reduction in guard area makes the systematic design potentially important to intercropping experimentation, where it will certainly be necessary to consider a wide range of spacing treatments combined factorially with many other factors (Mead, 1989). However, this is not appropriate for intercropping experiments in which destructive sampling is carried out to estimate growth traits.

2.6.2. Statistical analysis

A linear response model equation for univariate analysis is of the form:

$$Y_{hi} = \mu + \tau_i + \rho_h + \epsilon_{hi},$$

Where Y_{hi} represents the response of the i th treatment, $i = 1, 2, \dots, v$, in the h th block, $h = 1, 2, \dots, r$, μ is an effect common to every observation, τ_i is the effect of the i th treatment, ρ_h is the effect of the h th block, and ϵ_{hi} are random error components normally and independently distributed with mean zero and common variance σ^2 (Federer, 1993).

However, the only form of analysis which retains all the available information is multivariate. A bivariate analysis is a joint analysis of the pairs of yields for the two crops intercropped on a set of experimental plots (Mead, 1989). The philosophy is that because two yields are measured for each plot, and the yields will be interrelated, they should be analyzed together (Mead, 1989). The interrelationship is important since it implies that conclusions drawn independently from two separate analyses of the two sets of yields may be misleading. There are two major causes of interdependence of yield of two crops grown on the same plot. If the competition between the two crops is intense, then it might be expected that on those plots where crop A performs unusually well, crop B will perform unusually badly and vice versa. This would lead to a negative background correlation between the two crop yields, quite apart from any pattern of joint variation caused by the applied treatments. Failure to take this negative correlation into account could lead to high standard errors (SEs) of means for each crop analyzed separately, which could mask real differences between treatments (Mead, 1989). Alternatively, it may be that on apparently identical plots, the two crops respond similarly to small differences between plots producing a positive background correlation. Again, looking at separate analyses for the two crops distorts the assessment of the pattern of variation.

The calculation for a bivariate analysis are formally identical with those required for covariance analysis. The difference is that whereas in covariance analysis there is a major variable and a secondary variable whose purpose is to improve the precision of comparison of mean values of the major variable, in a bivariate analysis the two variables are treated symmetrically (Mead, 1989). Bivariate analysis of variance consists of an analysis of variance for X_1 , analysis of variance for X_2 , and a third analysis (of covariance) for the products of X_1 and X_2 . However, Federer (1993) noted that bivariate analysis is suitable for intercropping situations in which both component crop species are main crops: in experiments where a main crop is supplemented with a second crop, combined analyses of both crop responses are not required.

2.7. Concluding remarks from the review of literature

It is evident from the literature reviewed, that studies of mixtures of maize and beans in which climbing beans is the preferred crop, have not received attention. Work on maize+climbing bean mixtures in Central and South America emphasizes maize as the main crop, while beans is regarded as a minor crop. Maize in intercrops is planted at the same population as in pure stands, i.e., a range of 40,000 to 60,000 plants ha^{-1} . An additional yield of beans ("bonus" crop) without a significant reduction in maize yield is the farmer's production goal. However, in areas where beans is more important than maize, as in the case of Kabale district, the above range of maize population cannot be recommended for use in mixtures with climbing beans by Kabale farmers, because there has to be a yield "trade-off" in favour of the beans.

The "replacement series" technique for forming mixtures as described by de Wit (1960), and

used by Willey and Osiru (1972) is, indeed, suitable for intercropping systems in which one component species does not need support from the companion species. However, the technique appears to be inappropriate for maize+climbing bean mixtures, in which maize serves as a support for the beans. Varying both plant population (by altering the within-row spacing), and the proportional areas allocated to the component species (by gradual replacement of maize rows by those of beans), while keeping total population pressure constant, may not be suitable for maize+climbing bean association, because the degree of "intimacy" in the spatial arrangement of component species is very crucial (Natarajan, 1989).

Firstly, by having more than two rows of beans in the space between maize rows, it would not only undermine the bean's competitive ability, but also render management of the mixture quite cumbersome. Consequently, the system's productivity would inevitably decline.

Secondly, when the "equivalence factor" is computed according to the ratio of the component optimum populations in pure stand (Willey and Osiru, 1972), the values would be 1 : 2.5 or 1 : 3 of maize : beans in the mixtures, if sole maize population is taken as 37,037 and 44,444 plants ha⁻¹ for tall and medium stature varieties respectively, and 111,111 plants ha⁻¹ of sole beans. Results of a study of climbing bean husbandry conducted on farmers' fields in Kabale district indicate that not more than four bean plants should share one strong wooden stake (UNBP, 1991) in order to realise high bean yield. Therefore, one maize plant may not be strong enough to support more than three bean plants.

By varying the component populations from, say, 75% + 25% to 25% + 75% (or any other combination) of maize and beans, would definitely violate the concept of "equivalence" in forming mixtures. In the first combination, bean population would be too low, whereas that

of maize would be high; the reverse would be true for the second combination. In both cases, low bean yields would be realised. This implies that in order to improve the performance of climbing beans in mixtures with maize, plant population and/or spatial arrangement have to be manipulated. Against this background, the effect of plant population on yield of maize+climbing bean mixture, was investigated at Kachwekano (Kabale District Farm Institute) near Kabale town, in south-western Uganda. The main objective of the study was to identify the appropriate plant population of the component species that would maximise bean yield. A randomised complete block design was used for testing experimental treatments because it is more efficient than split-plot designs.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Site Characteristics

The experiment was conducted at Kachwekano (1°15'S, 30°E; altitude 2200 m), located 8 km south-west of Kabale town, in south-western Uganda. The soils are well drained, clayey, oxidic, isomesic, Typic Palehumults; soil moisture-temperature regime is Udic-Isothermic; soil pH ranges from about 5.8 to 6.2, with acid subsoils (Yost and Eswaran, 1990). The site receives an annual precipitation of about 950 mm which has a bimodal distribution: short rains (February-May with a peak in March/April, subsequently referred to as season "A" in this thesis), and long rains (August-December with a peak in September/October, subsequently referred to as season "B"). Mean maximum temperature is about 21°C while mean minimum temperature is 14°C. The field used for the experiment in 1996B season was previously under a bean crop, whereas in 1997A, a different field formerly under bush fallow was used.

3.2. Treatments and experimental design

The factors were: (a) maize plant population, and (b) bean plant population. In 1996B, treatments were formed by planting maize in mixtures with climbing beans at a spacing of 1.0 m x 0.35 m, 1.0 m x 0.30 m, and 1.0 m x 0.25 m, to achieve corresponding populations of 28 571, 33 333, and 40 000 maize plants ha⁻¹. Beans in mixtures was planted at a spacing of 0.40 m x 0.45 m, 0.40 m x 0.40 m, 0.40 m x 0.35 m, and 0.40 m x 0.30 m, to achieve corresponding populations of 63 492, 71 428, 81 632, and 95 238 bean plants ha⁻¹. However, in 1997A season, maize populations of 28,571 and 40,000 plants ha⁻¹, and bean population

of 63,492 plants ha^{-1} , were replaced with 25,000 maize plants ha^{-1} and 57,142 bean plants ha^{-1} , achieved by planting at an intra-row spacing of 0.40 m and 0.50 m, respectively. The decision to drop the said populations was partly based on the general trend in bean yield response to maize population in 1996B (i.e., bean yield was lowest in mixtures involving maize population of 40,000 plants ha^{-1}), and lack of adequate space for the trial. Sole crops were planted at the recommended populations of 44,444 and 111,111 plants ha^{-1} of maize and climbing beans, respectively.

All possible combinations of maize and bean plant populations for intercrops plus two sole crop treatments (at the recommended plant populations) were tested in a randomized complete block design. A total of fourteen treatments were replicated three times (a single replicate is shown in Fig. 1). Plots measured 6 m by 7 m.

101	102	103	104	105	106	107
2	5	10	7	4	1	13
9	3	14	8	11	12	6
108	109	110	111	112	113	114

Fig. 1: Lay out of a single replicate (block) in 1996b season. Numbers 1-14 represent treatments (all combinations of maize and bean populations and two pure stands), while nos. 101-114 stand for experimental units (plots).

3.3. Pattern of crop arrangement

Mixtures were planted using a one maize row to two bean rows arrangement. The two rows of beans were 0.30 m away from either maize row. Sole maize was planted in single rows at the recommended spacing of 0.75 m x 0.30 m to achieve a population of 44,444 plants ha^{-1} .

For convenience during staking of the crop, pure stand beans was sown at the recommended population of 111,111 plant ha^{-1} in double rows spaced 0.6 m apart, with 0.3 m within-the-pair and 0.2 m between plants within-the-row (Fig. 2). For both crops, two seeds were planted at each planting station, and subsequently thinned to one plant per hill at two weeks after emergence.

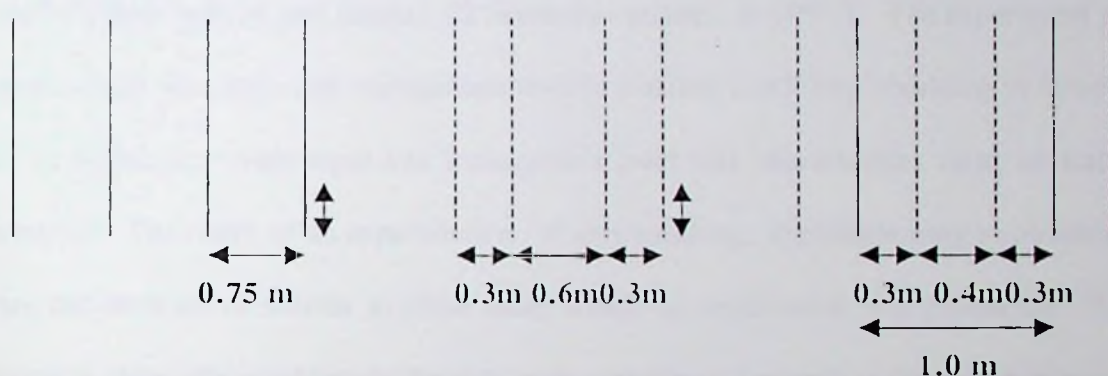


Fig. 2: Field planting patterns: (a) – (c) represent sole maize, sole beans, and maize+bean intercrop, respectively.

3.4. Crop management

Two climbing bean genotypes (Umubano and Gisenyi) with differences in both seed size and yield potential, and one maize genotype POOL 9A, were used in the study. Umubano is a red, small-seeded variety with a yield potential of 4.0 t ha^{-1} whereas Gisenyi is a white, black-speckled, large-seeded variety with a yield potential of 3.5 t ha^{-1} . Both are of Type IV growth habit (indeterminate) and mature in about 120 days. Umubano was used only in 1996b but not in 1997a due to its susceptibility to leaf rust (*Uromyces appendiculatus*) under dry spells, especially during the first rains season. Maize genotype POOL 9A has white, medium-size

grain, grows to a height of about 2.5 m, matures in about 180 days, and has a yield potential of up to 7.0 tons ha⁻¹ at Kachwekano. Maize in pure stand and in mixture were planted on the same date, i.e., September 20 (1996B) and 3 March (1997A). Climbing beans in mixtures was sown 10 days after emergence (DAE) of maize, to ensure that maize plants would be ready to support those of beans. Sole bean crop was planted on the same date as beans in intercrop.

Land preparation of the field and weeding of the trial were carried out manually using hand-hoes. The trial was weeded twice. Harvesting dates were 12 February (beans), 2 April (maize) in 1996B, and 29 July (beans), 22 September (maize), in 1997A. The experiment was conducted under low input and management level to simulate conditions obtaining in farmers' fields, as opposed to high input and management level that characterizes most on-station experiments. The result of an experiment is, strictly speaking, applicable only to conditions that are the same as, or similar to those under which the experiment was conducted. This limitation is especially troublesome because most agricultural research is done on experiment stations where average productivity is higher than that for ordinary farms (Gomez and Gomez, 1984).

3.5. Experimental measurements

Destructive sampling was carried out at fortnightly intervals, i.e., 20, 34, 48, 62, 76 and 17, 31, 45, 59 days after emergence (DAE) of maize and beans, respectively, to estimate plant height, leaf area (beans), leaf area index (maize), and total dry matter of the two species. Maize plant height was obtained by measuring from the stem base to the collar of the upper most fully opened leaf, and from stem base to the base of the tassel during the vegetative and reproductive phases, respectively (Daugherty and Hollinger, 1984). Bean plant height (total

length) was measured from the stem base up to the tip of the main stem (Ugen and Wien, 1996). To determine leaf area (LA) in beans, 50 leaves representing various physiological stages were randomly picked from bean plants within rows associated with the 2nd and 7th rows of maize in intercroops and from the 9th and 10th rows of sole bean plots. The leaves were arranged to form a thick layer, from which disks were cut out by pressing into the mass a 10-mm diameter borer. The number of disks multiplied by the cross-sectional area gave total area of the sub-sample. The area:oven-dry weight ratio of the disks was calculated and multiplied by the total oven-dry weight of the laminae to give the total LA of the sample (Watson and Watson, 1953). In maize, the area of each fully opened leaf on 4 plants randomly picked from the 2nd and 7th rows in intercrop plots and the 2nd and 8th rows in sole maize plots, was estimated as the product of the length and maximum width multiplied by a constant factor (0.75) to correct for leaf shape. LAI was then estimated by dividing LA by land area occupied by the plant sample (Rao and Murty, 1963).

To determine TDM, 4 maize and 8 bean plants randomly picked from the same rows used for LAI estimation (representing a total area of 1.6 m²), were cut at ground level. Maize stalks were cut into segments 20 to 30 cm long, then each segment split to minimize extraneous errors in maize stalk dry weights due to non-uniform drying (Daughtry and Hollinger, 1984).

Plant samples for maize and beans were then put in separate labelled paper bags and oven-dried to constant dry weight at 70°C for 72 hrs (Lu *et al.*, 1989), then weighed immediately after cooling. TDM was estimated as described by Hunt (1978) and used by Sears *et al.* (1989), and Osiru and Hahn (1994).

At harvesting time, border plants within 1.00, 1.22 and 1.52 m distance on either end of the

4th, 5th maize rows (with associated bean rows) in maize+bean intercrop, 4th, 5th, 6th rows in sole maize, and 2nd, 3rd, 4th paired rows in sole beans plots, respectively, were left out as guard rows. Grain yield per hectare and yield components were estimated from a harvested area of 8 m². Number of rows in the sample harvested varied with treatment used for the three cropping systems, and were as follows: two maize rows plus four bean rows in intercrop; three maize rows in sole crop; and six bean rows (three pairs) in sole crop. Random samples of 10 bean and 20 maize plants from the harvest area, were used to estimate number of pods plant⁻¹ and cobs plant⁻¹, respectively. After harvesting and sun-drying plot harvests, random samples of 20 pods and 5 cobs per plot were taken and used to estimate number of grains pod⁻¹ and grains cob⁻¹, respectively. Two samples each 100 grains of beans, and two samples each 500 grains of maize were used to estimate mean grain weight.

Data on growth parameters, yield and yield components were subjected to a two-way analysis of variance (ANOVA) using MSTAT-C computer software. Treatment means were separated using the Least Significant Difference (LSD) test. To determine the interaction effect between treatment and stage of observation on the growth pattern (or rate of change), data from all stages of observation was combined to obtain a single analysis of variance. Time of observation was considered as an additional factor in the experiment and was treated as if it were a subplot or the smallest experimental unit (Gomez and Gomez, 1984). Because heterogeneity of variance was detected when the Chi-square test for homogeneity of variance was applied to error mean squares for the stages of observation, data was subjected to logarithmic (plant height, TDM) and square root (LAI) transformations before carrying out a pooled ANOVA for the sampling periods (Gomez and Gomez, 1984). Correlation analysis was carried out for selected parameters. Mean yields of intercrops and sole crops of maize and

beans were used to calculate land equivalent ratios (LERs) and monetary advantages (total income). A combined ANOVA on data from the two seasons was not carried out, because intercrop treatments were not uniform across seasons. Since targeted plant populations were not attained, the actual populations at harvest are used in presenting the results on yield and yield components. agronomic and economic evaluation of the maize/climbing bean intercropping system.

CHAPTER FOUR

RESULTS

4.1. Weather conditions

There was more rainfall in 1996b which was fairly well distributed over five months, compared to the amount of rainfall in 1997a which was spread over only three months. Data for amount and distribution of rainfall for 1996b and 1997a growing seasons are given in Tables 1 and 2.

Rainfall data (mm) for 1996b season.

Month	Week 1	Week 2	Week 3	Week 4	Total rainfall	Rain days
September	-	-	4.1	21.5	25.6	4
October	39.8	19.8	4.0	53.5	117.1	13
November	44.4	63.5	22.3	75.5	205.7	19
December	4.6	29.5	31.6	16.2	81.9	10
January	52.1	3.1	16.2	18.2	89.6	9
February	nil	nil	nil	nil	nil	nil
Seasonal Total:					519.9	55

Table 2: Rainfall data (mm) for 1997a season.

Month	Week 1	Week 2	Week 3	Week 4	Total rainfall	Rain days
March	9.4	5.6	23.9	44.8	83.7	13
April	41.0	23.3	32.5	120.9	217.7	21
May	32.9	49.9	22.1	na	104.9	10
June	na	na	na	na	na	
Seasonal Total:					406.3	44

na = Data not available, but end of May and the whole of June were relatively dry.

4.2. Effect of plant population density (PPD) on growth of maize and climbing beans in intercrops.

Maize plant height decreased with increasing maize PPD during both seasons (Figs. 1a (i) & 1b (i)). However, the effect of maize PPD on plant height was significant at 76 days after emergence (DAE) in 1996b (Table 3), whereas in 1997a, the effect was not significant at all sampling dates. The mean value for maize plant height in intercrop at 76 DAE was 192 cm in 1996b compared to 80 cm in 1997a, implying that maize plant height in intercrop was 4 % and 15 % lower than for sole maize in 1996b and 1997a, respectively. Maize leaf area index (LAI) increased with increasing maize PPD in both seasons (Figs. 1a (ii) & 1b (ii)). The effect of maize PPD on LAI was significant at 76 DAE in both seasons. The mean value for maize LAI in intercrop was 2.97 in 1996b compared to 1.56 in 1997a, implying that maize LAI in intercrop was 26 % and 45 % less than for sole maize in 1996b and 1997a, respectively. Maize total dry matter (TDM) in intercrop generally had a trend similar to that of LAI (Figs. 1a (iii) & 1b (iii)). However, the effect of increasing maize PPD on this parameter was not significant at all sampling dates in both seasons. The mean value for maize TDM in intercrop was 545 g m⁻² in 1996b compared to 366 g m⁻² in 1997a, implying that maize TDM in intercrop was 34 % and 40 % less than for sole maize in 1996b and 1997a, respectively.

As bean population increased, maize plant height, LAI and TDM in intercrop decreased (Fig. 2 a & b). However, increasing bean PPD had no significant effect on all three maize growth traits at all sampling dates in both seasons.

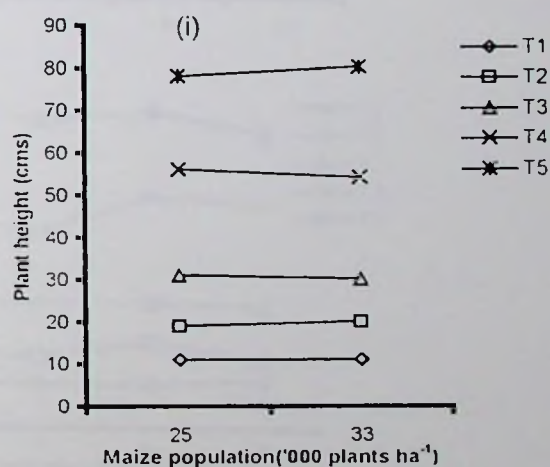
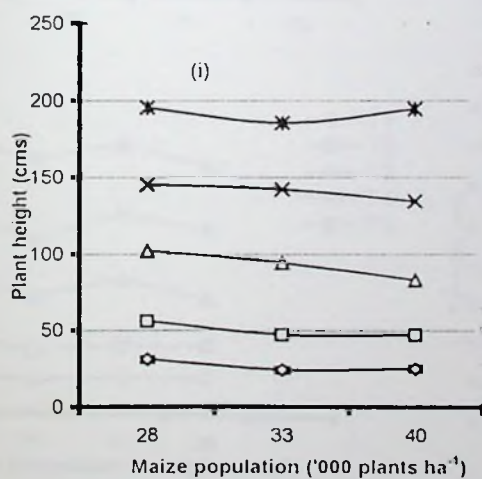
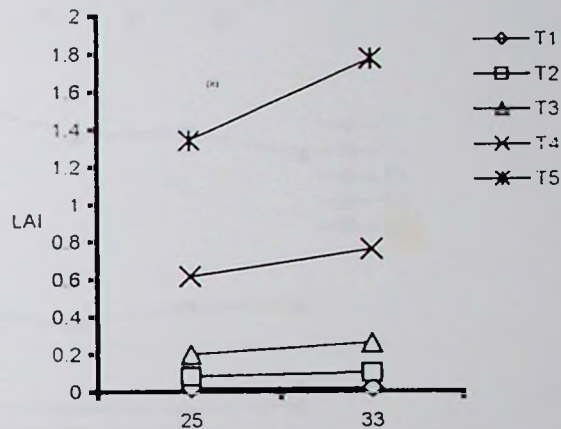
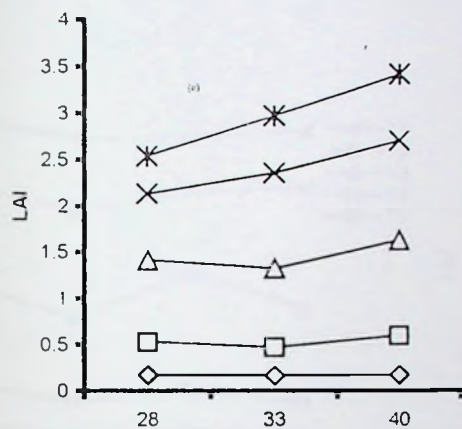
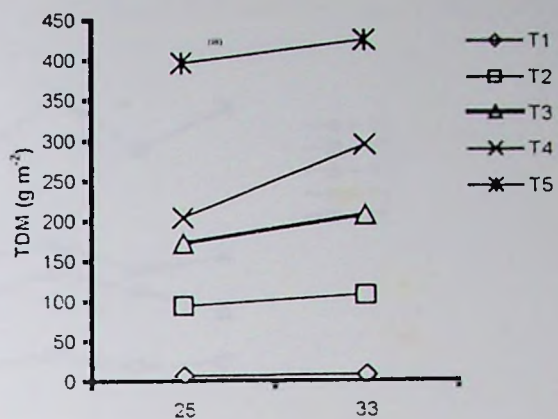
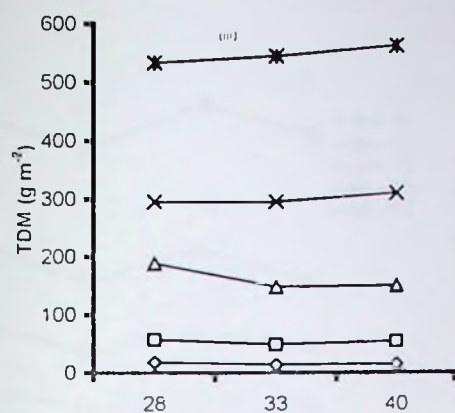


Fig. 1a: Effect of maize population on maize growth in maize/climbing bean intercrops, up to tasseling stage in 1996b season. T1 = 20, T2 = 34, T3 = 48, T4 = 62, T5 = 76 days after emergence.

Fig. 1b: Effect of maize population on maize growth in maize/climbing bean intercrops prior to tasseling stage in 1997a season. T1 = 20, T2 = 34, T3 = 48, T4 = 62, T5 = 76 days after emergence.

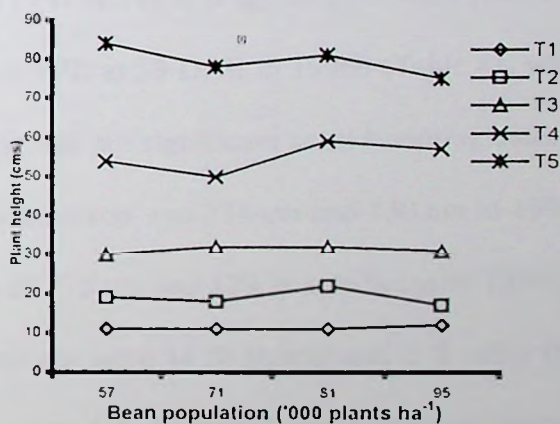
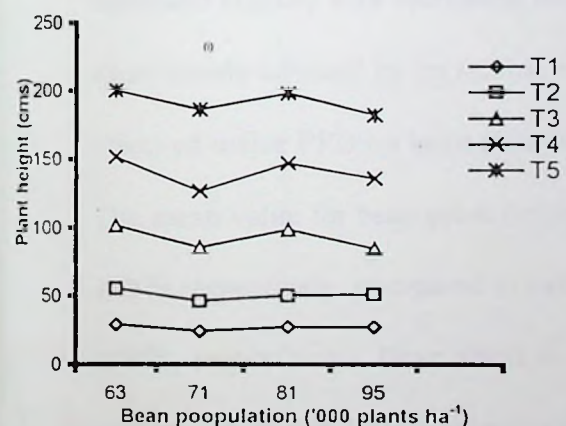
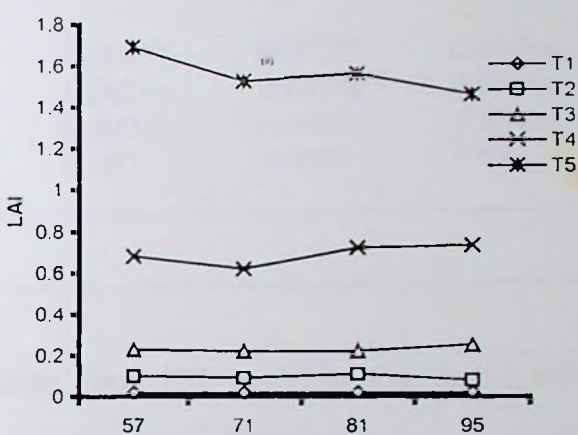
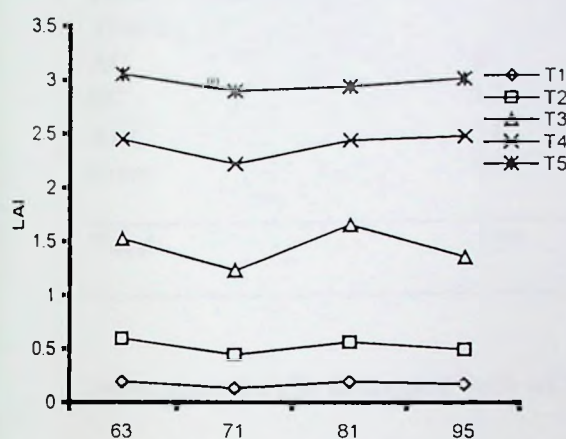
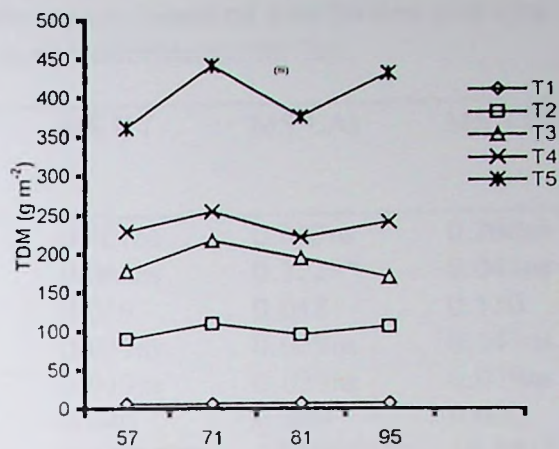
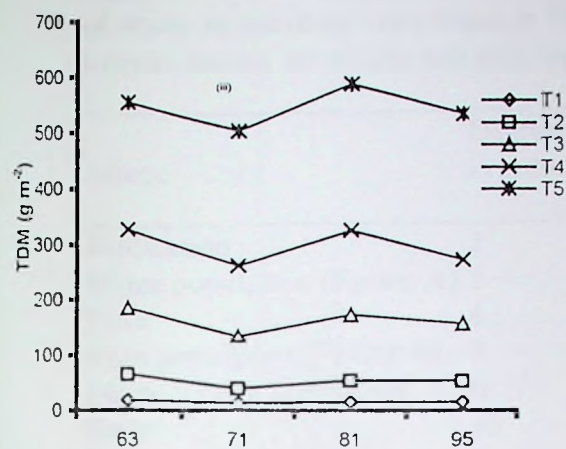


Fig. 2a: Effect of bean population on maize growth in maize/climbing bean intercrops, up to tasseling stage in 1996b season. T1 = 20, T2 = 34, T3 = 48, T4 = 62, T5 = 76 days after emergence.

Fig. 2b: Effect of bean population on maize growth in maize/climbing bean intercrops prior to tasseling in 1997a season. T1 = 20, T2 = 34, T3 = 48, T4 = 62, T5 = 76 days after emergence.

Table 3: Pooled analysis of variance for plant height, leaf area index and total dry matter of maize in intercrop with beans in 1996b season, based on transformed data (log. transformation for height and tdm; sq. root transformation for lai).

Source	Degree of Freedom	MS HT	MS LAI	MS TDM
Replication	2	0.101ns	0.062ns	0.260ns
Maize population (Factor A)	2	0.066ns	0.222**	0.041ns
Error	4	0.019	0.018	0.110
Bean population (Factor B)	3	0.039ns	0.069ns	0.147ns
Maize x bean population	6	0.019ns	0.029ns	0.079ns
Error	18	0.040	0.030	0.020
Time of observation (Factor C)	4	4.442****	10.986****	14.881****
AC	8	0.008**	0.037**	0.010ns
BC	12	0.002ns	0.007ns	0.009ns
ABC	24	0.003ns	0.010ns	0.014ns
Error	96	0.003	0.009	0.012
Total	179			

Bean plant height decreased with increasing maize PPD in 1996b (Fig. 3a (i)), whereas it increased slightly with increasing maize PPD in 1997a (Fig. 3b (i)). Bean plant height was significantly affected by increasing maize PPD at 59 DAE in 1996b (Table 4), whereas the effect of maize PPD on bean plant height was not significant at all sampling dates in 1997a. The mean value for bean plant height in intercrop was 234 cm and 130 cm in 1996b and 1997a respectively, compared to values of 272 cm and 129 in sole beans in 1996b and 1997a, respectively. Bean plants in intercrop were 14 % shorter and 1 % taller than in sole crop in 1996b and 1997a, respectively. Bean LA decreased with increasing maize PPD in both seasons (Figs. 3a (ii) & 3b (ii)). Bean LA was significantly affected by increasing maize PPD at 59 DAE in 1996b (Table 4), whereas in 1997a, the effect of maize PPD on bean LA was not significant at all sampling dates. The mean value for bean LA in intercrop was 3103 cm² and 326 cm² in 1996b and 1997a respectively, compared to values

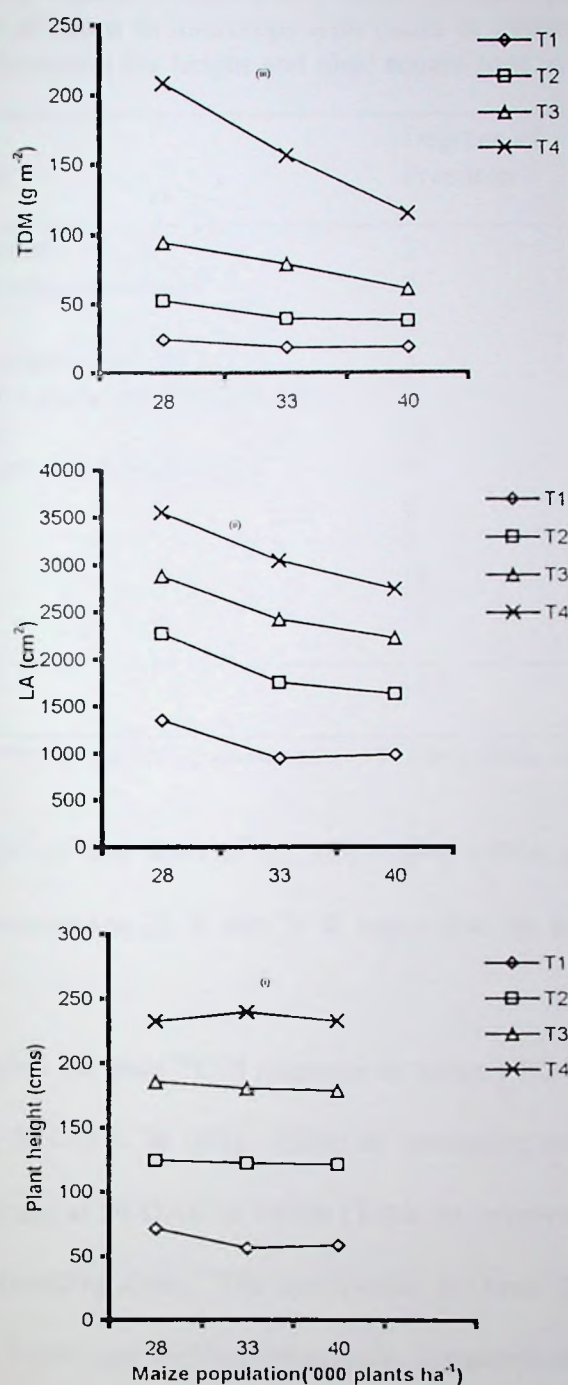


Fig. 3a: Effect of maize population on bean growth in maize/climbing bean intercrops up to podding stage in 1996b season. T1 = 17, T2 = 31, T3 = 45, T4 = 59 days after emergence.

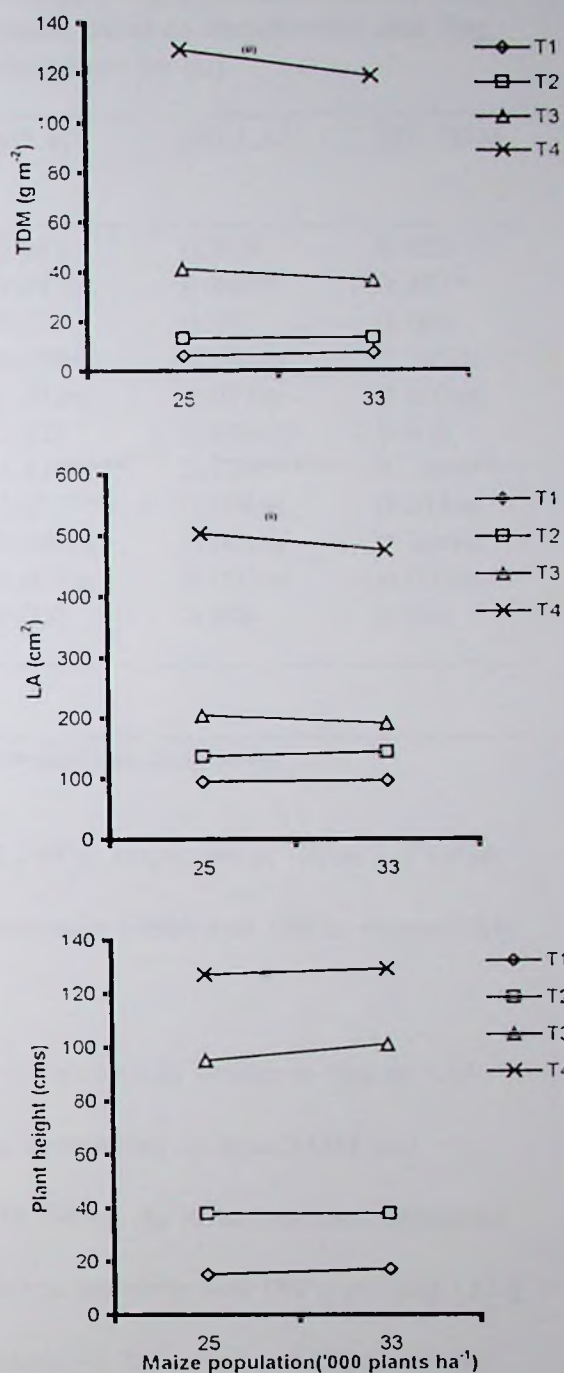


Fig. 3b: Effect of maize population on bean growth in maize/climbing bean intercrops prior to podding in 1997a season. T1 = 17, T2 = 31, T3 = 45, T4 = 59 days after emergence.

Table 4: Pooled Analysis of Variance for bean plant height, leaf area index and total dry matter of beans in intercrops with maize in 1996b season, based on transformed data (log. transformation for height and tdm; square root transformation for lai).

Source	Degrees of Freedom	MS HT	MS LAI	MS TDM
Replication	2	0.081	0.269	0.423
Maize population (A)	2	0.017ns	0.466*	0.371*
Error	4	0.031	0.052	0.066
Bean population (B)	3	0.009ns	0.178ns	0.145ns
Maize x Bean population (AB)	6	0.014ns	0.013ns	0.105ns
Error	18	0.022	0.096	0.078
Time of observation (C)	3	2.419****	2.729****	5.114****
AC	6	0.011**	0.006ns	0.014ns
BC	9	0.002ns	0.001ns	0.004ns
ABC	18	0.003ns	0.003ns	0.007ns
Error	72	0.003	0.009	0.010
Total	143			

*, **, ****, ns = F test significant at 5%, 1%, 0.01% levels, and not significant, respectively.

of 3724 cm² and 404 cm² for sole crop in 1996b and 1997a, respectively. Bean LA value in intercrop was 20 % and 24 % lower than for sole crop in 1996b and 1997a, respectively.

The trend for bean TDM response to maize PPD in intercrop was similar to that of LAI (Figs. 3a (iii) & 3b (iii)). Effect of increasing maize population on bean TDM was significant at 59 DAE in 1996b (Table 4), whereas in 1997a, the effect was not significant at all sampling dates. The mean value for bean TDM in intercrop was 159 g m⁻² and 123 g m⁻² in 1996b and 1997a respectively, compared to values of 253 g m⁻² and 152 g m⁻² for sole crop in 1996b and in 1997a. Bean TDM in intercrop was 37 % and 19 % lower than for sole crop. There was a non-significant tendency for intercrop bean plant height to decline with increasing bean PPD in both seasons (Figs. 4a (i) & 4b (i)). Intercrop bean LA and TDM increased (non-significant) with increasing bean PPD during both

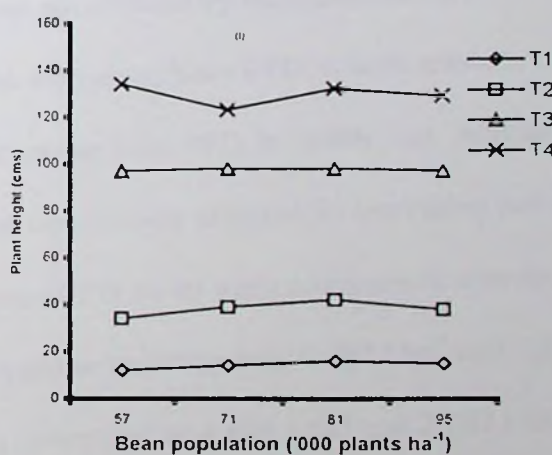
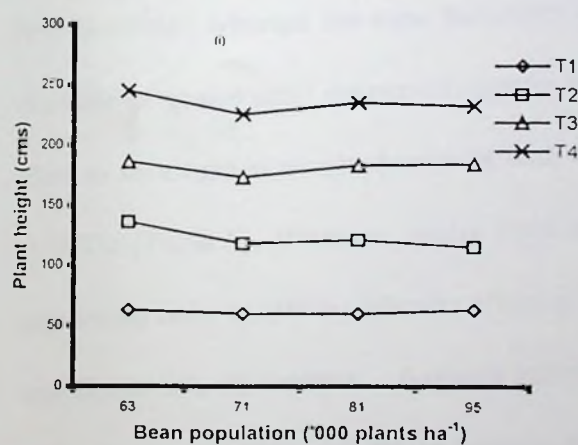
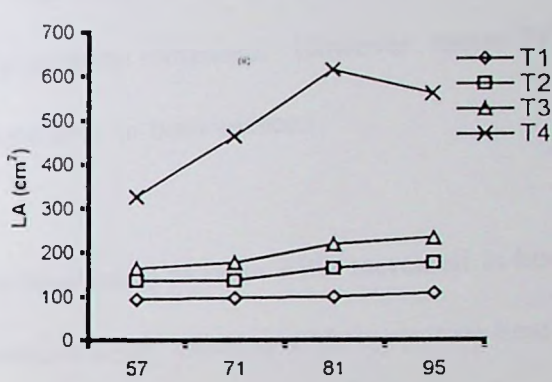
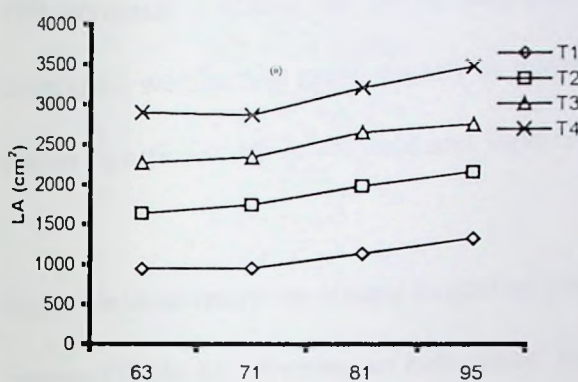
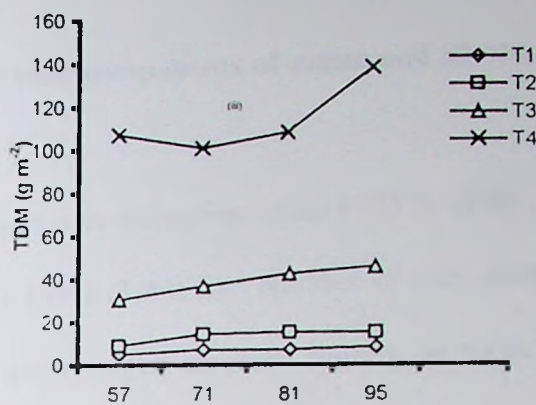
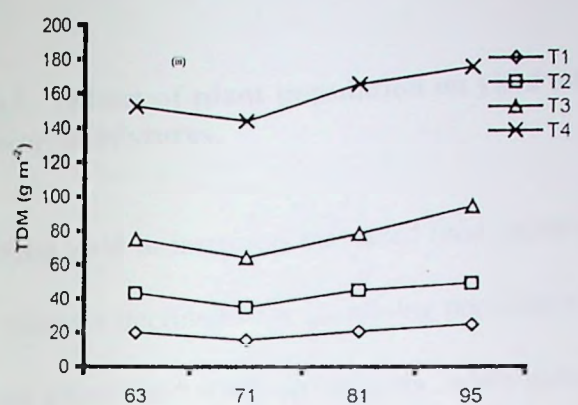


Fig. 4a: Effect of bean population on bean growth in maize/climbing bean intercrops up to podding stage in 1996b season. T1 = 17, T2 = 31, T3 = 45, T4 = 59 days after emergence.

Fig. 4b: Effect of bean population on bean growth in maize/climbing bean intercrops prior to podding stage in 1997a season. T1 = 17, T2 = 31, T3 = 45, T4 = 59 days after emergence.

(Figs. 4a (ii), 4b (ii) and 4a (iii), 4b (iii), respectively).

Effect of plant population on yield and yield components of maize and climbing mixtures.

Yield in intercrop increased (non-significant) with increasing maize PPD in 1996b, as it declined with increasing population in 1997a (Table 5). Number of cobs plant⁻¹ and grains cob⁻¹ decreased slightly, while mean grain weight increased slightly, as maize population increased in 1996a. In 1997a, cobs plant⁻¹ was unaffected, while grains cob⁻¹ and mean grain weight decreased slightly as maize population increased. However, maize PPD had no significant effect on yield and yield components in both seasons.

Maize yield in intercrop tended to decline (non-significant) as bean PPD increased in both seasons (Table 5). Number of cobs plant⁻¹ showed a slight increase with increasing bean population in 1996b, whereas the same parameter was not affected by bean population in 1997a. Number of grains cob⁻¹ decreased slightly with increasing bean PPD in both seasons. Mean grain weight decreased with increasing bean PPD in 1996b, but increased in 1997a (Table 5). However, maize yield was significantly affected by increasing bean population only in 1997a, whereas effect of bean PPD on all yield components was not significant in both seasons. Average maize yield in intercrop was 4.182 t ha⁻¹ and 1.486 t ha⁻¹ of grain in 1996b and 1997a respectively, compared to 4.605 t ha⁻¹ and 2.082 t ha⁻¹ for maize sole crop in 1996b and 1997a, respectively. Maize yield in intercrop was 9 % and 32 % lower than in sole crop in 1996b and 1997a, respectively. However, maize yield reduction was significant only in 1997a. The mean value for cobs plant⁻¹ in intercrop was 9.6 % lower than in maize pure stand in 1996b, whereas in 1997a, this yield component was not

Table 5: Effect of plant population on maize yield ($t\ ha^{-1}$) and yield components in the maize+climbing bean mixtures.

Intercrop population (plants ha^{-1})		Yield ha^{-1} (tons)	Yield plant $^{-1}$ (g)	Cobs plant $^{-1}$	Grains cob $^{-1}$	Meangrain weight (mg)
Maize	Beans					
1996B						
25 714	44 444	3.905ab	136.7	1.17ab	394bc	448a
27 820	52 428	4.271ab	149.5	1.27ab	417abc	388ab
27 428	57 142	4.257ab	149.0	1.30ab	423abc	398ab
24 576	66 667	3.433b	120.1	1.13b	400abc	379b
Means :		3.967	138.8	1.22	408	403
25 666	53 968	4.148ab	124.4	1.37ab	443a	411ab
27 666	45 079	3.830ab	114.9	1.33ab	416abc	383b
25 333	57 142	4.303ab	129.1	1.47a	435ab	410ab
27 666	70 476	4.481ab	134.4	1.47a	443a	418ab
Means :		4.191	125.7	1.41	434	406
31 600	53 333	5.120a*	128.0	1.33ab	405abc	414ab
30 800	48 571	3.899ab	97.5	1.20ab	413abc	398ab
31 200	58 775	4.212ab	105.3	1.23ab	388c	406ab
27 200	74 286	4.321ab	108.0	1.33ab	415abc	375b
Means :		4.388	109.7	1.27	405	407
Grand means :		4.182	124.7	1.30	416	402.4
LSD _{0.05} :		1.358	NS	0.330	44.78	60.96
CV (%) :		19.17		15.08	6.36	8.95
sole maize :		4.605	103.6	1.20	397	372
1997A						
21 115	51 924	1.749a	69.6	1.15	401ab	269
154	60 862	1.632ab	63.9	1.06	375b	288
231	73 469	1.395bc	55.8	1.12	425a	258
077	84 034	1.502ab	60.1	1.13	396ab	277
Means :		1.561	62.4	1.12	399	273
49	46 753	1.493ab	44.8	1.06	376b	275
10	63 492	1.572ab	47.2	1.18	372b	262
24	70 745	1.099c	38.8	1.10	365b	268
0	81 633	1.288bc	38.6	1.16	410ab	278
s :		1.411	42.3	1.12	381	271
Means :		1.486	52.3	1.12	390	272
) :		0.352	NS	NS	46.71	NS
:		14.25			6.84	
maize :		1.807	40.6	1.07	384	257

Values in the same column followed by the same letter are not significantly different using the Least Square Difference Test at 0.05 alpha level.

value for mean grain weight was 8.9 % and 5.8 % higher than for maize sole crop in 1996b and 1997a respectively, whereas the mean value for grains cob⁻¹ in intercrop was 4.8 % and 1.6 % higher than for sole crop 1996b and 1997a respectively, whereas the mean value for maize yield plant⁻¹ in intercrop declined (non-significant) with increasing population, but was higher than for sole maize crop in both seasons.

Bean yield and pods plant⁻¹ in intercrop showed a non-significant decrease with increasing maize PPD, whereas grains pod⁻¹ and mean grain weight were not affected by increasing maize PPD in both seasons (Table 6). Number of pods plant⁻¹ were significantly affected by maize PPD only in 1997a. The mean values for bean yield and pods plant⁻¹ in intercrop were 0.784 t ha⁻¹ of grain and 12.3 pods plant⁻¹ respectively, compared to 2.132 t ha⁻¹ and 20 pods plant⁻¹ for sole crop in 1996b. In 1997a, values for bean yield and pods plant⁻¹ in intercrop were 0.631 t ha⁻¹ and 8.2 pods plant⁻¹ respectively, compared to 2.175 t ha⁻¹ and 12.2 pods plant⁻¹ for sole crop. Intercropping maize and beans resulted in a significant reduction of 63 % and 71 % in bean yield in 1996b and 1997a respectively, and 39 % and 33 % reduction in pods plant⁻¹ in 1997a. Correlation between bean and maize grain yield in the intercrop was negative and significant ($r = -0.62$, $P < 0.05$) in 1996b, but was not significant ($r = -0.31$, $P > 0.05$) in 1997a.

Bean yield in intercrop increased (non-significant) with increasing bean PPD in 1996b, whereas it showed a decline in 1997a (Table 6). Number of pods plant⁻¹ decreased (non-significant) with increasing bean PPD, whereas grains pod⁻¹ and mean grain weight were, apparently, not affected by bean PPD in both seasons.

Table 6: Effect of plant population on bean yield and yield components in the maize + climbing bean intercrop.

Intercrop population (plants ha ⁻¹)		Yield ha ⁻¹ (tons)	Yield plant ⁻¹ (g)	Pods plant ⁻¹	Grains pod ⁻¹	Meangrain weight (mg)
Maize	Beans					
1996B						
25 714	44 444	0.926	14.6	17.40a*	7.00	233
27 820	52 842	0.714	10.0	12.90ab	6.53	232
27 428	57 142	0.727	8.9	10.67b	6.63	233
24 576	66 667	1.075	11.3	13.87ab	6.60	232
Means	:	0.860	11.2	13.71	6.70	232.5
25 666	53 968	0.633	10.0	11.30b	6.93	230
27 666	45 079	0.851	11.9	12.23ab	6.17	240
25 333	57 142	0.775	9.5	12.49ab	6.33	226
27 666	70 476	0.754	7.9	12.50ab	6.47	225
Means	:	0.753	9.8	12.13	6.48	230.2
31 600	53 333	0.665	10.5	11.00b	6.37	234
30 800	48 571	0.620	8.7	11.37b	6.53	241
31 200	58 775	0.648	7.9	11.70ab	6.50	226
27 200	74 286	0.672	7.1	9.70b	6.00	231
Means	:	0.651	8.6	10.94	6.35	231.8
Grand means	:	0.784	9.8	12.26	6.51	231.8
LSD _{0.05}	:			5.76		
CV (%)	:			27.74		
Sole beans	:	2.132	19.2	20.00	6.70	236.0
1997A						
22 115	51 924	0.844	14.8	10.30a	4.05	582
21 154	60 862	0.621	8.7	7.83ab	4.07	560
19 000	73 469	0.647	7.9	8.70ab	4.10	582
23 077	84 034	0.648	6.8	6.63b	3.90	604
Means	:	0.690	9.6	8.36	4.03	582
22 549	46 753	0.575	10.1	9.03ab	3.95	606
23 510	63 492	0.600	8.4	9.33ab	3.97	571
23 524	70 745	0.521	6.4	6.43b	4.13	603
24 510	81 633	0.587	6.2	7.40ab	4.00	576
Means	:	0.571	7.8	8.05	4.01	589
Grand means	:	0.631	8.7	8.21	4.02	586
LSD _{0.05}	:	NS	NS	3.121	NS	NS
CV (%)	:			21.71		
Sole beans	:	2.175	19.6	12.20	4.30	590

* = Means in the same column followed by the same letter are not significantly different using the Least Significant Difference Test at 0.05 alpha level.

3.3. Effect of plant population on yield advantages and total income from maize and climbing beans in mixtures.

Partial land equivalent ratio (LER) of maize in intercrop increased (non-significant) with increasing maize PPD in 1996b, but decreased with increasing maize PPD in 1997a (Table 7). However, effect of population on partial LER of maize was not significant in both seasons. Bean population also did not significantly affect maize partial LER.

Partial LER of beans in intercrop decreased (non-significant) with increasing maize population in both seasons (Table 7). Partial LER of beans in intercrop also decreased (non-significant) with increasing bean PPD in both seasons. Maize was more competitive than beans, with competition ratios (CRs) for maize and beans of 2.6:1 and 2.4:1 in 1996b and 1997a, respectively.

The highest mean total LER value of 1.42 was achieved with a population of 31,600 and 53,333 plants ha⁻¹ of maize and beans respectively, while a mixture of 30,800 and 48,571 plants ha⁻¹ of maize and beans respectively, had the lowest mean total LER value of 1.14 in 1996b (Table 7). In 1997a, a mixture of 21,080 and 51,924 plants ha⁻¹ of maize and beans respectively, had the highest mean total LER value of 1.23; the lowest mean total LER value of 0.86 was achieved with a mixture of 23,529 and 70,681 plants ha⁻¹ of maize and beans, respectively. Intercrops had a mean total LER value of 1.26 in 1996b, indicating a yield advantage of 26 % over sole cropping of both maize and climbing beans. However, the mixtures in 1997a had a mean total LER value of 1.00, implying that intercropping was as efficient in land use as sole cropping of both component species. The same maize+bean mixtures which had the highest and lowest mean total LER values in both seasons, also

Table 7: Effect of plant population on yield advantages and total income of the maize and climbing bean intercrops.

Intercrop population (plants ha ⁻¹)		Intercrop yield (t ha ⁻¹)		Partial LER		Total income	
Maize	Beans	Maize	Beans	Maize	Beans	LER	(000' Ug. Shs)
				1996b			
25,714	44,444	3.905	0.926	0.85ab	0.43	1.28	2,488
27,820	52,842	4.271	0.741	0.93ab	0.33	1.26	2,423
27,428	57,142	4.257	0.727	0.92ab	0.34	1.26	2,430
24,476	66,667	3.433	1.075	0.75b	0.50	1.24	2,448
Means	:	3.967	0.861	0.86	0.40	1.26	2,447
25,666	53,968	4.148	0.633	0.90ab	0.30	1.20	2,292
27,666	45,079	3.830	0.851	0.83ab	0.40	1.23	2,383
25,333	57,142	4.303	0.775	0.93ab	0.36	1.29	2,496
27,666	70,476	4.481	0.754	0.97ab	0.35	1.32	2,547
Means	:	4.191	0.753	0.91	0.35	1.26	2,429
31,600	53,333	5.120	0.665	1.11a*	0.31	1.42	2,713
30,800	48,571	3.899	0.620	0.85ab	0.29	1.14	2,180
31,200	58,775	4.212	0.648	0.91ab	0.30	1.22	2,333
27,200	74,286	4.321	0.672	0.94ab	0.32	1.2	2,410
Means	:	4.388	0.651	0.95	0.31	1.26	2,407
Grand means	:	4.182	0.755	0.90	0.35	1.26	2,456
LSD _{0.05}	:	NS	NS	0.308	NS	NS	NS
CV (%)	:			19.17			
Sole maize	:	4.605				1.00	1,842
Sole beans	:	2.132				1.00	2,132

Table 7 contd.

Intercrop population (plants ha ⁻¹)		Intercrop yield (t ha ⁻¹)		Partial LER		Total income	
Maize	Beans	Maize	Beans	Maize	Beans	LER	(000' Ug. Shs)
				1997a			
22,115	51,924	1.749	0.844	0.84	0.39	1.23	1,544a*
21,154	60,862	1.632	0.621	0.77	0.28	1.05	1,261d
19,231	73,469	1.395	0.647	0.67	0.30	0.97	1,205bc
23,077	84,034	1.502	0.648	0.72	0.30	1.02	1,249b
Means	:	1.561	0.690	0.75	0.32	1.07	1,315
22,549	46,753	1.493	0.575	0.72	0.26	0.98	1,172bcd
23,510	63,492	1.572	0.600	0.75	0.27	1.02	1,229bc
23,524	70,745	1.099	0.521	0.62	0.24	0.86	1,174bcd
24,510	81,633	1.288	0.587	0.62	0.27	0.89	1,102cd
Means	:	1.412	0.571	0.68	0.26	0.94	1,136
Grand means	:	1.486	0.631	0.71	0.29	1.00	1,217
LSD _{0.05}	:	NS	NS	NS	NS	NS	130.9
CV (%)	:						19.12
Sole maize	:	1.807				1.00	723
Sole beans	:	2.175					2,175

* = Market prices used in computing TI are Shs.400/= and 1000/= per kg of maize and bean grain, respectively. Bean grain normally fetches twice the price of maize grain on Kabale markets.

produced the highest and lowest total income (TI) of Uganda shillings 2.71 and 2.18 million ha⁻¹ respectively, in 1996b, compared to Shs. 1.544 and 1.04 million ha⁻¹ respectively, in 1997a (Table 7). The mean value for TI of Shs. 2.427 million ha⁻¹ realised from mixtures in 1996b was 32 % and 14 % higher than TI accruing from sole cropped

maize (Shs. 1.842 million ha⁻¹) and climbing beans (Shs. 2.132 million ha⁻¹), respectively. In 1997a, mean value for TI of Shs. 1.217 million ha⁻¹ realised from mixtures was 68 % higher than TI from maize sole crop (Shs. 0.723 million ha⁻¹), but was 44 % less than TI accruing from climbing bean sole crop (Shs. 2.175 million ha⁻¹).

CHAPTER FIVE

GENERAL DISCUSSION

Maize LAI in intercrop was the only growth trait which was significantly affected by increasing maize PPD in 1996b, whereas in 1997a maize population had no significant effect on all maize vegetative growth traits. Bean PPD had no significant effect on maize growth in both seasons, presumably due to advanced maize planting, and the fact that the canopy was stratified: consisting of maize in the upper story and beans in the lower story. The effect of maize population on bean LA and TDM in intercrop was significant in 1996b, presumably due to vigorous maize growth favoured by weather conditions. However, bean growth was not significantly affected by maize PPD in 1997a, presumably because the weather conditions did not favour vigorous maize growth. Bean plant height, LA and TDM in intercrop were not significantly affected by increasing bean population in 1996b, presumably due to maize dominance over the beans. In 1997a, only bean LA and TDM were significantly affected by bean PPD, presumably because maize was less aggressive under low rainfall.

The values for maize plant height, LAI and TDM in intercrop were, respectively, 4 %, 26 % and 34 % lower than those for sole crop in 1996b. In 1997a, the corresponding values for the growth traits were 15 %, 45 %, and 40 % less than values for sole cropped maize. Bean plant height, LA and TDM in mixtures were, respectively, 7 %, 20 % and 37 % lower than for sole cropped beans in 1996b, whereas in 1997a, the corresponding values were 2 %, 24 % and 19 % less than for sole crop. Bean plant height was not significantly affected by intercrop PPD in both seasons, presumably because climbing in beans is stimulated by the presence of a support such as maize (Davis *et al.*, 1986). Maize growth

in intercrop was favoured by adequate soil moisture supply in 1996b, whereas drought stress at the beginning of the 1997a growing season significantly affected maize growth. The weather conditions generally affected bean growth in intercrop much more in 1996b compared to 1997a, presumably due to more vigorous maize growth in 1996b compared to 1997a. The amount and distribution of rainfall may have had diverse effects on crop growth during both seasons. For good performance, maize requires 500 to 700 mm of rainfall (Lafitte, 1994), while beans require 300 to 600 mm of rainfall (Onwueme and Sinha, 1991) which should be well distributed. The experimental site received 520 mm in 55 rain-days in 1996b, and 406 mm in 44 rain-days in 1997a season. In 1996b season, rainfall was spread over five months, whereas in 1997a, it was spread over only three months.

The main effect of drought during the vegetative period is to reduce leaf growth, so the crop intercepts less sunlight (White and Izquierdo, 1989). The effect is reflected in mean values for maize LAI in intercrop of about 3.0 in 1996b versus 1.6 in 1997a at 76 DAE of maize, and bean LA values of 3103 cm² in 1996b versus 326 cm² in 1997a at 59 DAE. In 1997a season, the rains tailed off towards the end of May before maize and beans had reached the grain filling phase, implying that drought stress may have contributed to lower yield values in 1997a compared to those of 1996b season. Similar results were reported by Fisher (1977), and Ugen and Wien (1996) for maize+bush bean mixtures. A deficiency of water during any growth stage of maize often results in loss of grain yields (Lorens *et al.*, 1987). However, the magnitude of the yield reduction depends on the growth stage of the crop at the time of stress, the severity and duration of the stress, and the susceptibility of the genotype to stress (Lorens *et al.*, 1987). Low moisture between tasseling and silking

leads to a delay in the exertion of silks and a reduction in seed set (Onwueme and Sinha, 1991), while drought occurring during the linear growth phase of kernel development primarily affects mean seed weight by reducing assimilate production or duration of grain-filling (Lorens *et al.*, 1987). The early vegetative stage (20 to 40 days after sowing) and the tasseling and silking stages (45 to 60 days after sowing) of maize are the most critical growth stages (Onwueme and Sinha, 1991). Compared to 1996b season, maize yield in intercrops in 1997a was 17 % lower, and this was mainly associated with a reduction in no. of grains cob⁻¹ and mean grain weight. This implies that the effect of drought became severe during the grain-filling period. Competition between maize and beans for growth factors, especially water could have been much more intense during 1997a compared to 1996b. The dry conditions obtaining in 1997a probably reduced the amount of available photosynthates for grain filling (Misbahulmunir *et al.*, 1989).

In beans, adequate soil moisture early in the season as well as during and immediately after flowering to pod-filling is also essential (Onwueme and Sinha, 1991). Intercropping maize with beans resulted in significant reduction in intercrop bean yield, which was associated with a significant reduction in pods plant⁻¹ in both seasons. This suggests that drought stress may have set in between flowering and pod-filling, thereby contributing to flower and pod abortion. Similar findings were reported by Fisher (1977), Davis and Garcia (1983), Wajja-Musukwe (1987), and White and Izquierdo (1989). Like plant growth, yield and yield components of both maize and beans were not significantly affected by plant population, presumably because beans matured much earlier than maize, and the removal of the former could have enabled the latter to compensate in the last growth phase to have an adequate grain-fill.

Yield of climbing beans declined with increasing maize plant population and increased (though not significantly) as bean population increased. Watson (1952) noted that yield declines at higher plant population due to mutual shading of leaves and interplant competition. Climbing beans were subjected to both intraspecific (non-significant) and interspecific (significant) competition for growth factors, plus additional shading from maize plants. Maize mean partial LER values of 0.9 and 0.71, compared to values of 0.35 and 0.29 for beans in 1996b and 1997a respectively, suggest that beans were dominated by maize in mixtures (Francis *et al.*, 1982). Bean yield and pods plant⁻¹ were highest at the lowest maize PPD, presumably because maize plants were too sparse to exert great competition for growth factors. Low maize population may have allowed more light to reach the beans, thus enabling the latter to increase assimilate production, since values for bean LA and TDM were highest at the lowest maize PPD. Intercrop maize and bean yield values in 1997a season were, respectively, 66 % and 17 % lower than for 1996b season, suggesting that competition for soil moisture between component species, could have been much more intense in 1997a than in 1996b.

Bean yield in mixtures was 63 % and 71 % lower than for sole crop in 1996b and 1997a, respectively. The big yield reduction may be partly attributed to a significant reduction of 25 % in bean population compared to only 16 % reduction in maize population in 1996b. Sole crop populations were reduced by 43 % in beans and 18 % in maize. In 1997a, plant losses in intercrops were about 13 % in beans and 22 % in maize, compared to 7 % in sole beans and 28 % in sole maize. Plant losses were attributed mainly to root rots of beans (especially in 1996b) and stalk borers in maize. Root rots of beans are mainly due fungal pathogens and lead to death of susceptible plants between seedling emergence and

flowering. In maize, plants did not lodge or die due to stalk borer damage; however, those with barren cobs were excluded from final stand. Weather did not favour rapid establishment of maize plants in 1997a; consequently, maize was not ready to support the beans when the need arose. Bean plants relied on each other more than on maize plants for support. This also may have contributed to low bean yields, because seed yield and quality are highly correlated with trellis or stake height, which ensures high pod clearance (Edje (1984). Climbing beans are generally less affected by diseases due to the escape mechanism of climbing which allows better aeration and limits the development of foliar pathogens (Graf *et al.*, 1991). Staking of crops that need support ensures that the leaves are well exposed to solar radiation, thereby considerably minimizing mutual shading (Edje, 1984; Osiru and Hahn, 1994). The implication for relative planting dates of the intercrop components is that planting of climbing beans should be deferred until there is sufficient soil moisture to guarantee rapid establishment of maize.

Correlation between bean and maize yield in intercrop was negative and significant ($r = -0.62$, $P < 0.05$) in 1996b, presumably due to intense competition between the two species for light, water and nutrients (Francis *et al.*, 1982; Clark and Francis, 1985). In 1997a, correlation between maize and bean yield was negative but not significant ($r = -0.31$, $P > 0.05$), suggesting that maize was less aggressive in 1997a compared to 1996b. Donald (1963) noted that if a component crop in an association absorbs or intercepts less than its share of a factor, for example, light, it is likely to acquire a correspondingly smaller share of all the other factors of production. The subordinate position of bean LAI relative to that of maize may also contribute to the commonly low intercrop bean yields derived from beans of varying monocrop yield potential (Clark and Francis, 1985). Since

crop photosynthetic rates depend on light interception patterns, yield potential should vary with canopy structure (White and Izquierdo, 1989). The relatively horizontal leaf orientation detected in studies of light interception in bean canopies implies loss of efficiency due to excessive illumination of upper leaves and shading of lower ones (White and Izquierdo, 1989). This situation may have been aggravated by intercropping climbing beans with maize.

Low yield of climbing beans may also have been due to increased pod abscission in the later stages of growth which could have coincided with increasing competition for light from maize (Fisher, 1977). Causes of abscission vary with growing conditions and cultivar. Abscission may result from water stress or competition among developing pods for nitrogen or other nutrients, and carbohydrates (White and Izquierdo, 1989). Although data on flower and pod abscission counts was not taken, results of the present study indicate that no. of pods plant⁻¹ in intercropped beans was consistently and significantly lower than in sole cropped beans across both seasons. Drought stress during 1997a season affected pods plant⁻¹ more than grains pod⁻¹ and mean grain weight suggesting that stress occurred during early flowering to pod formation.

Efficiency in resource utilization by an intercropping system, such as maize+climbing beans, is influenced by weather conditions. For instance, when amount of rainfall was adequate (as in 1996b), intercropping maize and beans was more efficient in land use than sole cropping of both species, whereas under drought stress (as in 1997a) intercropping generally had no yield advantage (i.e., with a mean total LER value of 1.0) over sole cropping of both components. Similar findings were reported by Fisher (1977) for a

maize+bush bean mixture. However, findings contrary to the above were reported by Ugen and Wien (1996) for a maize+bush bean mixture. In 1996b, mean total LER values for intercrops ranged from 1.14 - 1.42, whereas only one treatment had an LER value of 1.23 in 1997a; the other treatments had LER values ranging from 0.86 - 1.05. Generally, intercrops had lower mean LER values in 1997a compared to those achieved in 1996b, suggesting that intercropping may be more risky than sole cropping of beans in seasons which tend to have less than 500 mm of rainfall, and which is poorly distributed.

Competition overrides complementarity in resource use when growth factors such as soil moisture supply are limiting. Nutrient uptake and utilization by plants is greatly influenced by soil moisture availability. For instance, using fertilizer N at rates of 0, 80, and 160 kg ha⁻¹ on a maize+bush bean mixture, Ugen and Wien (1996) reported that yield of both maize and beans under drier conditions were up to 50 % lower than under wet conditions. The total plant density that can be sustained in an intercrop situation depends on environmental resources (Davis *et al.*, 1986). In 1997a, an intercrop of 21,080 maize plants ha⁻¹ and 51,924 bean plants ha⁻¹ had the highest mean LER value of 1.23; this is close to a 50:50 population mixture of maize and beans. Therefore, if maize and climbing beans have to be intercropped during seasons which experience drought conditions, plant population should be as low as possible, preferably at one-half the optimum sole crop population for each of maize and climbing beans.

In 1996b season, an intercrop of 31,600 and 53,333 plants ha⁻¹ of maize and beans respectively, had the highest mean values of LER and total income (TI). Although this mixture gave the highest maize yield of 5.120 t ha⁻¹, climbing bean yield was low

(i.e. 0.665 t ha⁻¹). The planting pattern which produces the highest physiological advantage cannot always be the one used by the farmer, because the farmer's choice is likely to be influenced by other considerations such as preference for a specific component (Natarajan, 1989). The highest intercrop bean yield of 1.075 t ha⁻¹ was realized from a mixture of 24,576 and 66,667 plants ha⁻¹ of maize and beans respectively, though mean LER and TI values were lower than for intercrop treatment mentioned earlier. Therefore, this latter mixture is more relevant to the farmers' production goal of maximizing bean yield and not total income in Kabale district since beans are produced mainly for home consumption.

Total income from the maize+climbing bean association was indirectly affected by the weather conditions which caused variable crop performance. In 1996b season, when rainfall was favourable for both maize and bean growth, TI realized from the intercropping system was higher than that accruing from sole cropping of component crops. Drought stress conditions during 1997a rendered the intercropping system more risky than sole cropping the beans, but potentially less risky than growing maize in pure stand.

The optimum mixture of two species also depends on economic factors such as relative prices of the two crops and their costs of production (Francis *et al.*, 1982). In the present study, the bean:maize price ratio used in computing TI was 2.5:1, which made intercropping to appear more profitable than growing climbing beans in pure stand under favourable weather conditions. However, at a price ratio of 1:1, sole cropping of maize may be more profitable than intercropping with beans whereas a price ratio higher than 3:1 could make sole cropping of climbing beans more profitable than intercropping with maize (assuming that cost of stakes remains at a favourable level). As the beans become of

relatively higher value, the optimum mixture contains an increasing proportion of this species. Similar views were held by Osiru (1974) for a maize+bush bean mixture, and Francis and Sanders (1978) for a maize+climbing bean mixture. The probability of at least breaking even was highest with the maize+bean intercropping system, suggesting that the intercropping system was less risky than climbing bean monoculture to the Colombian farmer (Francis and Sanders (1978)).

CHAPTER SIX

CONCLUSIONS AND SUGGESTIONS

Maize growth was generally not significantly affected by maize and climbing bean PPDs. Maize population significantly affected bean growth, whereas bean PPD had no significant effect on bean growth. Intercropping resulted in significant reduction in maize LAI and TDM, and bean TDM presumably due to lower plant populations in intercrops than in sole crops.

Maize yield and yield components were not significantly affected by maize PPD in both seasons, whereas maize yield was significantly affected by bean PPD only in 1997a. This suggests that in 1997a, maize competitive ability was reduced as reflected in competition ratio values for maize: beans. Rainfall pattern in 1997a did not favour maize growth and yield at high population. Bean yield and yield components were not significantly affected by maize PPD in both seasons. Bean PPD had no significant effect on bean yield parameters in 1996b, but pods plant⁻¹ was significantly affected by bean PPD in 1997a implying that beans should not be planted at high densities during seasons with unreliable rainfall. Intercropping significantly reduced bean yield in 1996b, and yield of both beans and maize in 1997a season. Under favourable weather conditions (as in 1996b), maize yield and yield components were least affected by intercropping, whereas unfavourable weather (as in 1997a) resulted in significant reduction in maize yield, which was largely associated with a reduction in both grains cob⁻¹ and mean grain weight. With regard to climbing beans, yield reduction in both seasons was mainly associated with a significant reduction in pods plant⁻¹.

Adequate rainfall during 1996b favoured growth of both component species, consequently rendering the maize+climbing bean mixture both agronomically and economically superior

to sole cropping of both components, whereas under drought stress in 1997a, intercropping was superior only to sole cropping of maize. Greater yield advantages due to complementary use of resources are realized from crop mixtures when maturity differences of the components are large enough (Willey and Osiru, 1972; Osiru, 1974; Ssekabembe, 1983). Climbing beans were harvested about one and a half months earlier than maize, thus presumably enabling the maize to compensate in the remaining growth period, by having a better grain fill than maize in pure stand in 1996b. Higher values (non-significant) for grains cob⁻¹ and mean grain weight in intercropped compared to sole cropped maize seem to suggest such a possibility. The possibility of nitrogen transfer from beans to maize (through decomposing roots, nodules) in 1996b cannot be ruled out. Similar views were held by Agboola and Fayemi (1971), Rweyemamu (1989), and Chemining'wa and Nyabundi (1994).

In order to improve the competitiveness and hence intercrop yield of climbing beans, plant population in mixtures should not exceed 25,000 and 75,000 plants ha⁻¹ of maize and beans in seasons with ample rainfall. Plant losses will have to be minimized by chemical control of stalk borers in maize, and identification of a climbing bean variety which can tolerate root rots. Intercrop system yield may also be sustained by application of inorganic fertilizer and/or organic manures. Yield advantages from mixtures planted in seasons with rainfall deficit may be realized if intercrop PPD is low, preferably by having 50 % of the optimum sole crop population of each species (i.e., 22,222 and 55,556 plants ha⁻¹ of maize and beans, respectively). A study on response of maize/climbing bean intercrop to fertilizer application (especially N and P) at low to moderate rates needs to be initiated, and an economic analysis of fertilizer use carried out to determine net benefits. Studies on crop combinations of sorghum and climbing bean genotypes also should be conducted since sorghum is more

drought tolerant than maize and is grown in Kabale district during the first rains season. The effect of relative planting dates on performance of the intercrop components also deserves investigation to determine the optimum planting date for beans in order to fully exploit temporal complementarity in resource use by the component species.

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