WATER USE EFFICIENCY AND ECONOMIC EFFECTS OF A MAIZE-LEGUME INTERCROPPING SYSTEM

BY

SHADRECK YONA NSONGELA

A DISSERTATION SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN AGRONOMY (CROP SCIENCE)

THE UNIVERSITY OF ZAMBIA
LUSAKA

1999

DECLARATION

I, Shadreck Yona Nsongela hereby declare that all the work presented in this dissertation is my own and has never been submitted for a degree at this or any other University.

Signature....................................

Date....31/04/99....

APPROVAL

This dissertation of Shadreck Yona Nsongela is approved as fulfilling part of the requirements for the award of the Master of Science Degree in Agronomy (Crop Science) by the University of Zambia.

Name and signature	Date
1	21/4/99 ....
2	21/4/99 ....
3	....
4	....

ABSTRACT

Maize-Legume intercropping systems are a common practice amongst small scale farmers in Zambia. However, the benefits of this practice are not fully understood due to inadequate information on the agronomic and economic effects of the system. There is need to find out more about the effects of maize-legume intercropping on water use efficiency, soil fertility, land use and labour needs. A study was conducted during the 1991 - 92 cropping season at the University of Zambia to establish the agronomic effects and economic benefits of a maize-legume intercrop. The specific objectives of the study were to investigate the effect of a maize-legume row intercropping system on water use efficiency by the crop components, and to establish the economic advantages of intercropping maize with legumes. Three intercropping experiments were conducted, and each consisted of a legume and maize. Soyabean (Glycine max L) variety Kaleya, common bean (Phaseolus vulgaris) variety Carioca and sunhemp (Clotalaria juncia) variety NIRS 3 were separately intercropped with maize (Zea mays L.) variety MM502. Each experimental unit was made up of four treatments namely maize monocrop, legume monocrop, maize-legume intercrop and bare (unplanted plot). The treatments were arranged in a Randomized Complete Block Design with four replications. Soil moisture, biomass and grain yield were measured The study found that intercropping improved Water Use Efficiency (WUE). This improvement was attributed to high biomass yield due to increased planting densities. Intercropping was also found to be a more economic way of growing crops compared to monocropping because higher economic indices were obtained in intercrops than in monocrops. Land Equivalent Ratio (LER) and the Cropping Index (CI) were 1.31 and 2.00 respectively for the maize-soyabean intercropping system. The indices show that the intercrop required 31% less land in producing yield equivalent to the sum of the two monocrops, and two different crops were simultaneously produced from the same piece of land. Similar results were observed in the maize-common bean intercropping system where the CI was 2.00. This study showed that although intercropping has been documented to offer both agronomic and economic benefits, these gains vary with factors such as prevailing agro-climatic conditions, farming techniques and cultural practices. There is thus need for continued research into intercropping systems under varying environmental conditions in order to develop technologies suitable for specific farming conditions.

DEDICATION

To my beloved Father and dearest late Mother who tirelessly struggled to bring me to what I am.

ACKNOWLEDGEMENTS

I am deeply indebted to my supervisors, Dr. A. Sichinga and Dr. O. Lungu for the inspiration, guidance and encouragement throughout the course of this work. I would like to thank all members of staff in the school, who in one way or another contributed towards the success of this work. In particular, I wish to acknowledge the cooperation and assistance of the Crop and Soil Science Departments and staff of the School of Agricultural Sciences field station.

Finally, I am very grateful to my sponsors (SACCAR-GTZ) for their financial support throughout the course of this work. My gratitude goes to the management and staff of Marshlands University Village for their hospitality and to all my friends who made my stay at the University of Zambia enjoyable.

Not to forget, I thank my wife and children for their love and patience in allowing me stay away from them for long hours.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ACRONYMS

BNF	- Biological Nitrogen Fixation
MAWD	- Ministry of Agriculture and Water Development
LER	- Land Equivalent Ratio
VSMC	- Volumetric Soil Moisture Content
CI	- Cropping Index
OM	- Organic Matter
IRRI	- International Rice Research Institute
CEC	- Cation Exchange Capacity
ANOVA	- Analysis of Variance
WUE	- Water Use Efficiency
USDA	- United States Department of Agriculture
FAO	- Food and Agricultural Organisation

LIST OF FIGURES

LIST OF PLATES OF TREATMENTS

1. INTRODUCTION

The population of Zambia will exceed ten million by the year two thousand if the present growth rate of 3.2 % continues (Kayope, 1992). There will be at least twice as many people to feed as in 1960 (Masuku, 1973). This means that the demand for food will have more than doubled and so should food production. With current conventional farming methods, this means increased demand on production resources such as land, water, fertilisers and other inputs. However, these resources are not unlimited. It is necessary therefore to search for farming systems which will increase food production through more efficient use of available resources (Wrigley, 1982).

The ideal cropping system is the one which will present agronomic benefits, increase resource utilisation efficiency and provide appreciable economic returns. Intercropping which is a system of growing more than one crop species simultaneously in the same field is one way of achieving increased and sustained food production more efficiently (Baldy, 1963). Among the advantages of intercropping include the reduction of risks resulting from pests, diseases, weather and other uncertainties; the reduction and more balanced distribution of labour requirements throughout the season and provision of a continuous and diversified food supply to the farmer and the community. Intercropping is a conservative way of using the limited resources, resulting in higher yields per unit input, area and time.

Amongst the major disadvantages of the intercropping system is the difficulty encountered in mechanising farm operations due to variations in the characteristics of the crop species involved. Use of chemicals is also difficult in intercrop systems due to difference in response and specifications for the different crop components (Wrigley, 1982). However, this does not present a major constraint to the small scale farmers as most of them do not have access to resources for heavy mechanisation and chemical use.

Legumes are an ideal crop to use in intercropping because they contribute to soil fertility maintenance by fixing atmospheric nitrogen (Wrigley, 1982). When legumes are intercropped with a crop such as maize, wheat or sorghum, the cereal will benefit from the nitrogen fixed by the legume. Nitrogen transfer takes place either directly through root secretions or indirectly through decomposition of the legume plant tissue (Power et al., 1983; Agboola and Fayemi, 1972; Shearer and Kohl, 1986). Martin and Touchton, (1983) reported that legumes can improve crop yields indirectly by reducing erosion, conserving water, recycling nutrients, and improving soil physical characteristics.

Maize-legume intercropping systems are a common practice among peasant farmers in Zambia especially with bean (Mwania, 1988). However, the benefits of this practice have not been exploited to the full owing to inadequate research and information on agronomic and economic characteristics of the various intercrop combinations (MAWD, 1987). Consequently, proven intercropping technology is not available (Kamona, 1989).

While the agronomic and economic advantages of intercropping maize with legumes have been documented elsewhere, little of this research has been done in Zambia (MAWD, 1987). Very little if any investigations have been carried out to study the effect of the maize-legume intercropping system on water use efficiency. Many small scale farmers occupy marginal rainfall areas and crop failure due to inadequate rainfall is a common occurrence. Improving crop production in these areas will require the search for cropping systems which are more efficient in the use of the scarce water resources. Intercropping is one of the cultural practices which promises increased water use efficiency. There is thus need for intensified research on maize-legume intercropping systems under varying environmental conditions to generate data for use to develop precise technological recommendations suitable for various agro-climatic conditions of Zambia. This could result in the improvement of the traditional intercropping systems practised by most peasant farmers.

A meeting to review progress made on food legumes research in Zambia, (Mulila et al., 1989) recommended amongst other research activities that economic assessment of promising intercrops needs to be undertaken and that the role of cultural practices in minimising crop losses due to biotic and abiotic stress factors should be thoroughly investigated.

This study was conducted to investigate the effect of the maize-legume row intercropping system on water use efficiency and economic considerations. The specific objectives of the study were to:

(a) Determine the effect of a maize-legume row intercropping system on water use efficiency by the crop components, and to

(b) Establish the economic advantages of intercropping maize with legumes.

2. LITERATURE REVIEW

2.1. CROP INTERACTIONS IN INTERCROPPING SYSTEMS

Crop interactions refer to the influences of individual or groups of crops within a population (intra-specific), or populations of different species (inter-specific) upon each other (Solomon, 1976). These can be classified as competitive, non competitive and complementary (Hall, 1974; Trenbath, 1974). Competitive interaction occurs when growth inputs are not sufficient enough to meet the full requirements of the individual crops in a mixture resulting in poor growth and yield (Grime, 1979). The situation usually occurs when crops are grown at densities which surpass the carrying capacity of a given environment, causing interference in the utilisation and uptake of growth resources such as light, nutrients, water and space. According to Steiner, (1984), competition for soil resources such as water and nutrients is often more limiting than competition for air and light. This is because the root system develops much faster than the shoot and thereby triggers early competition. In addition, the availability of water and nutrients in the soil is not as abundant as light and air is above the ground. It is thus important for the components in an intercrop to consist of crops with varying rooting patterns in order to exploit different soil layers and effectively utilise soil moisture and nutrient resources.

Shading is the main problem in intercrops because of different crop heights. Taller plants create shady conditions for short ones. Practising double intercropping and proper orientation of rows together with the careful selection of shade-tolerant crops and crops with upright leaf inclination will help reduce the problem (Steiner, 1984). In Nigeria, intercropping maize with cassava was found to offer the advantage of a 2 storey canopy, giving a higher light interception capacity than either maize or cassava alone (Aina et al., 1979).

Non competitive interactions occur when different species growing together share a growth resource such as air which is present in sufficient amounts so that it is not limiting to any of the component crops (Hall, 1974; Trenbath, 1974). Consequently, plant growth and yield are not adversely affected. Complementary interactions on the other hand are, non competitive interaction in which one plant or species helps the other (Hall, 1974; Trenbath, 1974). For example, in an intercrop of climbing bean (Phaseolus sp.) and maize (Zea mays L.) the maize was found to be offering support to the climbing bean thus enabling it to better intercept light (CIAT, 1973).

The success of intercropping depends on maximising the complementary effects and minimising the competitive ones (Willey, 1979). Combining crops to achieve maximum spatial and temporal differences will enhance the complementary effects of intercropping (Steiner, 1984). In this regard, crop components of different height and shoot structure, different root depth and structure, growth rate, and maturity period tend to give superior yields compared to monocrops. Solomon (1976) observed that competition between crops of the same species, which is characteristic of the monocropping system is more damaging compared to the one between crops of different species owing to minimal spatial and temporal differences between crops.

In Zambia, reduced yields have been reported in bean and soyabean intercropped with maize when planted at the same time (MAWD, 1984; Kanenga et al., 1989). The observations were attributed to the shading effect of maize on the bean and soyabean crops. When maize was planted later, an intercrop advantage was measured. Similar results were obtained in a maize-climbing bean intercrop where maize yield was only 30 - 60% of the sole crop compared to 90 - 108% when beans were relay-planted three weeks after maize. Yield increases of 80 % were obtained with 85-day pearl millet and 150-day sorghum intercrops as compared to intercrops of equal growth lengths (Andrews, 1972). This intercrop advantage was a result of the two crops having different stages of maximum demand for light, water and nutrients even though planting was done at the same time.

2.2. WATER USE EFFICIENCY IN MAIZE-LEGUME INTERCROPPING SYSTEMS

Water is a very important growth resource because it forms the basis for the plant's metabolic processes including photosynthesis. Once water application is stopped, a plant will not grow. Similarly, a crop growing under limited moisture conditions cannot grow well and attain maximum yield (Rim et al., 1987; Doorenbos et al., 1979; Wrigley, 1982). It is therefore important to understand crop water requirements under different growing conditions. This is because crop productivity is dependent on how much the crop's water requirements are met.

The amount of water required by a plant depends on plant type and stage of growth while the amount available is governed by soil characteristics and meteorological conditions (Chae, 1984). The amount of water available to the plant determines its growth and yield potential (Rim et al., 1987). When the full water requirements are met, crops are able to attain optimal growth and achieve maximum potential yield provided other conditions are not limiting. When the full water requirements are not met, the crop is unable to attain optimal growth and actual yield will be less than its maximum potential. There is thus a very close relationship between relative yield decrease and relative water deficit. According to Doorenbos et al., (1979), this relationship is expressed by the formula:

$$(1 - Ya/Ym) = ky(1 - ETa/ETm)$$

where, Ya is actual harvested yield, Ym is maximum possible yield, ky is yield response factor, ETa is actual evapotranspiration and ETm is maximum evapotranspiration. Maximum evapotranspiration can only be achieved when the water requirements of the crop are fully met. Actual evapotranspiration will then be equal to maximum evapotranspiration and the crop's maximum potential yield will be attained as long as other growth factors are not limiting

The maximum possible yield of a crop is primarily determined by its genetic characteristics and secondly by how well the crop is adapted to the prevailing environmental conditions (Doorenbos et al., 1979). There is a very close relationship between crop growth and climate, water and other soil conditions. These relationships are complex and involve biological, physical, physiological and chemical processes. The climatic factors which influence crop development and yield are rainfall, humidity, temperature, radiation and length of the growing season. The length of the growing season is in turn determined by the duration of an assured water supply of good quality.

The amount of soil water that is readily available to the plant is that which lies between field capacity and wilting point (Chae, 1984). The actual rate of crop water uptake in relation to its maximum evapotranspiration is determined by the amount of available water in the soil. Doorenbos et al., (1979) defined Water Use Efficiency as a measure of the amount of dry matter produced per unit amount of water evapotranspired. When soil water conditions are not limiting, water use efficiency differences between plants are insignificant as long as other conditions are not limiting. However, under water stress conditions crop response to water varies between varieties and growth stages. Maize for example has a relatively higher Water Use Efficiency than sorghum when moisture conditions are not limitimg. However, sorghum produces more dry matter than maize when moisture is deficient. Crop demand for moisture is generally higher during germination, flowering, pollination and the early grain-filling stage.

According to Sanchez, (1976), Water Use Efficiency is higher in intercropping systems compared to monocropping systems due to the spatial and temporal differences in the water requirements of the component crops. In one experiment it was found that crops of different maturity periods reached periods of peak moisture demand at different times, thereby allowing for a uniform distribution of available moisture. In another experiment involving maize and soyabean, it was found that the fibrous root system of maize colonised the soil nearest to the surface while the tap root system of the soyabean plant penetrated deeper in the soil. Water was thus exploited from two levels, resulting in maximised exploitation of the soil's water resources. De, (1980) reported an increase of 6.5 kg/m^3 and 9.1 kg/m^3 in water use efficiency for maize/soyabean and maize/mung bean intercrops respectively over sole maize.

One other advantage of intercropping is that it induces competition in the root system. Increased plant population in intercrops results in the quick crowding of the soil with roots and consequently trigger competition leading to some roots growing deeper in search of water (Robertson et al., 1973).

Intercropping allows for the formation of a thick canopy due to higher planting densities. Dense canopies minimise water loss by reducing evaporation due to the wind-break effect and temperature reduction at the crop-atmosphere interface (Baldy, 1963). The effect is enhanced by intercropping tall crops with short ones. Tall crops create a windbreak effect which helps reduce evapotranspiration . Sunhemp has been intercropped with maize in Tanzania with the advantage of conserving moisture for the companion crop (maize) due to its formation of a dense canopy and its deep rootedness which allows it to exploit water from deep down, resulting in more effective use of water (Gerold, 1989). In another experiment, intercropping maize with soyabean reduced the rate of evapotranspiration by 20 - 25 % and consequently increased soil moisture and humidity by 10 % and 20 % respectively (Wonsan, 1982). The dense canopy formed in intercrops also helps prevent soil erosion by rain water action. Fewer raindrops reach the soil surface with great impact because the dense canopy intercepts and break-up heavy rain drops. High plant densities together with the litter-fall block water flow while the increased volume of roots further opens up the soil. Erosion is thus controlled and infiltration is improved. Lal, (1977) reported an annual reduction in soil erosion from 12.5 kg/m^2 in a cassava monocrop to 8.6 kg/m^2 when cassava was intercropped with maize.

2.3. FERTILITY STATUS IN MAIZE-LEGUME INTERCROPPING SYSTEMS

One of the main advantages of maize-legume intercropping systems is its potential to to improve soil fertility through nitrogen and organic matter supplementation (Frye and Blevins, 1982). Nitrogen is a very important plant nutrient because it is used in making proteins and other substances in the plant tissue. Soil fertility in the maize-legume intercropping systems benefits mainly from nitrogen accumulated from biological nitrogen fixation by the legume (Searl et al., 1981; Singh et al., 1986; Waghmare and Singh, 1984). Symbiotic rhizobium bacteria are potentially able to fix up to 300 kg of nitrogen per hectare (Kim, 1983). About one third of the nitrogen fixed by the legume is found in the root and above-ground biomass, and this becomes available to the soil after mineralisation (Yagodin, 1984). The effect of a legume on soil fertility depends on the amount and treatment of the crop residues left in the field. Legumes with long growing periods give high accumulation of fixed nitrogen (Sanchez, 1976). Grain crop residues and grazed pastures have lower N contents compared to green manures because 60 - 90% of the fixed N is removed with the grain and plant tops respectively.

Yagodin, (1984) found that the amount of biologically fixed nitrogen was not sufficient for a marked increase in soil fertility. It only compensated for the nitrogen removed in yields and lost through leaching and denitrification. However, Doorenbos et al., (1979) maintain that crops such as beans and soyabean were capable of fixing adequate amounts of atmospheric nitrogen which met their requirements for high yields. Similar results were recorded at Msekera Research Station where the yield of a well-nodulated bean variety was not significantly different from that of a fertilised one with poor nodulation (MAWD, 1986). Herridge and Bergerson, (1988) found that even in a poor nitrogen fixing crop, there are benefits because the legume will remove less nitrogen from the soil. This will reduce competition for the nutrient between the legume and companion or subsequent cereal crop. For efficient use of the fixed nitrogen, the beneficiary crop should be planted in time to utilise the nitrogen released during decomposition before it is volatilised, leached or used by microbes.

De, (1980) observed greater nitrogen uptake by sorghum when intercropped with mung bean than when grown as a single crop. They found that 18.1 % of total nitrogen absorbed by sorghum was from fertiliser, 21.9 % from biological nitrogen fixation and the rest from soil reserves. They further observed that sorghum benefited from residual nitrogen from the legume. Sorghum yield was 5.13 t/ha when grown after beans compared to 3.47 t/ha when grown consecutively. Results showed that the legume benefited both the companion cereal (sorghum) and the subsequent one.

Intercropping legumes with non-legumes promotes nitrogen fixation. Rerkasem et al., (1988) studying a rice-bean and maize intercrop found that the proportion of nitrogen derived from biological fixation was higher in rice bean grown in association with maize than when grown as a sole crop. The result was attributed to the symbiotic effect of intercropping where maize inhibited nitrogen uptake by the legume and forced it into biological nitrogen fixation for its requirements. Biological nitrogen fixation is a natural process by which legumes satisfy their nitrogen requirements. The process is enhanced when soil nitrogen is deficient but inhibited when abundant (Sanchez, 1976). Symbiotic biological nitrogen fixation occurs when legumes are intercropped with cereals because cereals tend to inhibit the legume's uptake of soil nitrogen by absorbing most of it. Biological nitrogen fixation is consequently triggered in the legume to satisfy its nitrogen requirements.

Patra, et al., (1986), working on an intercrop of maize and cowpeas under field conditions, found that 28 % of the total nitrogen uptake by maize (representing 21.2 kg/ha) came from the atmosphere. The nitrogen was obtained by the transfer of fixed nitrogen by cowpea to the maize. They, however, found that plant population density, ratio of the legume to the non-legume, the legume's nitrogen fixing efficiency and distance between the legume and non-legume as well as rooting patterns were the main determining factors. Nitrogen transfer was found to be more effective when the ratio of legumes to cereals was high and crops were planted closely, allowing for the roots of the two crops to interact.

One of the main determining factors of biological nitrogen fixation is moisture. Moisture stress inhibits the activity of biological nitrogen fixation. This happens because biological nitrogen fixation is a high moisture-consuming process, and its effectiveness in improving soil fertility in areas of low rainfall is greatly limited. Hera, (1978), working with soyabean found that water stress was one of the most limiting factors in biological nitrogen fixation by soyabeans. In another experiment, Bennet and Albretch, (1984) reported a reduction in biological nitrogen fixation when nodulated soyabean was exposed to drought and that normal fixation resumed when drought was relieved. Similar results were observed by Ahmed et. al., (1981). These results suggest the need to ensure optimum efficient use of available moisture in order to maximise benefit from BNF.

Organic matter is a very important component of the soil because it helps keep the soil aggregated, reducing soil erosion (Allison, 1973). It acts as a reserve for soil nutrients especially N and also helps conserve moisture in the soil. Organic matter improves soil by building up light soils and opening up heavy ones, thereby giving the soil the desirable friable structure. Furthermore, organic matter plays the other important role of creating a favourable environment for soil organisms which contribute to soil fertility. A soil without organic matter loses condition, becomes lifeless and is hard to work.

The amount of soil organic matter in the soil depends on the rate at which plant and animal residues are added, and the rate of their decomposition (Greenland and Hayes, 1981). The rate of decomposition is dependent on the management of the crop residues, being faster if the residues are ploughed-in than when they are left on the surface..

Most intercropping systems yield higher organic residues than monocrops due to increased planting densities and land use efficiency (Andrews and Kassam, 1976;). The rate of residue decomposition is equally higher in most intercrops due to increased population of soil organisms and improved conditions for organic matter decomposition and turnover. Frye and Blevins, (1982) reported increased soil organic matter and nitrogen contents as well as water infiltration when the legume was used as a cover crop in maize. They further observed that run-off and evapotranspiration reduced due to greater organic matter production. They found that although the cover crop depleted soil water during its growth, the condition was reversed within two weeks after cutting the legume to make a mulch. The beneficial result was *attributed to increased infiltration and reduced evapotranspirational loss. In addition, greater* fertiliser use efficiency was observed. Intercropping altered the crops' rooting patterns, resulting in a greater volume of soil being exploited.

2.4. ECONOMIC ADVANTAGES OF THE MAIZE-LEGUME INTERCROPPING SYSTEM

Improving crop productivity is every farmer's desire. Productivity is the measure of output per unit input. Output refers to the product whereas input refers to the resources used in making a particular product. In crop production inputs refer to all the growth resources including biological resources such as seed, physical resources such as land and social resources such as labour. It has been reported that intercrop systems give higher economic returns compared to monocrops. Intercropping allows for crop diversification, increased yield per unit land, and higher income per unit input. Intercrops offer economic complement by producing more for the same cost. Andrews and Kassam, (1976) reported that most intercrop systems show advantage in terms of Cropping Index (CI), Land Equivalent Ratio (LER), Income Equivalent Ratio (IER) and net economic benefits. The Cropping Index (CI) is the number of crops grown per annum on a given area of land expressed as a percentage. LER is the ratio of the area needed under sole cropping to one of intercropping at the same management level to give an equal amount of yield. IER is the ratio of the area needed under sole cropping to produce the same gross income as one hectare of intercropping at the same management level.

Intercropping increases the resource utilisation efficiency. Land, labour, machinery and other capital investments are better utilised, resulting in higher net returns per unit input. Norman, (1968) reported high labour use efficiency and a high Cropping Index (CI) in long duration intercrop sequences producing three or four crops in a 10 month period. Only one primary tillage operation was required per year. More than one tillage would have been required to grow the same crops under monocropping. In Egypt, the introduction of multiple cropping on commercial basis increased the Cropping Index (CI) from 100.4% to 159.1% (Dalrymple, 1971). Land Equivalent Ratios of up to 1.6 have been reported for farmers' fields in Northern Nigeria (Baker and Norman, 1975). Experimental LERs of up to 2.0 have been reported at the International Rice Research Institute in the Philippines (IRRI, 1974). Daniel and Stephen (1981) reported LER of 1.7 for the maize-soyabean row intercrop system.

Flor and Francis (1975) reported results from agronomic and economic experiments of bean and maize row intercropping system in Palmira, Columbia, in which an intercrop trial consisting of 100% maize (44 000 plants/ha) and 100% bean (222 000 plants/ha) was studied. A Land Equivalent Ratio of 1.63 was achieved while income generated was twice that of the bean monocrop. The LER increased to 1.89 when the bean plant population was reduced by 50%.

Intercropping increases the land use efficiency. Intercropping short crops in between young trees made it possible to utilise the land in between the trees, which would have remained idle until the trees had grown enough to occupy the space (Wonsan, 1982). Coconut, oil palm, and young rubber trees are often intercropped, in the early years of the plantation, to a range of annual crops such as cassava, soyabean, groundnuts, maize, and other crops (Blencowe, 1969).

Andrews and Kassam, (1976) showed that intercropping systems gave higher yields than monocropping patterns because of higher plant population densities. Kanenga et al., (1989), working on a groundnut:maize intercrop reported a 21% increase in yield at 100% maize and 100% groundnuts in a 1:1 row arrangement with additional fertiliser to maize. A 2:1 row arrangement with 100% maize and 67% groundnut plant density with additional fertiliser to maize resulted in a 15% increase in grain yield. The data showed that reduced performance in one of the component crops was compensated by increase in the yield of the companion crop.

A study conducted by the North Carolina State University, (1973) on the maize-bean intercrop found that the maize crop reduced the bean yield to only one third of the single crop. The reduction was found to be negligible compared to the total intercrop yield. Lepiz (1971) reported data from an intercropping trial of maize and bean at various seeding densities, conducted for three consecutive years in Mexico. The results showed that although the yields of individual crops in the intercrop were lower than their respective monocrops, overall intercrop yield was higher. Total income realised was also higher.

3. MATERIALS AND METHODS

3.1. DESCRIPTION OF THE EXPERIMENTAL SITE

The experiment was conducted at the University of Zambia, School of Agricultural Sciences Field Station. The site is located $15^0 23'$ S and $28^0 20'$ E and is about 1140 m above sea level (Chikuma et al., 1985). The area experiences a tropical continental type of climate with marked wet (November to March) and dry (April to October) seasons. The dry season is divided into the cool dry (April to July) and the dry hot (August to October).

Table 1: Selected characteristics of the soil at the experimental site

Soil Depth (cm)		0 - 30
Soil Texture	Sand (%)	51.60
	Silt (%)	16.00
	Clay (%)	32.40
Organic Matter (%)		1.70
Total Nitrogen (%)		0.10
Soil Acidity ($pH_{(H2O)}$)		7.80
Effective CEC ($cmol(+)kg^{-1}$)		11.80
Bulk Density (g/cm^3)		1.50
Porosity (%)		43.00
Soil Water Capacity (mm/m)		140.00
Field Capacity (mm/m)		280.00
Wilting Point (mm/m)		140.00

The soil, a sandy clay is deep, well-drained and slightly alkaline. It is classified in Soil Taxonomy as an Oxic Paleustalf (Gill et. al., 1993). The soil characteristics are given in Table 1.

3.2. EXPERIMENTAL DESIGN

Three intercropping experiments were conducted. Each consisted of a legume and maize. Soyabean (Glycine max L) variety Kaleya, common bean (Phaseolus vulgaris) variety Carioca and sunhemp (Clotalaria juncia) variety NIRS 3 were separately intercropped with maize (Zea mays L.) variety MM502. Each experimental unit was made up of the following four treatments (Plates 1 - 8):

Treatment 1: Bare (Unplanted plot)
Treatment 2: maize monocrop
Treatment 3: legume monocrop
Treatment 4: maize-legume intercrop

Monocrop treatments were taken as controls for the intercrop treatment in each experiment. A bare plot treatment was included in order to provide data on water entry into the soil and its loss due to evaporation under undisturbed soil conditions.

The treatments were arranged in a Randomized Complete Block Design with four replications, and they were randomly allocated to the plots in each block according to the field plan shown in Table 2.

The main crop in each experiment was maize and the legume was the poly crop. The choice of common bean, soyabean and sunhemp as legumes was based on the popularity of common bean in traditional cropping, significance of soyabean as a cash crop and potential of sunhemp as a nitrogen fixer.

Table 2: Field Plan

Experiment 1

BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
maize/soyabean	Soyabean	Soyabean	unplanted
Soyabean	Unplanted	Maize	soyabean
Unplanted	Maize	maize/soyabean	maize
Maize	Maize/soyabean	unplanted	maize/soyabean

Experiment 2

BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
c-bean	Unplanted	c-bean	c-bean
maize/c-bean	Maize/c-bean	maize	unplanted
Unplanted	c-bean	maize/c-bean	maize
Maize	Maize	unplanted	maize/c-bean

c-bean - common bean

Experiment 3

BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
Sunhemp	Sunhemp	sunhemp	unplanted
Unplanted	Unplanted	maize	sunhemp
Maize	maize/sunhemp	unplanted	maize
maize/sunhemp	Maize	maize/sunhemp	maize/sunhemp

3.3. CULTURAL PRACTICES

The site was ploughed by a moldboard plough and subsequently harrowed to a fine tilth. The site was then demarcated into 4 blocks each containing 4 treatment plots (blocks). The plot size was 2 m x 2 m and a border strip of 2 m wide was left between the treatment plots.

One aluminium access tube of 2 m long and 5 cm in diameter was firmly installed at the centre of each treatment plot for measuring soil moisture using a neutron probe moisture meter. The access tubes were sunk down to a depth of 1.8m into the ground. Water entry into the access tubes was blocked by plugging the bottom end and covering the upper end with empty aluminium soda cans.

3.3.1. Planting

Crops were planted on the 24th of December 1991. The inter-row spacing for both mono and intercropped maize was 70 cm while that of monocropped legumes was 50 cm. Legumes were planted in-between the maize rows (35 cm from the maize rows) in the intercrop treatments. Seeds were planted at depths of 5 cm for maize, 3.5 cm for soyabean and common bean, and 2.5 cm for sunhemp.

Two seeds of maize were planted per station at an intra-row spacing of 26 cm between the stations. The plants were thinned out 20 days after emergence, leaving one plant per station. Gap-filling was done twice to maintain a plant population of 55 000 plants/ha in both the mono and the intercropped maize treatments. The first gap-filling was done ten days after planting by replanting, and the second was done ten days later by transplanting the thinned out plants.

Soyabean was planted by drilling, and seedlings were thinned out 20 days later leaving an intra-row spacing of 5 cm to maintain a plant population of 400 000 plants/ha in the mono and 286 000 plants/ha in the intercrop treatments. The soyabean seed was treated with a peat-based inoculum - Rhizobium japonicum just before planting. Standard procedures were followed in treating the seed (Wellving, 1984).

Common bean was planted in stations 5 cm apart at one seed per station. Plants were thinned out 20 days after planting to maintain an intra-row spacing of 10 cm and a plant population of 200 000 plants/ha in the monocrop and 142 000 plants/ha in the intercrop treatments. No inoculum was applied.

Sunhemp was closely planted for later thinning. Plants were thinned out 20 days later leaving plants 15cm apart to maintain a plant population of 133 333 plants/ha in the monocrop and 95 200 plants/ha in the intercrop treatments. No inoculum was applied according to the usual practice with this crop (Welving, 1984).

3.3.2. Fertiliser Application

Compound "D" fertiliser was applied as basal dressing to all crops in the three experiments. The fertiliser was placed below the seed. Application in maize was at a rate of 350 kg/ha supplying 35 kg N/ha, 70 kg P_2O_5/ha and 35 kg K_2O/ha. The soyabean and common bean received 300 kg/ha supplying 30 kg N/ha, 60 kg P_2O_5/ha and 30 kg K_2O/ha. Basal dressing in sunhemp was at a rate of 600 kg/ha supplying 60 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha. In addition, Triple Super Phosphate was applied to sunhemp at a rate of 180 kg/ha supplying 79.2 kg P_2O_5/ha.

Only maize was top dressed with urea at a rate of 240 kg/ha, supplying 110 kg N/ha. This application was done 60 days after planting, and fertiliser was placed on the soil surface 5 cm to the side of the maize plant along the row, and covered.

3.3.3. Management of the Experiment

The experimental management activities undertaken included weeding and sunhemp slashing. Weeding was done by handhoeing at 23 and 35 days after planting for all the treatment plots. Sunhemp was slashed down each time it grew to the height of maize or 1 m high, which ever occurred first. This was done to control the crop's shading on maize. It also helped accelerate sunhemp growth, thereby increasing biomass yield. Slashing was done at a crop height of 30 cm above the ground, and this was done three times during the season. The first slashing was done at 48 days, the second at 78 days and the final at 130 days after planting.

3.3.4. Crop Harvesting

The crop was harvested manually by cutting down the stems at ground level for biomass determination. Maize was cut down using a machete while a sickle was used to harvest the legume crop. An area of 4 m^2 in the middle of each treatment plot was harvested leaving out the 2 m wide border areas. The harvested crop was weighed for biomass yield after which the maize cobs and legume pods were removed and threshed to obtain grain.

3.4. DATA COLLECTION AND ANALYSIS

3.4.1. Soil Moisture

Soil moisture content was determined using a neutron probe moisture meter. Measurements were taken by lowering the probe to the appropriate depth down the access tube and operating the moisture meter. Readings were taken at 5 cm, 15 cm, 30 cm, 45 cm and 60 cm depths. Neutron probe readings for each depth were converted to volumetric soil moisture content (VSMC) (%) using correlation procedures (Little and Hill, 1978). A calibration curve giving the relationship between the count ratio (CR) and soil water was separately established for each depth in each experimental site to facilitate the conversion of probe readings to soil water content (Figures 1 - 5). The values obtained were then averaged over the 60 cm soil depth to obtain one figure per treatment plot. The figures were finally averaged over ten day periods to give one VSMC reading per treatment plot per dekad (Appendices 1 - 3)

Crop water use was determined by employing the modified Penman's method (Doorenbos et al., 1979). Rainfall, pan evaporation, wind speed, sunshine, relative humidity and temperature data for the season were used to calculate the potential (reference) evapotranspiration (ETo) using the Lotus, Instat and Clicom computer programmes. Maximum evapotranspiration (ETm), or water requirement was calculated as a product of ETo and crop coefficient (kc) (Appendices 21 - 24):

$$ETm = ETo \times kc \quad \ldots\ldots \quad 1$$

Crop coefficients for maize, soyabean and common bean are given in Appendix 37.
Soil Water Capacity (SWC) was taken as the difference between water content at Field Capacity (FC) and Wilting Point (WP):

$$SWC = FC - WP \quad \ldots\ldots \quad 2$$

Actual precipitation (Pa) was determined as the difference between precipitation (P) and ETm as shown in equation 3. .

$$Pa = P - ETm \quad \ldots\ldots \quad 3$$

The Pa was added to the Soil Water Reserves or water content (Ra) to give Total Soil Water Reserve (Rt):

$$Rt = Ra + Pa \quad \ldots\ldots \quad 4$$

Actual evapotranspiration (ETa) was calculated as the product of ETm and the ratio of Rt to SWC:

$$ETa = ETm \times Rt/SWC \quad \ldots\ldots \quad 5$$

Water Use Efficiency (WUE) was taken as the amount of dry matter produced, biomass yield (Ya) per unit amount of water used (ETa):

$$WUE = Ya/ETa \quad \ldots\ldots \quad 6$$

Combined WUE of the intercrop was calculated using the combined biomass yield of the individual components of the intercrop and their mean ETa. Similarly, the combined WUE of the monocrops was calculated using the combined biomass yield of the individual monocrops and their mean ETa. The mean ETa was taken as the mean of the individual ETa values of maize and the legume.

3.4.2. Economic Analysis

Evaluation of the economic advantages of the intercrop systems over the monocrop was accomplished by determining the Cropping Index (CI) and Land Equivalent Ratio (LER). The CI was taken as the number of crops grown per annum on a given area of land expressed as a percentage of the whole cropping area (Andrews and Kassam, 1976):

$$CI (\%) = \frac{\text{number of crops grown per annum}}{\text{Cropped area (ha)}} \times 100$$

The LER was taken as the ratio of the area needed under sole cropping to that of intercropping at the same management level to give an equal amount of yield (Steiner, 1984; Andrews and Kassam, 1976):

$$LER = \frac{\text{total yield of intercrops}}{\text{cropped area (ha)}} : \frac{\text{total yield of sole crops}}{\text{cropped area (ha)}}$$

LER was based on grain yield.

3.4.3. Meteorological Data

Agrometeorological data on rainfall, temperature, wind speed, humidity, sunshine and pan evaporation for the season were obtained from the Geography Department of the University of Zambia (Appendices 4 - 9). In addition, normal meteorological data (representing ordinary weather patterns for the area) were obtained from the Central Meteorological Office (appendices 4 - 9). The data were used to establish the suitability of the area to the experimental crops and also to determine if the year during which the experiment was conducted experienced normal weather patterns.

3.4.4. Plant Growth

Plant growth was measured by taking note of the period to emergence, germination percentage, period to tussling and flowering, and period to physiological maturity (Appendices 38 and 39).

3.4.5. Yield

Biomass and grain yield were measured. Biomass yield was determined by weighing the above-ground matter including grain from each treatment plot area (excluding borders). Grain yield was determined by weighing the grain obtained from each treatment plot. The thousand grain weight was determined by randomly picking and weighing a sample of 1000 grains from each treatment plot. Grain yield was adjusted to 12% moisture content.

3.4.6. Data Analysis

Data were statistically analysed for significance of variance, and Least Significant Difference (LSD) tests were used to separate means. The MSTAT computer programme was used to analyse variance while the Range subprogramme was used to separate the means.

4. RESULTS AND DISCUSSION

4.1. EFFECT OF MAIZE-LEGUME INTERCROPPING SYSTEM ON WATER USE EFFICIENCY (WUE)

4.1.1. RESULTS

EXPERIMENT 1: THE MAIZE-SOYABEAN INTERCROPPING SYSTEM

The raw data for biomass yield from both the monocrop and intercrop treatments are given in Appendices 40 to 45. Mean biomass yields are shown in Table 3.

Table 3: Mean biomass yields for maize and soyabean (kg/ha)

Cropping System	Maize	Soyabean
Monocrop	22002.45	10218.00
Intercrop	16644.27	4267.00
Coefficient of Variation (%)	19.26	20.05
LSD (0.05)	5137.79	2699.52

There were significant differences in biomass yield between the mono and intercrop treatments (Appendix 14). Both maize and soyabean monocrop yields were higher than their respective components in the intercrop. However, the combined mean yields of maize and soyabean in the intercrop was higher than that of monocrops (Table 4). This means that the intercrops produced more biomass (30%) than the monocrops based on an equivalent area of land. Thus the intercrop can be said to be more efficient in land utilisation, indicating potential usefulness in alleviating problems associated with shortage of arable land.

Table 4: Combined means of maize and soyabean biomass yields(kg/ha)

Crop	Cropping System		CV (%)	LSD (0.05)
	Monocrop	Intercrop		
Maize	22002.50	16644.25	19.26	5137.79
Soyabean	10218.00	4267.20	20.05	2699.52
Combined mean yield	16110.25	20911.45	14.82	2727.10

Maize ETa figures for the entire growing period are given in Table 5 and that of soyabean in Table 6. There was no significant difference between the mono and intercrop treatments (Appendices 15 and 16).

Table 5. Maize ETa (mm) in a maize-soyabean intercropping system

D	1	2	3	4	5	6	7	8	9	10	11	12	T
M	-	-	1.17	1.32	3.30	3.72	3.21	6.58	6.11	6.10	5.17	3.20	39.88
I	-	-	1.17	1.32	3.30	3.72	3.21	6.05	6.11	6.10	5.56	3.20	39.74

Coefficient of Variation (%) 47.10

D - Dekad; M - Monocrop; I - Intercrop; T - Total

Table 6. Soyabean ETa (mm) in a maize-soyabean intercropping system

D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	T
M	-	-	1.17	1.32	3.30	3.72	3.21	4.39	5.82	5.81	4.92	4.00	4.55	2.69	44.90
I	-	-	1.17	1.32	3.30	3.72	3.21	4.11	5.82	5.81	5.30	4.00	4.55	2.64	44.95

Coefficient of Variation (%) 39.90

D - Dekad; M - Monocrop; I - Intercrop; T - Total

These data show that the cropping system did not affect overall water use. The high plant population in the intercrop did not affect the evapotranspirational capacity and did not induce competition among component crops for soil moisture. Consequently, the yield difference observed between the mono and intercrop treatments (Table 3) can not be attributed to soil moisture stress or excess as there was no comparative advantage in water use between the two cropping systems. This information shows that intercropping is a more economical way of growing crops as more biomass yield was produced without needing extra water resources.

Table 7: WUE in a maize-soyabean intercropping system

Crop	Biomass Yield (kg/ha)		ETa (mm)		WUE (kg/ha/mm)			CV (%)	LSD (%)
	M	I	M	I	M	I	IEG		
Maize	22002.20	16644.25	39.88	39.74	551.70	418.83	-24.08	17.20	118.73
Soyabean	10218.00	5377.90	44.90	44.95	227.57	119.64	-45.67	48.61	88.92

M - Monocrop; I - Intercrop; IEG - Intercrop Efficiency Gain (%)

The data on maize and soyabean WUE is presented in Table 7. There was no advantage of intercropping in WUE for either the maize or soyabean component of the intercrop . Rather, both maize and soyabean in the intercrop gave lower WUE than their respective monocrops. This result shows that intercropping is less efficient in moisture utilisation when only a single component crop of the intercrop is considered. However, consideration of only one component of the intercrop is not a true reflection of intercrop productivity. Intercrop productivity can best be measured by considering all the components of the intercrop simultaneously. Consequently, combined WUE was calculated and values are given in Table 8.

Table 8: Combined WUE in a maize-soyabean intercropping system

Combined Biomass Yield (kg/ha)		Mean ETa (mm)		Combined WUE (kg/ha/mm)			CV (%)	LSD (%)
M	I	M	I	M	I	IEG		
16110.30	20911.45	42.39	42.35	380.05	493.78	30.00	14.87	64.35

M - Monocrop; I - Intercrop; IEG - Intercrop Efficiency Gain (%)

The WUE of a combination of component crops in the intercrops was larger than that of a single crop in the monocrops. An IEG of 30% was obtained for the maize legume intercrop, indicating that intercropping was more efficient in utilising soil moisture than monocrops. Biomass production was 30% more than that of the monocrop for the same amount of moisture. Therefore, intercropping provides one way of increasing crop production without increasing production costs through water supply. The ever increasing demand for water shows the importance of intercropping as one way of ensuring sustained crop production.

EXPERIMENT 2: THE MAIZE-COMMON BEAN INTERCROPPING SYSTEM

Maize and common bean biomass yields are given in Appendices 41 and 44 respectively. Mean biomass yields are shown below (Table 9).

Table 9: Mean biomass yield for maize and common bean (kg/ha)

Cropping System	Maize Yield	Common bean Yield
Monocrop	22002.45	8437.41
Intercrop	12143.62	3392.83
Coefficient of Variation (%)	19.26	11.48
LSD (0.05)	5137.79	1678.82

The data in Table 9 show significant differences between the mono and intercrop treatments. Both maize and common bean yields in the monocrop were higher than in their respective intercrops. However, the combined output of intercrops was similar to that of monocrops as shown in Table 10.

Table 10: Combined means for maize and common bean biomass yields(kg/ha)

Crop	Cropping System		CV (%)	LSD (0.05)
	Monocrop	Intercrop		
Maize	22002.45	12143.62	19.26	5137.79
Common bean	8437.41	3392.83	11.48	1678.82
Combined mean yield	15219.93	15536.45	28.73	2680.04

Although the combined intercrop advantage was non-significant, there was an indication that the intercrops utilised land more efficiently than monocrops. This is because the nutritional and economic value of common beans can be higher than that of maize giving higher returns per unit of land utilised compared to sole maize. On the other hand, intercropping would result in labour savings in land preparation, and these savings could help improve the farmer's profitability.

Table 11. Maize ETa (mm) in a maize-common bean intercropping system

D	1	2	3	4	5	6	7	8	9	10	11	12	T
M	-	-	1.17	1.32	3.30	3.72	3.21	6.58	6.11	6.10	5.16	3.20	39.87
I	-	-	1.17	·1.32	3.30	3.72	3.21	6.03	6.11	6.10	5.58	3.20	39.54

Coefficient of Variation (%) 46.90

D - Dekad; M - Monocrop; I - Intercrop; T - Total

Table 12. Common bean ETa (mm) in a maize-common bean intercropping system

D	1	2	3	4	5	6	7	8	9	10	11	T
M	-	-	1.17	1.32	3.30	3.72	3.21	6.58	6.11	6.10	3.44	34.95
I	-	-	1.17	1.32	3.30	3.72	3.21	6.03	6.11	6.10	3.38	34.34

Coefficient of Variation (%) 49.40

D - Dekad; M - Monocrop; I - Intercrop; T - Total

The ETa data for maize and common bean are given in Tables 11 and 12 respectively. There were no significant differences in ETa between the mono and intercrop treatments (Appendices 17 and 18), meaning that water use by the crops was not affected by the cropping system. As for the maize-soyabean intercrop, the yield difference observed between the mono and intercrops can not be attributed to differences in consumptive use of water between the two cropping systems.

Table 13: WUE in a maize-common bean intercropping system

Crop	Biomass Yield (kg/ha)		ETa (mm)		WUE (kg/ha/mm)			CV (%)	LSD (%)
	M	I	M	I	M	I	IEG		
Maize	22002.20	12143.63	39.88	39.54	551.70	307.12	-44.33	37.26	193.17
Common bean	8437.40	3392.80	34.98	34.34	241.41	98.80	-59.07	48.33	42.38

M - Monocrop; I - Intercrop; IEG - Intercrop Efficiency Gain (%)

Table 13 shows decreased WUE for the individual components of the intercrop while the combined WUE of the intercrops were similar to that of monocrops (Table 14). Thes results show that intercropping makes it possible to grow more thanone crop on the same piece of land for the same amount of water. Crop production can thus be diversified without having to provide for extra water. Although the improvement observed in WUE is not significant this finding is very important especially for farmers in low raifall areas and those who would like to divesify crop production..

Table 14: Combined WUE in a maize-common bean intercropping system

Combined Biomass Yield (kg/ha)		Mean ETa (mm)		Combined WUE (kg/ha/mm)			CV (%)	LSD (%)
M	I	M	I	M	I	IEG		
15219.90	15536.45	37.42	36.94	406.73	420.59	3.41	25.53	230.85

M - Monocrop; I - Intercrop; IEG - Intercrop Efficiency Gain (%)

EXPERIMENT 3: THE MAIZE-SUNHEMP INTERCROPPING SYSTEM

Biomass yields for maize (Appendix 42) and sunhemp (Appendix 45) were used to compute the mean biomass yields given in Table 15. Data analysis showed significant differences between the monocrop and intercrop yields where monocrops gave higher yields than their respective intercrop components. However, like in the previous two experiments, the combined yield of maize and sunhemp in the intercrop was greater than in monocrops as can be seen from the data in Table 16.

Table 15: Mean biomass yield for maize and sunhemp (kg/ha)

Cropping System	Maize Yield	Sunhemp Yield
Monocrop	22002.45	29510.96
Intercrop	15 922.48	22094.95
Coefficient of Variation (%)	19.30	11.50
LSD (0.05)	5137.79	8185.22

Table 16 Combined means of maize and sunhemp biomass yields (kg/ha)

Crop	Cropping System		CV (%)	LSD (0.05)
	Monocrop	Intercrop		
Maize	22002.45	15922.48	19.30	5137.79
Sunhemp	29510.96	22094.95	11.50	8185.22
Combined mean yield	25756.71	38017.44	23.21	5565.26

Contrary to observations made in Table 15 where yields from the monocrop were greater than their respective intercrop components, land-equivalent-based yields show that yields from the intercrop were greater than any of the monocrops. These results show that intercropping does not only offer the advantage to increase crop production without increasing the land under cultivation, but makes it possible to diversify crop production as well. Crop diversification offers some form of security to the farmer for his investment in that when one crop fails he can expect some returns from the other. On the other hand, crop diversification has the potential to improve the farmer's nutrition as there is a wider range of food crops to choose from in the harvest.

The ETa data for maize and sunhemp from the entire growing period (Tables 17 and 18 respectively) were analysed for variance. There were no significant differences between the monocrop and intercrop treatments (Appendices 19 and 20), meaning that intercropping did not affect the crops' transpirational flux.

Table 17. Maize ETa (mm) in a maize-sunhemp intercropping system

D	1	2	3	4	5	6	7	8	9	10	11	12	T
M	-	-	1.17	1.32	3.30	3.72	3.21	6.58	6.11	6.10	5.17	3.20	39.88
I	-	-	1.17	1.32	3.30	3.72	3.21	6.02	6.11	6.09	4.97	3.20	39.74

Coefficient of Variation (%) 46.73

D - Dekad; M - Monocrop; I - Intercrop; T - Total

Table 18. Sunhemp ETa (mm) in a maize-sunhemp intercropping system

D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	T
M	-	-	1.17	1.32	3.30	3.72	4.81	2.51	4.07	4.07	5.56	1.60	3.18	3.12	3.85	42.28
I	-	-	1.17	1.32	3.30	3.72	4.81	2.37	4.07	4.07	4.97	1.60	3.14	2.61	3.33	40.48

Coefficient of Variation (%) 39.58

D - Dekad; M - Monocrop; I - Intercrop; T - Total

Table 19 shows calculated WUE values for the maize-sunhemp intercropping system. Intercropping resulted in a reduction of 26.2% in water use efficiency for maize, indicating that the maize monocrop performed better than the intercropped maize. There was no significant difference in biomass yield between the sunhemp monocrop and the intercrop. The situation, however, changed when the yield data for intercropped maize and sunhemp were pooled. The combined WUE for intercrops was then 52% higher than that of single crops. The intercrops produced 52% more biomass than the monocrops for the equivalent amount of water used. The data indicate that intercropping may provide one way of making maximum use of available soil water.

Table 19: Water use efficiency in a maize-sunhemp intercropping system

Crop	Biomass Yield (kg/ha)		ETa (mm)		WUE (kg/ha/mm)			CV (%)	LSD (%)
	M	I	M	I	M	I	IEG		
Maize	22002.20	15922.48	39.88	39.11	551.70	407.12	-26.21	19.20	135.42
Sunhemp	29511.00	22094.94	42.36	40.48	696.83	545.82	-21.67	18.46	162.20

M - Monocrop; I - Intercrop; IEG - Intercrop Efficiency Gain (%)

Table 20: Combined water use efficiency in a maize-sunhemp intercropping system

Combined Biomass Yield (kg/ha)		Mean ETa (mm)		Combined WUE (kg/ha/mm)			CV (%)	LSD (%)
M	I	M	I	M	I	IEG		
25756.60	38017.42	41.12	39.80	626.38	955.33	52.51	24.33	139.87

M - Monocrop; I - Intercrop; IEG - Intercrop Efficiency Gain (%)

4.1.2. Discussion

This study has shown that intercropping results in improved Water Use Efficiency (WUE). However, this improvement could not be attributed to improved consumptive use as ETa values in the monocrops were not significantly different from those of the intercrops, meaning that WUE was not affected by crop interactions arising from intercropping. Rather, WUE improved due to high planting densities in the intercrops which resulted in high biomass yield for the equivalent amount of water used. The advantage of intercropping in terms of WUE occurs only when yields are treated on the basis of land equivalents.

When individual components of the intercrop system are considered independently, WUE attains a lower value. This is because planting densities are either less or equal to those of the monocrop and yet the competitive effect of one crop species will negatively affect the other (Trenbath, 1974) resulting in decreased yield (as observed in this study) and consequently WUE would decrease.

The findings made in this study on WUE have contributed to the understanding of the effect of intercropping on water consumptive use. Increased WUE in intercrops is not only a result of regulated ETa due to the wind break effect created by the dense canopy in the intercrop as reported by Sanchez (1976) and Steiner (1984). Rather, it is also a factor of higher biomass production. The higher planting densities, characteristic of intercrops, result in increased combined biomass yield which is responsible for improved WUE.

This study was conducted for only one rainfed cropping season, and it was not replicated over sites varying in agro-climatic conditions. Therefore, no definite conclusions can be drawn regarding the influence of these factors. Doorenbos et al., (1979) found that differences in WUE are insignificant when soil water conditions are not limiting. Data from this study showed that although drought periods were experienced during the season (Appendix 4), crop water requirements were not affected because actual evapotranspiration was not different from the maximum potential (Appendix 25 - 36). Thus it would be advisable to repeat the experiment over 2 - 3 years in areas representive of low, medium and high rainfall in order to verify the findings reported here.

4.2. ECONOMIC EFFECTS OF MAIZE-LEGUME INTERCROPPING SYSTEM

4.2.1. RESULTS

The economic effects of the maize-legume intercropping systems were evaluated by comparing grain yield, Land Equivalent Ratio (LER) and the Cropping Index (CI) between the mono and intercrop treatments. Only the maize-soyabean and maize-bean intercropping systems were assessed. The maize-sunhemp intercropping system was not included in the analysis because sunhemp is grown for green manure and not for grain, which was the basis for calculating LER.

EXPERIMENT 1: THE MAIZE-SOYABEAN INTERCROPPING SYSTEM

Grain yield data for maize and soyabean are given in Appendix 48. The statistical analysis of the effect of the cropping system on grain yield are given in Appendices 10 and 12. The mono and intercrop yields were significantly different (Table 21).

Table 21: Mean grain yields for maize and soyabean (kg/ha)

Cropping System	Maize	Soyabean
Monocrop	8647.60	3662.40
Intercrop	6541.70	1529.50
Coefficient of Variation (%)	10.88	20.05
LSD (0.05)	1859.33	1170.91

These data show that intercropping maize with soyabean resulted in a yield loss of 24.4% compared to the sole maize crop. Soyabean yield also decreased by 58.2% when intercropped with maize. However, the combined yield of maize and soyabean in the intercrop out-yielded both the maize and soyabean single crops (Table 22). The calculated LER was 1.31 for intercrops, showing that the crop mixture produced 31 % more yield than the single crops. Intercropping also allows for 2 crops to be grown on the same piece of land during the same season as opposed to only 1 in the monocrops.

Table 22: Economic indices for maize and soyabean in a maize-soyabean intercropping system

	Cropping System		CV%	LSD (0.05)
	Monocrop	Intercrop		
Maize Yield (kg/ha)	8647.61	6541.69	10.88	1859.33
Soyabean Yield (kg/ha)	3662.34	1529.44	20.05	1170.91
Combined Yield (kg/ha)	6154.97	8071.10	15.34	1047.58
Yield gain (%)	100.00	131.11		
LER	1.00	1.31		
CI	1.00	2.00		

EXPERIMENT 2: THE MAIZE-COMMON BEAN INTERCROPPING SYSTEM

Maize and common bean grain yield data are shown in Appendix 47. The effect of intercropping on grain yield was statistically analysed as for Experiment 1 (Appendices 11 and 13). Only maize yields showed significant differences between the mono and intercropped systems (Table 23). No significant differences were observed in yields of the common bean. The high coefficient of variation (74.15%) recorded also made it difficult to draw any meaningful conclusions from the data obtained from this experiment. The common bean crop suffered a severe attack by the bean common mozaic virus (BCMV), which resulted in very low yields of 461.5kg/ha and 319.5 kg/ha for the mono and intercrops respectively. This situation may have adversely affected the results. In spite of these difficulties, a CI of 2 was recorded for the intercrops, meaning that even where yields are poor, intercropping offers the advantage of diversifying crop production without opening up new land.

Table 23: Mean grain yields for maize and common bean (kg/ha)

Cropping System	Maize	Common bean
Monocrop	8647.60	1845.79
Intercrop	4651.93	1278.01
Coefficient of Variation (%)	17.89	74.15
LSD (0.05)	1859.33	670.58

4.2.2. Discussion

This study has shown that intercropping is a more economical way of growing crops. Although the individual components of the intercrop yielded lower than their respective monocrops, the combined yield of the intercrops was higher than that of any of the monocrops. Andrews and Kassam, (1976) found the ability of one crop to compensate for the other in case of crop failure as one of the main advantages of intercropping. This has been proved in the maize-common bean experiment where the common bean yield failed but the maize crop gave a gain in yield (4651 kg/ha). In such adverse situations, the companion maize crop offers some economic returns to the farmer. This benefit would not have been possible if the farmer planted only common beans on the particular piece of land. Effort on land preparation and crop management would be lost completely.

The intercrops showed higher LER and CI values than those from the monocrops. The significance of a high LER index in intercrops lies in the need to use limited resources more efficiently in order to meet food requirements for the increasing population. Intercropping has proved to be economical in *those areas where arable land is increasingly becoming scarce because it makes use of it more* efficient. Similarly, the need to diversify crop production as a way of sustaining the genetic base for agriculture as well as meeting the ever changing human needs signifies the importance of the CI. Intercropping offers a chance to meet theese challenges through enhancing crop production as demonstrated in this study.

The economic advantages of intercropping have been documented (Lepiz, 1971; Norman, 1968). Economic indices of LER and CI improve under intercropping. The study has thus demonstrated that these economic indices are applicable to maize-legume intercropping systems under field conditions. Consequently, the findings from this study have relevance to other areas with similar environmental conditions.

5. CONCLUSION

The rapidly growing Zambian population presents a challenge to increased food production. There is need to adopt sustainable agricultural production systems if the ever increasing demand for food is to be met. The sustainability of a productive system is dependent on its ability to meet the present needs without necessarily compromising that of the future. This strategy would require the efficient use of available production resources. Intercropping is one such intensive form of farming which aims at producing more with fewer resources such as land, water and other inputs.

This study examined the resource use efficiency of the maize-legume intercropping system in terms of water use and economic benefits. The data obtained from the study showed that intercropping improved WUE. The intercropping system was also found to be more economical in land utilisation compared to monocrops. Intercrops produced higher yield than monocrops per unit amount of land utilised. Crop diversification was also possible as more than one crop could simultaneously be grown on the same piece of land.

The study has helped to further understand the intercropping systems especially those involving maize and legumes such as soyabean, common bean and sunhemp. It was found that under experimental conditions of the study, improved WUE in intercrops could be attributed to increased biomass production arising from higher planting densities. There was no evidence of improved WUE due to differences in evapotranspiration between the two cropping systems. The study has also shown that intercropping is a more economical way of growing many crops and obtaining greater yields with less resources.

Adopting intercropping systems will help alleviate the problems associated with the ever increasing pressure on farmland and declining water resources. Furthermore, the use of legumes as companion crops has the potential to improve soil fertility. There is need for continued research into legume intercropping systems under varying environmental conditions in order to develop proven technologies for specific farming conditions. A continuation of this study is justified to verify the findings reported here and also to investigate the effect of maize-legume intercropping systems on soil fertility, especially the accumulation of nitrogen and organic matter.

6. REFERENCES

Agboola, A.A. and A.A.A. Fayemi. 1972. Fixation and excretion of nitrogen by tropical legumes. Agronomy Journal 64: 409 - 412.

Ahmed, F.A.M., H.M. Selim, and E.P. Dunigan. 1981. Effect of soil moisture status on nodulation, N_2 fixation and P uptake by soyabean. Agronomy Abstracts. 1981 Annual Meetings. American Society of Agronomy Journal: 171 - 179.

Aina, P.O., R. Lal, and G.S. Taylor. 1979. Effects of vegetable cover on soil erosion on an alfisol. **In:** Lal, R. and Greenland, D.J. (Eds.) Soil Physical Properties and Crop Production in the Tropics, Wiley, New York. pp. 501 - 508.

Allison, F.E. 1973. Soil organic matter and its role in crop production. Elservier Scientific Publishing Company, Amsterdam. London. New York. pp. 500 - 509.

Andrews, D.J. 1972. Intercropping with sorghum in Nigeria. Experimental Agriculture 8: 139 - 150.

Andrews, D.J. and A.H. Kassam. 1976. The importance of multiple cropping in increasing world food supplies. **In:** Papendick, R.I., P.A. Sanchez and G.B. Triplett (Eds.). Multiple Cropping. American Society of Agronomy Special Publication Number 27: 2 - 7.

Baker, E.F.I and D.W. Norman. 1975. Cropping systems in Northern Nigeria. **In:** Proceedings of the Cropping Systems Workshop, 18 – 20 March, 1975. IRRI, Los Banos, Philipines.

Baldy, C. 1963. Cultures associ'es et productivite' de eau. Annals of Agronomy Journal 14: 489 - 534.

Bennet, J.M. and S.L. Albretch. 1984. Drought and flooding effects on nitrogen fixation. Water relations and diffusive resistance of Soy. Agronomy Journal 81: 735 - 740.

Blencowe, J.W. 1969. Crop diversification in Malaysia. Incorporated Society of Planters, Kuala Lumpur. pp. 300.

Chae S. D. 1984. Crop Physiology (2). Agricultural Publishing House. Pyongyang. pp. 294 - 296.

Chikuma, G. Veronica, W.M.A. Chileshe, and L. Pungwa. 1985. Resource atlas for Zambia. National Education Company of Zambia. pp. 12 - 94.

CIAT (Centro International de Agricultura Tropical). 1973. Annual Report. CIAT, Palmira.

Dalrymple, D.G. 1971. Survey of multiple cropping in less developed nations. Foreign Economic Development Service, USDA.

Daniel, H.P. and J.H. Stephen. 1981. Planting patterns of intercropped corn and soyabeans for silage. Agronomy Abstracts. 1981 Annual Meeting. American Society of Agronomy Journal: 112.

De, R. 1980. Role of legumes in intercropping systems. **In:** Nuclear techniques in the development of management practices for multiple cropping systems. Proceedings of the Advisory Group meeting on nuclear techniques in developing of fertilizer and water management practices for multiple cropping systems. 8 - 12 October, 1979. Ankara. pp. 73 - 84.

Doorenbos, J., A.H. Kassam, C.L.M. Bentvelsen, V. Branscheid, J.M.G.A. Plusje, M. Smith, G.O. Uittenbogaard, and H.K. Van Der Wal. 1979. Yield response to water. FAO Irrigation and Drainage Paper 33: 1 - 137.

Flor, C.A and C.A. Francis. 1975. Propuesta de estudio de algunos componentes de una metodologia para investigar los cultivos associados en el tropico americano. Programa Cooperativo Centro-Americano para el Mejaramiento de cultivos Alimenticios, San Salvador. Memoria. XXI Reunion Ann I. pp. 45 - 61.

Frye, W.W. and R.L. Blevins. 1982. Effect of legume cover crops on soil fertility. Journal of Soil and Water Conservation 44: 57 - 63.

Gerold, O.S.B. 1989. Sunhemp. Benedictine Publications, Ndanda-Peremiho. pp. 68 - 69.

Gill, K.S., J.S. Lenvain and O.I. Lungu. 1993. Physical conditions of two oxic paleustalfs and the rsponse of wheat to irrigation based on IW/COPE ratio. Zambian Journal of Agricultural Science 3: 1 - 6.

Greenland, D.J. and M.H.B. Hayes. 1981. Soil processes. The Chemistry of Soil Processes. Willey, New York. pp. 18 - 123.

Grime, J.P. 1979. Plant strategies and vegetation processes. Wiley, Chichester and New York. pp. 8.

Hall, R.L. 1974. Analysis of the nature of interference between plant species. Concepts and Extension of the De wit Analysis to Examine Effects. Australian Journal of Agricultural Research 25: 739 - 747.

Hera, C. 1978. Effect of management practice on dinitrogen fixation in temperate regions. Isotopes in Biological Dinitrogen Fixation. International Atomic Energy Agency, Viena. pp. 191 - 199.

Herridge, D.F. and F.J. Bergerson. 1988. Symbiotic nitrogen fixation. **In:** J.R. Wilson (Ed.), 1988. Advances in Nitrogen Cycling in Agricultural Ecosystems. CAB International, Wellingford. pp. 11 - 59.

IRRI (International rice Research Institute), 1974. Annual Report. IRRI, Los Banos, Phillipines.

Jon, U.S. and C.J. Jon. 1986. Evapotranspiration. Agricultural Encyclopaedia (Agrometeorology). Agricultural Publishing House, Wonsan. pp. 58 - 112.

Kamona R.M. 1989. The importance of food legumes at national level in Zambia. **In:** Mulila, M.N., J. Kannaiyan and S. Sithanthan (Eds.). 1989. Recent progress in food legumes research and improvements in Zambia. Procceedings of the National Workshop on Food Legumes Research and Improvement in Zambia, 9 - 11th March, 1988, Mfuwe. pp. 206 - 207.

Kanenga, K., M.S. Reddy, J.C. Musanya, and J. Kannaiyan. 1989. Agronomic and cropping systems research involving grain legumes in Zambia. **In:** Mulila, M.N., J. Kannaiyan and S. Sithanthan (Eds.). 1989. Recent progress in food legumes research and improvements in Zambia. Procceedings of the National Workshop on Food LegumesResearch and Improvement in Zambia, 9 - 11th March, 1988, Mfuwe. pp. 200 - 205.

Kayope V. 1992. Proceedings of the fifth conference of the South and Eastern African Rural and Urban Planners. Commonwealth Youth Africa Centre, Lusaka.

Kim S. B. 1983. Biological nitrogen fixation. Agriculture Journal 11: 1 - 14.

Lal, R. 1977. Soil conserving versus soil degrading crops and soil management for erosion control. **In:** Greenland, D.J. and R. Lal (Eds.). Soil Conservation and Management in the Humid Tropics. Willey, New York. pp. 81 - 86.

Lepiz, I.R. 1971. Asociacionde cultivors maiz-frijol. Agricultural Technology in Mexico 3: 98 - 101.

Little, T.M. and J.F.Hill. 1978. Calculating Linear Correlation. Agricultural Experimentation, Design and Analysis. John Willey and Son. New York. pp. 171 - 174.

Martin, G.W. and J.T. Touchton. 1983. Legumes as a cover crop and source of nitrogen. Journal of Soil and Water Conservation 38: 214 - 216.

Masuku, R.B.N. 1973. Chitemene Agriculture and Permanent Farming. Farming in Zambia 7: 39.

MAWD. 1984. Maize intercropping trial at N.I.R.S. MAWD Research and Specialist Services. Annual Report 1977-1978. Government Printer. Lusaka. pp. 30-32.

MAWD. 1986. Grain Legumes Research Annual Report 1985/6. Msekera Regional Research Station, Chipata. pp. 8 - 40.

MAWD. 1987. Grain Legumes Research Annual Report 1986/7. Msekera Regional Research Station, Chipata. pp. 18 - 93.

Mulila, M.N., J. Kannaiyan, and S. Sithanthan (Eds.). 1989. Recent progress in food legumes research and improvements in Zambia. Procceedings of the National Workshop on Food Legumes Research and Improvement in Zambia, 9 - 11th March, 1988, Mfuwe. pp. 7 - 10.

Mwania, M.N. 1988. On-Farm pre-extension demonstrations:experiences with maize and common bean production systems in Western Kenya. Towards Self Sufficiency -A Proceedings of the Second Eastern, Central and Southern African Regional Maize Workshop. CYMMIT. pp. 270 - 278.

Norman, D.W. 1968. Why practice intercropping. Samaru Agricultural Newsletter 6: 6.

North Carolina State University. 1973. Agronomic and economic research on tropical soils. Annual Report 1973, Soil Science Department, Raleigh. N.C. pp. 190.

Patra, D.D., M.S. Sachdev, and B.V. Subbiah. 1986. Nitrogen (^{15}N) studies on the transfer of legume-fixed nitrogen to associated cereals in intercropping studies. Biological Fertilisation and Soils 2:165 - 171.

Power, J.F., R.F. Follet, and G.E. Carlson. 1983. Legumes in conservative tillage systems: A research perspective. Journal of Soil and Water 38: 217 - 218.

Rerkasem, B., K. Rekasem, M.B. Peoples, D.F. Herridge, and F.J. Bergersen. 1988. Measurement of N_2 fixation in maize and rice bean intercrops. Plant and Soil Journal 108: 125 - 134.

Rim, J.Y., K.U. Byon, G.H. Ri, C.B. Jong, D.K. Chae, S.H. Kim, B.R. Kim, M.S. Kim and H.I. Ri, 1987. Crop Water Uptake and Use. Encyclopaaedia of Soil Sciences. Agricultural Publishing House, Wonsan. Pp. 162 - 70.

Robertson W.K., L.C. Hamoond, J.T. Johnson, and K.J. Boot. 1973. Effects of plant water stress on root distribution of maize, soy and groundnuts in sandy soils. Agoronmy Journal 72: 548 - 554.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Willey, London. pp. 618.

Searl, P.G.E., Y. Commudom, D.C. Shedden, and Nance, R.A. 1981. Effect of maize-legume intercropping systems and fertilizer nitrogen on crop yields and residual nitrogen. Field Crops Research 4: 133 - 145.

Shearer, G. and D.H. Kohl. 1986. Nitrogen fixation in field settings: Estimations based on natural nitrogen abundance. Australian Journal of Plant Physiology 13: 699 - 756.

Singh, N.B., P.P. Singh, and K.P.P. Nair. 1986. Effect of legume intercropping on enrichment of the soil nitrogen, bacterial activity and productivity of associated maize crops. Experimental Agriculture 22: 339 - 344.

Solomon, E. M. 1976. Population Dynamics. Second Edition. Edward Arnold Publishers ltd. London. pp. 32 - 47.

Steiner, K. G. 1984. Intercropping in Tropical Smallholder Agriculture with special reference to West Africa. Eschborn. West Africa. pp. 83 - 85.

Trenbath, B.R. 1974. Biomass production of mixtures. Advances in Agronomy 24: 117 - 120.

Waghmare, A.B. and S.P. Singh. 1984. Sorghum-legume intercropping and the effects of nitrogen fertilisation on yield and nitrogen uptake by crops. Experimental Agriculture 20: 251 - 259.

Wellving, A.H.A. 1984. Sunhemp. Seed Production Handbook of Zambia. Department of Agriculture, Lusaka. pp.197 - 287.

Willey, R.W. 1979. Intercropping - its importance and research needs. Part 1. Competition and yield advantages. Field Crop Abstracts 32: 1 - 85.

Wonsan University of Agriculture. 1982. Intercropping maize in a soyabean crop. Juche Agriculture. Higher Education Publishing House. Pyongyang. pp. 481 - 482.

Wrigley, G. 1982. Tropical agriculture: The Development of Production. ELBS/Longman, Singapore. pp. 71 - 73.

Yagodin, B.A. 1984. Nitrogen cycle in agriculture. Agricultural Chemistry 1. Mir Publishers, Moscow. pp. 252 - 254.

APPENDICES

SOIL MOISTURE CONTENT

Appendix 1: Soil moisture content in a maize-soyabean intercropping system

BLOCK	TREATMENT	VSMC (%)
1	1	22.68
1	2	20.09
1	3	20.09
1	4	22.96
2	1	20.09
2	2	18.60
2	3	17.68
2	4	16.76
3	1	18.31
3	2	17.56
3	3	18.25
3	4	16.41
4	1	20.67
4	2	18.08
4	3	18.43
4	4	17.85

VSMC - Volumetric Soil Moisture Content

Appendix 2: Soil moisture content in a maize-common bean intercropping system

BLOCK	TREATMENT	VSMC (%)
1	1	22.73
1	2	19.57
1	3	22.85
1	4	19.80
2	1	20.03
2	2	18.60
2	3	19.52
2	4	20.26
3	1	18.20
3	2	17.39
3	3	18.65
3	4	17.79
4	1	20.72
4	2	18.37
4	3	21.58
4	4	16.30

VSMC - Volumetric Soil Moisture Content

Appendix 3: Soil moisture content in a maize-sunhemp intercropping system

BLOCK	TREATMENT	VSMC (%)
1	1	22.56
1	2	19.40
1	3	21.70
1	4	18.88
2	1	20.15
2	2	18.54
2	3	19.06
2	4	17.79
3	1	18.31
3	2	17.39
3	3	19.00
3	4	15.78
4	1	20.32
4	2	18.48
4	3	18.20
4	4	17.22

VSMC - Volumetric Soil Moisture Content

AGROMETEOROLOGICAL DATA FOR THE 1991/92 GROWING SEASON AT THE UNIVERSITY OF ZAMBIA FIELD STATION, LUSAKA

Appendix 4: Dekadal rainfall(mm)

Month	Dekad	1991/92		Normal	
		Mean	Total	Mean	Total
December	1	2.64[b]	26.40[b]	6.60	65.90
	2	3.08[b]	30.80[b]	7.70	77.00
	3	6.10[b]	61.00[b]	7.10	71.00
January	1	4.30[b]	43.00[b]	7.10	70.70
	2	2.62[b]	26.20[b]	6.70	67.20
	3	4.28[b]	42.80[b]	8.20	81.60
February	1	0.38[b]	3.80[b]	7.80	78.40
	2	0.00[b]	0.00[b]	4.70	47.20
	3	0.43[b]	4.30[b]	3.90	39.40
March	1	0.15[b]	1.50[b]	3.70	36.90
	2	0.16[b]	1.64[b]	3.20	32.50
	3	0.74[b]	7.40[b]	2.90	29.40
April	1	0.00[b]	0.00[b]	1.10	11.40
	2	0.00[b]	0.00[b]	1.30	13.30
	3	0.17[b]	1.70[b]	1.10	10.80
May	1	0.44[b]	4.40[b]	0.20	1.80
	2	0.00[b]	0.00[b]	0.10	10.80
	3	0.00[b]	0.00[b]	0.00	0.20

[b]: below average

Normal: 1950/51-1990/91 averages

Source: Normal - Central Meteorological Office

1991/92 - University of Zambia Geography Department

Appendix 5: Dekadal mean wind speed(m/s)

Month	Dekad	1991/92	Normal
December	1	5.20[a]	2.50
	2	5.10[a]	2 30
	3	4.40[a]	2 10
January	1	4.70[a]	1 80
	2	5.50[a]	2 00
	3	4.60[a]	2 20
February	1	3.20[a]	2 20
	2	4.90[a]	2 00
	3	5.60[a]	1.90
March	1	7.80[a]	2.60
	2	4.80[a]	2.40
	3	3.60[a]	2.70
April	1	5.00[a]	3.30
	2	3.60[a]	2.80
	3	4.50[a]	3.20
May	1	7.00[a]	3.00
	2	6.20[a]	2.60
	3	3.90[a]	3.20

Normal: 1973-1976 averages

[a]: above normal

[b]: below normal

Source: Normal - Central Meteorological Office

1991/92 - University of Zambia Geography Department

Appendix 6: Dekadal mean temperature(°C)

Month	Dekad	1991/92		Normal	
		Minimum	Maximum	Minimum	Maximum
December	1	17.40[b]	28.50[a]	17.60	27.60
	2	18.20[a]	27.20[b]	17.90	27.60
		17.90[a]	26.30[b]	17.70	26.60
January	1	16.70[b]	28.00[a]	17.20	25.80
	2	16.90[b]	29.20[a]	17.30	26.20
	3	16.80[b]	28.10[a]	17.80	26.20
February	1	17.50[a]	29.20[a]	17.10	25.50
	2	17.80[a]	31.00[a]	17.50	27.70
	3	19.00[a]	30.50[a]	17.34	27.70
March	1	17.80[a]	28.90[a]	17.00	27.10
	2	18.40[a]	28.80[a]	16.90	27.40
	3	16.30[b]	26.40[a]	16.90	25.90
April	1	10.70[b]	24.60[b]	15.40	26.10
	2	11.10[b]	27.10[a]	14.30	26.00
	3	17.10[a]	30.00[a]	15.30	26.70
May	1	10.0[b]	27.60[a]	12.90	25.00
	2	14.60[a]	27.80[a]	11.70	24.40
	3	13.10[a]	26.70[a]	11.60	25.00

Normal: 1950-1990 averages

[a]: above normal

[b]: below normal

Source: Normal - Central Meteorological Office
1991/92 - University of Zambia Geography Department

Appendix 7: Dekadal pan A evaporation(mm)

Month	Dekad	1991/92		Normal	
		Mean	Total	Mean	Total
December	1	10.00[a]	100.00[a]	5.00	50.00
	2	7.40[a]	74.00[a]	5.10	51.00
	3	7.30[a]	73.00[a]	5.10	51.00
January	1	8.70[a]	87.00[a]	5.60	56.00
	2	10.50[a]	105.00[a]	5.40	54.00
	3	7.70[a]	77.00[a]	5.00	50.00
February	1	5.70[a]	57.00[a]	4.50	45.00
	2	7.00[a]	70.00[a]	4.70	47.00
	3	7.90[a]	79.00[a]	4.50	45.00
March	1	6.90[a]	69.00[a]	4.80	48.00
	2	6.10[a]	61.00[a]	5.20	52.00
	3	3.60[b]	36.00[b]	5.30	53.00
April	1	4.30[b]	43.00[b]	5.40	54.00
	2	5.40[a]	54.00[a]	5.10	51.00
	3	4.10[b]	41.00[b]	6.10	61.00
May	1	3.60[b]	36.00[b]	7.60	76.00
	2	6.90[a]	69.00[a]	5.90	59.00
	3	9.50[a]	95.00[a]	4.90	49.00

Normal: 1975-1985 averages

[a]: above normal

[b]: below normal

Source: Normal - Central Meteorological Office

1991/92 - University of Zambia Geography Department

Appendix 8: Dekadal mean sunshine(hours/day)

Month	Dekad	1991/92	Normal
December	1	4.90[b]	5.20
	2	2.40[b]	6.00
	3	2.70[b]	6.50
January	1	4.50[b]	6.60
	2	4.60[b]	6.80
	3	8.10[a]	4.90
February	1	5.90[b]	7.70
	2	8.10[a]	6.40
	3	7.90[a]	5.30
March	1	6.10[a]	5.60
	2	4.50[b]	6.50
	3	2.30[b]	7.10
April	1	6.40[b]	7.50
	2	6.20[b]	8.00
	3	5.70[b]	8.30
May	1	7.00[b]	7.90
	2	6.30[b]	8.70
	3	3.90[b]	8.70

Normal: 1974-1988 averages

[a]: above normal

[b]: below normal

Source: Normal - Central Meteorological Office

1991/92 - University of Zambia Geography Department

Appendix 9: Dekadal mean humidity (%)

Month	Dekad	1991/92	Normal
December	1	75.50[a]	72.40
	2	84.50[a]	78.80
	3	79.90[a]	77.70
January	1	79.70[a]	77.00
	2	80.20[a]	79.50
	3	76.30[b]	80.90
February	1	78.70[b]	81.20
	2	65.00[b]	80.10
	3	80.00[b]	81.20
March	1	74.61[b]	80.50
	2	75.60[b]	80.10
	3	85.00[a]	79.20
April	1	81.80[a]	74.80
	2	76.80[a]	75.60
	3	85.60[a]	71.90
May	1	78.40[a]	67.40
	2	80.40[a]	67.10
	3	75.70[a]	66.30

Normal: 1974-1988 averages

[a]: above normal

[b]: below normal

Source: Normal - Central Meteorological Office
1991/92 - University of Zambia Geography Department

ANALYSIS OF VARIANCE (ANOVA) TABLES

1. Maize Grain Yield

Appendix 10: Effect of cropping system on maize grain yield in a maize-soyabean intercropping system

Source of Variation	*Degrees of Freedom*	*Mean Squares*
Replication	3	418345.7
Treatments	1	8869802.6 *
Error	3	682874.8

Coefficient of Variation (%) 10.88

* Significant at 0.05 level of probability

Appendix 11: Effect of cropping system on maize grain yield in a maize-common bean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication	3	2851583.3
Treatments	1	31930950.4*
Error	3	1415994.0

Coefficient of Variation (%) 17.89

* Significant at 0.05 level of probability.

2. Soyabean Grain Yield

Appendix 12: Effect of cropping system on soyabean grain yield in a maize-soyabean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication	3	40768.0
Treatments	1	9098528.9 *
Error	3	270816.4

Coefficient of Variation (%) 20.05%

* Significant at 0.05 level of probability

3. Common bean Grain Yield

Appendix 13: Effect of cropping system on common bean grain yield in a maize-common bean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication	3	36163.3
Treatments	1	40287.3 ns
Error	3	88825.2

Coefficient of Variation (%) 74.15

ns Non-significant at the 0.05 level of probability

4. Biomass Yield

Appendix 14: Effect of cropping system on maize biomass yield

Source of Variation	Degrees of Freedom	Mean Squares
Replication	3	4954840.13
Treatment	3	65976387.10*
Error	9	10316591.26

Coefficient of Variation (%) 19.30

* Significant at the 0.05 level of probability

5. Effect of Cropping System on ETa

Appendix 15: Effect of cropping system on ETa in a maize-soyabean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication (dekad)	9	3.3800
Treatment	1	0.0004^{ns}
Error	9	3.8300

Coefficient of Variation (%) 47.10

ns Non-significant at the 0.05 level of probability

Appendix 16: Effect of the cropping system on soyabean ETa in a maize-soyabean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication (dekad)	11	2.3200
Treatment	1	0.068^{ns}
Error	11	2.3300

Coefficient of Variation (%) 39.90

^{ns} Non-significant at the 0.05 level of probability

Appendix 17: Effect of cropping system on maize ETa in a maize-common bean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication (dekad)	9	3.6500
Treatment	1	0.0008^{ns}
Error	9	3.6600

Coefficient of Variation (%) 46.90

^{ns} Non-significant at the 0.05 level of probability

Appendix 18: Effect of cropping system on common bean ETa in a maize-common bean intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication (dekad)	8	3.8400
Treatment	1	0.0018^{ns}
Error	8	3.8600

Coefficient of Variation (%) 49.40

^{ns} Non-significant at the 0.05 level of probability

Appendix 19: Effect of cropping system on maize ETa in a maize-sunhemp intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication (dekad)	9	3.5900
Treatment	1	0.004^{ns}
Error	9	3.600

Coefficient of Variation (%) 46.7

^{ns} Non-significant at the 0.05 level of probability

Appendix 20: Effect of the cropping system on sunhemp ETa in a maize-sunhemp intercropping system

Source of Variation	Degrees of Freedom	Mean Squares
Replication (dekad)	12	1.6400
Treatment	1	0.0113^{ns}
Error	12	1.6800

Coefficient of Variation (%) 39.6

^{ns} Non-significant at the 0.05 level of probability

CROP EVAPOTRANSPIRATION

Appendix 21: Maize maximum evapotranspiration (ETm)

Dekad	Growth stage	ETo (mm)	Kc	ETm (mm)
1	Preplant	4.20	-	-
2	Preplant	3.33	-	-
3	.Germination/Establishment	3.91	0.30	1.17
4	Establishment	4.40	0.30	1.32
5	Vegetative	4.72	0.70	3.30
6	Vegetative	5.31	0.70	3.72
7	Vegetative/Flowering	4.58	0.70	3.21
8	Flowering	6.27	1.05	6.58
9	Grain development	5.82	1.05	6.11
10	Grain development	5.81	1.05	6.10
11	Grain development	5.30	1.05	5.56
12	Grain development/Ripening	4.00	0.80	3.20
13	Ripening	4.55	0.80	3.64
14	Ripening/Drying	4.45	0.80	3.56
15	Drying	3.67	0.55	2.02
16	Postharvest	4.27	-	-
17	Postharvest	4.32	-	-
18	Postharvest	4.85	-	-

ETo - Potential Evapotranspiration; Kc - Crop Coefficient

Appenidx 22: Common bean maximum evapotranspiration (ETm)

Dekad	Growth stage	ETo (mm)	Kc	ETm (mm)
1	Preplant	4.20	-	-
2	Preplant	3.33	-	-
3	Germination/Establishment	3.91	0.30	1.17
4	Establishment	4.40	0.30	1.32
5	Vegetative	4.72	0.70	3.30
6	Vegetative	5.31	0.70	3.72
7	Flowering	4.58	0.70	3.21
8	Flowering/Grain development	6.27	1.05	6.58
9	Flowering/Grain development	5.82	1.05	6.11
10	Grain development/Ripening	5.81	1.05	6.10
11	Grain development/Ripening	5.30	0.65	3.44
12	Ripening	4.00	0.65	2.60
13	Ripening/Drying	4.55	0.65	2.96
14	Drying	4.45	0.25	1.11
15	Drying	3.67	0.25	0.92
16	Postharvest	4.27	-	-
17	Postharvest	4.32	-	-
18	Postharvest	4.85	-	-

ETo - Potential Evapotraspiration; Kc - Crop Coefficient

Appendix 23: Soyabean maximum evapotranspiration (ETm)

Dekad	Growth stage	ETo (mm)	Kc	ETm (mm)
1	Preplant	4.20	-	-
2	Preplant -	3.33	-	-
3	Germination/Establishment	3.91	0.30	1.17
4	Establishment	4.40	0.30	1.32
5	Vegetative	4.72	0.70	3.30
6	Vegetative	5.31	0.70	3.72
7	Vegetative	4.58	0.70	3.21
8	Vegetative	6.27	0.70	4.39
9	Flowering	5.82	1.00	5.82
10	Flowering.	5.81	1.00	5.81
11	Flowering/Grain development	5.30	1.00	5.30
12	Grain development	4.00	1.00	4.00
13	Grain development	4.55	1.00	4.55
14	Grain development/Ripening	4.45	0.70	3.13
15	Ripening	3.67	0.70	2.57
16	Drying	4.27	0.40	1.71
17	Drying	4.32	0.40	1.73
18	Postharvest	4.85	-	-

ETo - Potential Evapotraspiration; Kc - Crop Coefficient

Appendix 24: Sunhemp maximum evapotranspiration (ETm)

Dekad	Growth stage	ETo (mm)	Kc	ETm (mm)
1	Preplant	4.20	-	-
2	Preplant	3.33	-	-
3	Germination/Establishment	3.91	0.30	1.17
4	Establishment	4.40	0.30	1.32
5	Vegetative	4.72	0.70	3.30
6	Vegetative	5.31	0.70	3.72
7	Flowering	4.58	1.05	4.81
8	Establishment	6.27	0.40	2.51
9	Vegetative	5.82	0.70	4.07
10	Vegetative	5.81	0.70	4.07
11	Flowering	5.30	1.05	5.56
12	Establishment	4.00	0.40	1.60
13	Vegetative	4.55	0.70	3.18
14	Vegetative	4.45	0.70	3.12
15	Flowering	3.67	1.05	3.85
16	Establishment	4.27	0.40	1.71
17	Vegetative/Drying	4.32	0.40	1.73
18	Vegetative/Drying	4.85	0.40	1.94

ETo - Potential Evapotraspiration; Kc - Crop Coefficient

Appendix 25: Actual evapotranspiration (ETa) for the maize monocrop in a maize-soyabean intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	216.10	220.40	0.00	1.17
4	4.68	1.32	3.360	217.10	220.40	0.00	1.32
5	3.48	3.30	0.18	208.00	208.18	0.00	3.30
6	3.05	3.72	-0.67	221.10	220.40	0.00	3.72
7	0.14	3.21	-3.07	191.20	188.13	0.00	3.21
8	0.00	6.58	-6.58	154.80	148.20	0.00	6.58
9	4.78	6.11	-1.33	158.00	156.70	0.00	6.11
10	1.51	6.10	-4.59	156.10	151.50	0.00	6.10
11	1.64	5.56	-3.72	134.00	130.28	0.07	5.17
12	6.76	3.20	3.56	166.70	170.30	0.00	3.20
Total							39.88

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapotranspiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 26: Actual evapotranspiration (ETa) for the maize intercrop in a maize-soyabean intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	201.80	206.10	0.000	1.17
4	4.68	1.32	3.36	200.80	204.20	0.000	1.32
5	3.48	3.30	0.18	197.30	197.50	0.000	3.30
6	3.05	3.72	-0.67	211.00	210.30	0.000	3.72
7	0.14	3.21	-3.07	167.80	164.70	0.000	3.21
8	0.00	6.58	-6.58	135.30	128.70	0.093	6.05
9	4.78	6.11	-1.33	174.20	172.90	0.000	6.11
10	1.51	6.10	-4.59	163.00	158.40	0.000	6.10
11	1.64	5.56	-3.92	144.30	140.40	0.000	5.56
12	6.76	3.20	3.56	210.00	213.56	0.000	3.20
Total							39.74

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 27: Actual evapotranspiration (ETa) for the soyabean monocrop in a maize-soyabean intercropping system

Dekad	P	Etm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	213.60	217.90	0.00	1.17
4	4.68	1.32	3.36	222.20	225.56	0.00	1.32
5	3.48	3.30	0.18	222.10	222.28	0.00	3.30
6	3.05	3.72	-0.67	208.00	207.30	0.00	3.72
7	0.14	3.21	-3.07	171.00	167.90	0.00	3.21
8	0.00	4.39	-4.39	145.80	141.40	0.00	4.39
9	4.78	5.82	-1.04	157.80	156.76	0.00	5.82
10	1.51	5.81	-4.30	160.70	156.40	0.00	5.81
11	1.64	5.30	-3.66	133.80	130.10	0.07	4.92
12	6.76	4.00	2.76	196.70	199.50	0.00	4.00
13	0.00	4.55	-4.55	152.10	148.40	0.00	4.55
14	0.00	3.13	-3.13	123.50	120.37	0.14	2.69
Total							44.90

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 28: Actual evapotranspiration (ETa) for the soyabean intercrop in a maize-soyabean intercropping system

Dekad	P	Etm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	201.80	206.10	0.00	1.17
4	4.68	1.32	3.36	200.80	204.20	0.00	1.32
5	3.48	3.30	0.18	197.30	197.50	0.00	3.30
6	3.05	3.72	-0.67	211.00	210.30	0.00	3.72
7	0.14	3.21	-3.07	167.80	164.70	0.00	3.21
8	0.00	4.39	-4.39	135.30	130.90	0.07	4.11
9	4.78	5.82	-1.04	174.20	173.20	0.00	5.82
10	1.51	5.81	-4.30	163.00	158.70	0.00	5.81
11	1.64	5.30	-3.66	144.30	140.60	0.00	5.30
12	6.76	4.00	2.76	210.00	212.80	0.00	4.00
13	0.00	4.55	-4.55	161.80	157.20	0.00	4.55
14	0.00	3.13	-3.13	121.30	118.20	0.16	2.64
Total							44.95

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 29: Actual evapotranspiration (ETa) for the maize monocrop in a maize-common bean intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	3.80	215.40	219.20	0.00	1.17
4	4.68	1.32	3.36	216.70	220.10	0.00	1.32
5	3.48	3.30	0.18	209.40	209.60	0.00	3.30
6	3.05	3.72	-0.67	221.00	220.30	0.00	3.72
7	0.14	3.21	-3.07	191.20	188.10	0.00	3.21
8	0.00	6.58	-6.58	154.00	147.40	0.00	6.58
9	4.78	6.11	-1.33	157.90	156.60	0.00	6.11
10	1.51	6.10	-4.59	156.40	151.80	0.00	6.10
11	1.64	5.56	-3.92	133.90	130.00	0.07	5.16
12	6.76	3.20	3.56	166.70	163.10	0.00	3.20
Total							39.87

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 30: Actual evapotranspiration (ETa) for the maize intercrop in a maize-common bean intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	206.40	210.70	0.00	1.17
4	4.68	1.32	3.36	203.80	207.20	0.00	1.32
5	3.48	3.30	0.18	196.10	196.28	0.00	3.30
6	3.05	3.72	-0.67	210.10	209.40	0.00	3.72
7	0.14	3.21	-3.07	163.80	160.70	0.00	3.21
8	0.00	6.58	-6.58	135.00	128.40	0.08	6.03
9	4.78	6.11	-1.33	165.90	164.60	0.00	6.11
10	1.51	6.10	-4.59	162.80	158.20	0.00	6.10
11	1.64	5.56	-3.92	139.30	135.40	0.03	5.38
12	6.76	3.20	3.56	214.60	218.20	0.00	3.20
Total							39.54

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 31: Actual evapotranspiration (ETa) for the common bean monocrop in a maize-common bean intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	214.40	218.74	0.00	1.17
4	4.68	1.32	3.36	234.00	237.40	0.00	1.32
5	3.48	3.30	0.18	225.10	225.28	0.00	3.30
6	3.05	3.72	-0.67	207.60	206.90	0.00	3.72
7	0.14	3.21	-3.07	185.40	182.30	0.00	3.21
8	0.00	6.58	-6.58	158.60	152.00	0.00	6.58
9	4.78	6.11	-1.33	194.50	193.20	0.00	6.11
10	1.51	6.10	-4.59	205.20	200.60	0.00	6.10
11	1.64	3.44	-1.80	171.40	169.60	0.00	3.44
Total							34.95

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 32: Actual evapotranspiration (ETa) for the common bean intercrop in a maize-common bean intercropping system

Dekad	P	Etm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	206.40	210.74	0.00	1.17
4	4.68	1.32	3.36	203.80	207.17	0.00	1.32
5	3.48	3.30	0.18	196.10	196.28	0.00	3.30
6	3.05	3.72	-0.67	210.10	209.40	0.00	3.72
7	0.14	3.21	-3.07	163.80	160.70	0.00	3.21
8	0.00	6.58	-6.58	135.00	128.40	0.12	6.03
9	4.78	6.11	-1.33	165.90	164.60	0.00	6.11
10	1.51	6.10	-4.59	162.80	158.20	0.00	6.10
11	1.64	3.44	-1.80	139.30	137.50	0.02	3.38
Total							34.34

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 33: Actual evapotranspiration (ETa) for the maize monocrop in a maize-sunhemp intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	212.40	216.74	0.00	1.17
4	4.68	1.32	3.36	216.70	220.10	0.00	1.32
5	3.48	3.30	0.18	208.80	209.00	0.00	3.30
6	3.05	3.72	-0.67	221.10	220.40	0.00	3.72
7	0.14	3.21	-3.07	191.20	188.10	0.00	3.21
8	0.00	6.58	-6.58	154.80	148.20	0.00	6.58
9	4.78	6.11	-1.33	158.00	156.70	0.00	6.11
10	1.51	6.10	-4.59	156.40	151.80	0.00	6.10
11	1.64	5.56	-3.92	134.00	130.10	0.02	5.17
12	6.76	3.20	3.56	169.90	173.50	0.00	3.20
Total							39.88

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 34: Actual evapotranspiration (ETa) for the maize intercrop in a maize-sunhemp intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	215.80	220.10	0.00	1.17
4	4.68	1.32	3.36	198.50	201.90	0.00	1.32
5	3.48	3.30	0.18	188.30	188.50	0.00	3.30
6	3.05	3.72	-0.67	208.80	208.10	0.00	3.72
7	0.14	3.21	-3.07	157.90	154.80	0.00	3.21
8	0.00	6.58	-6.58	134.70	128.10	0.09	6.02
9	4.78	6.11	-1.33	159.90	158.60	0.00	6.11
10	1.51	6.10	-4.59	144.30	139.70	0.00	6.09
11	1.64	5.56	-3.92	129.10	125.20	0.11	4.97
12	6.76	3.20	3.56	166.50	170.10	0.00	3.20
Total							39.74

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm) Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requiremen deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 35: Actual evapotranspiration (ETa) for the sunhemp monocrop in a maize-sunhemp intercropping system

Dekad	P	ETm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	208.70	213.00	0.00	1.17
4	4.68	1.32	3.36	219.60	222.90	0.00	1.32
5	3.48	3.30	0.18	211.30	211.48	0.00	3.30
6	3.05	3.72	-0.67	227.30	226.60	0.00	3.72
7	0.14	4.81	-4.67	182.10	177.40	0.00	4.81
8	0.00	2.51	-2.51	156.40	153.90	0.00	2.51
9	4.78	4.07	0.71	182.60	183.30	0.00	4.07
10	1.51	4.07	-2.56	176.10	173.50	0.00	4.07
11	1.64	5.56	-3.92	149.40	145.50	0.00	5.56
12	6.76	1.60	5.16	213.00	207.80	0.00	1.60
13	0.00	3.18	-3.18	178.90	175.50	0.00	3.18
14	0.00	3.12	-3.12	153.50	150.40	0.00	3.12
15	6.46	3.85	2.61	147.80	150.40	0.00	3.85
Total							42.28

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Appendix 36: Actual evapotranspiration (ETa) for the sunhemp intercrop in a maize-sunhemp intercropping system

Dekad	P	Etm	Pa=P-ETm	Ra	Rt	RWD	ETa
1	2.64	-	-	-	-	-	-
2	3.08	-	-	-	-	-	-
3	5.51	1.17	4.34	215.80	220.10	0.00	1.17
4	4.68	1.32	3.36	198.50	201.80	0.00	1.32
5	3.48	3.30	0.18	188.30	188.50	0.00	3.30
6	3.05	3.72	-0.67	208.80	187.60	0.00	3.72
7	0.14	4.81	-4.67	157.90	153.20	0.00	4.81
8	0.00	2.51	-2.51	134.70	132.20	0.06	2.37
9	4.78	4.07	0.71	159.90	160.60	0.00	4.07
10	1.51	4.07	-2.56	144.30	141.70	0.00	4.07
11	1.64	5.56	-3.92	129.10	125.20	0.11	4.97
12	6.76	1.60	5.16	166.50	171.60	0.00	1.60
13	0.00	3.18	-3.18	141.60	138.40	0.01	3.14
14	0.00	3.12	-3.12	120.10	117.00	0.16	2.61
15	6.46	3.85	2.61	118.40	121.00	0.14	3.33
Total							40.48

P - Precipitation (mm); Pa - Actual precipitation (mm); ETm - Maximum evapo-transpiration (mm); Ra - Soil Water Reserves (mm); Rt - Total soil water reserves (mm); RWD - Water requirement deficit

Note: Ra, Rt and RWD are values up to 60 cm of soil

Crop Yield Response Factor (ky)

Appendix 37: Crop yield response factor (ky) (Doorenbos et al., 1979)

Crop	Vegetative Period	Flowering Period	Yield Formation Period	Ripening Period	Total Growing Period
Maize	0.40	1.50	0.50	0.20	1.25
Soyabean	0.20	0.80	1.00	0.20	0.85
Common bean	0.20	1.10	0.75	0.20	1.15
Sunhemp	-	-	-	-	-

CROP GROWTH CHARTS

Appendix 38: Maize and sunhemp growth chart

Dekad	Date	Growth stage (maize)	Growth stage (sunhemp)
1	25.12.91	Germination	Germination
2	04.01.92	Establishment	Establishment
3	14.01.92	Vegetative	Vegetative
4	25.01.92	Vegetative	Vegetative
5	04.02.92	vegetative	Flowering
6	14.02.92	Flowering	Regrowth
7	25.02.92	Grain development	Vegetative
8	06.03.92	Grain development	Vegetative
9	16.03.92	Grain development	Flowering
10	26.03.92	Grain development	Regrowth
11	05.04.92	Ripening	Vegetative
12	15.04.92	Ripening	Vegetative
13	25.04.92	Drying	Flowering
14	05.05.92	Harvest	Regrowth
15	15.05.92	_	Vegetative/Drying
16	25.05.92	_	Vegetative/Drying

Appendix 39: Soyabean and common bean growth chart

Dekad	Date	Growth stage (soyabean)	Growth stage (common bean)
1	25.12.91	Germination	Germination
2	04.01.92	Vegetative	Establishment
3	14.01.92	Vegetative	Vegetative
4	25.01.92	Vegetative	Vegetative
5	04.02.92	Vegetative	Flowering
6	14.02.92	Vegetative	Flowering/Grain development
7	25.02.92	Flowering	Flowering/Grain development
8	06.03.92	Flowering	Grain development/Ripening
9	16.03.92	Flowering/Grain development	Grain development/Ripening
10	26.03.92	Flowering/Grain development	Ripening
11	05.04.92	Grain development	Drying
12	15.04.92	Grain development/Ripening	Drying
13	25.04.92	Ripening	Harvesting
14	05.05.92	Harvesting/Drying	_
15	15.05.92	Drying	_
16	25.05.92	_	_

CROP YIELD

Appendix 40: Maize biomass yield (kg/ha) in a maize-soyabean intercropping system

Replication	Monocrop	Intercrop
1	24372.30	17060.70
2	19498.20	18133.70
3	23692.20	15784.70
4	20447.10	15597.90
Average	22002.45	16644.25

Appendix 41: Maize biomass yield (kg/ha) in a maize-common bean intercropping system

Replication	Monocrop	Intercrop
1	24372.30	15803.00
2	19498.20	6245.00
3	23692.20	9698.40
4	20447.10	16828.10
Average	22002.45	12143.63

Appendix 42: Maize biomass yield (kg/ha) in a maize-sunhemp intercropping system

Replication	Monocrop	Intercrop
1	24372.30	15525.60
2	19498.20	18284.90
3	23692.20	16068.60
4	20447.10	13810.80
Average	22002.45	15922.48

Appendix 43: Soyabean biomass yield (kg/ha) in a maize-soyabean intercropping system

Replication	Monocrop	Intercrop
1	10680.10	3397.90
2	10981.80	3178.30
3	10562.70	5114.50
4	8647.21	5377.90
Average	10218.05	4267.20

Appendix 44: Common bean biomass yield (kg/ha) in a maize-common bean intercropping system

Replication	Monocrop	Intercrop
1	8928.50	3571.40
2	8392.80	2142.80
3	7678.50	3571.40
4	8749.90	4285.70
Average	8437.42	3392.83

Appendix 45: Sunhemp biomass yield (kg/ha) in a maize-sunhemp intercropping system

Replication	Monocrop	Intercrop
1	28291.20	26864.50
2	33508.20	22296.30
3	30673.70	21836.30
4	25570.80	17382.70
Average	29510.96	22094.95

Appendix 46: Grain yield in a maize-sunhemp intercropping system

Block	Treatment	Grain Yield (kg/ha)	
		Maize	Sunhemp
1	1	9579.00	-
1	2	6102.10	-
2	1	7663.30	-
2	2	7186.50	-
3	1	9311.70	-
3	2	6315.50	-
4	1	8036.40	-
4	2	5428.00	-
Average	1	8647.60	-
	2	6258.03	-

Treatment 1 - monocrop; Treatment 2 - intercrop

Appendix 47: Grain yield in a maize-common bean intercropping system

Block	Treatment	Grain Yield (kg/ha)	
		Maize	Common bean
1	1	9579.00	155.80
1	2	6211.00	269.10
2	1	7663.30	212.90
2	2	2454.40	512.50
3	1	9311.70	725.40
3	2	3811.80	227.00
4	1	8036.40	751.70
4	2	6130.50	269.50
Average	1	8647.60	461.50
	2	4651.93	319.50

Note: Treatment 1 - monocrop; Treatment 2 - intercrop

Appendix 48: Grain yield in a maize-soyabean intercropping system

Block	Treatment	Grain Yield (kg/ha)	
		Maize	Soyabean
1	1	9579.00	3828.00
1	2	6705.30	1217.90
2	1	7663.30	3936.10
2	2	7127.10	1139.20
3	1	9311.70	3785.90
3	2	6203.90	1833.20
4	1	8036.40	3099.40
4	2	6130.50	1927.60
Average	1	8647.60	3662.40
	2	6541.70	1529.50

Note: Treatment 1 - monocrop; Treatment 2 - intercrop

NEUTRON PROBE CALIBRATION CURVES

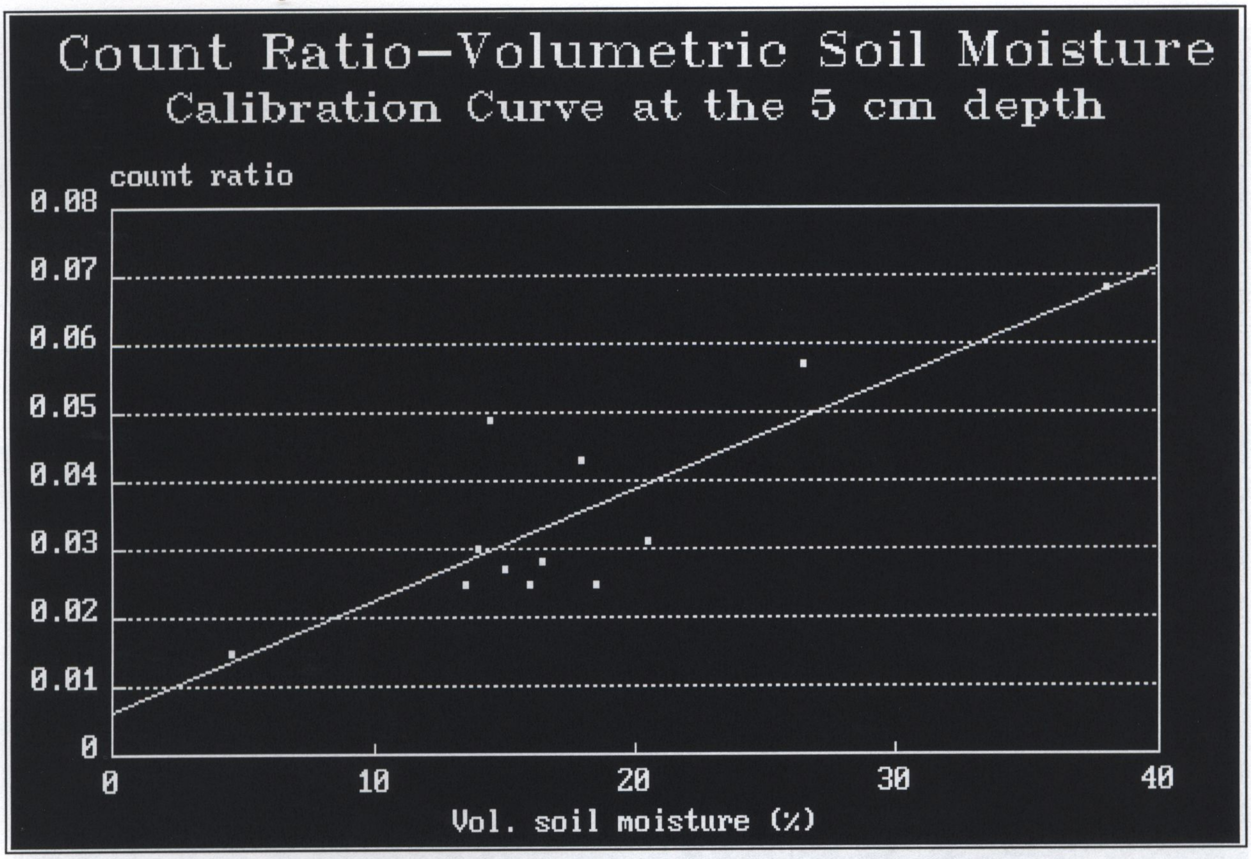

Figure 1

Y = - 0.037 + 0.014 x

Regression Table

K = 13

X-bar = 17.76

Var. X = 58.55

Y-bar = 0.035

Var. Y = 0.00

r = 0.837

a = -0.037

b = 0.014

s = 0.002

t = 5.08

P(%) = 0.000

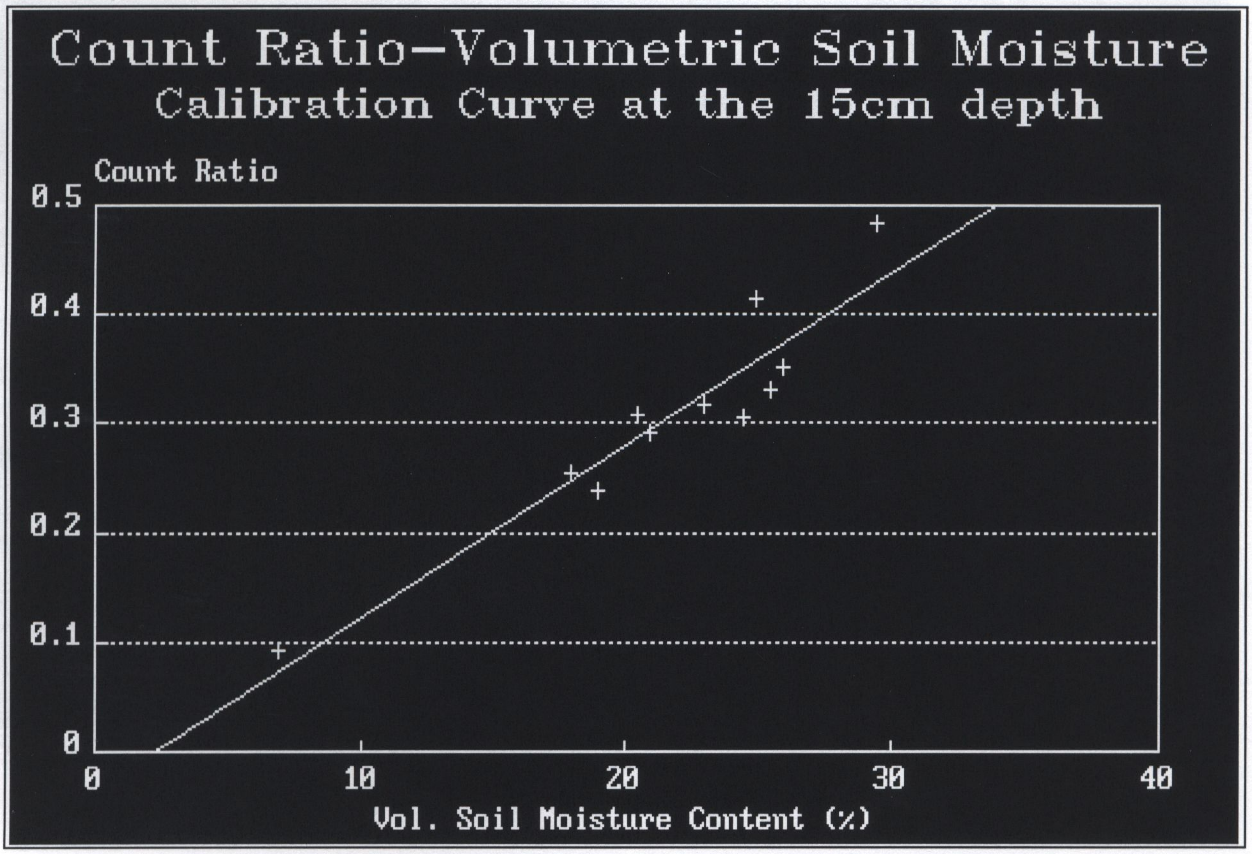

Figure 2

Y = - 0.042 + 0.016 x

Regression Table

K = 13

X-bar = 21.54

Var. X = 29.27

Y-bar = 0.303

Var. Y = 0.008

r = 0.942

a = -0.042

b = 0.016

s = 0.002

t = 9.31

P(%) = 0.000

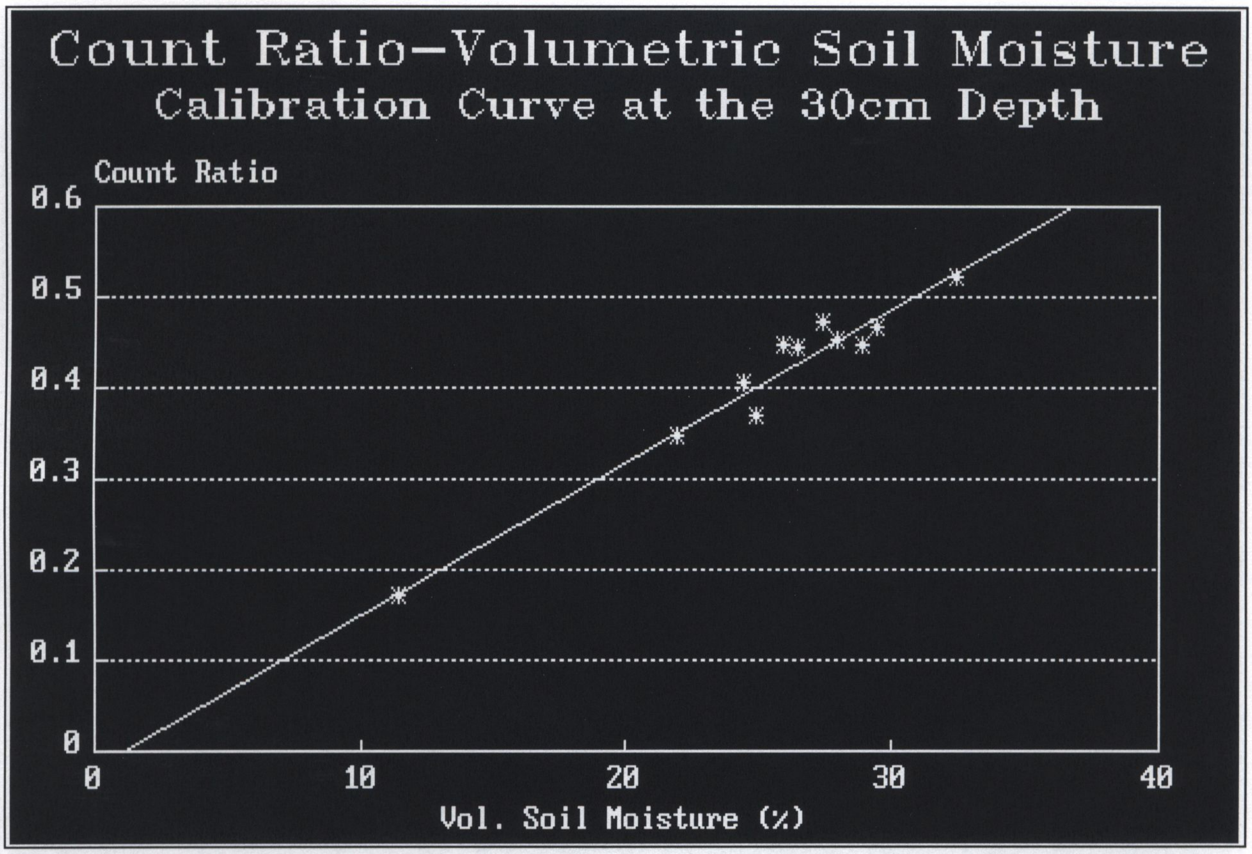

Figure 3

Y = 0.018 + 0.016 x

Regression Table

K = 26

X-bar = 27.04

Var. X = 27.58

Y-bar = 0.439

Var. Y = 0.007

r = 0.946

a = 0.018

b = 0.016

s = 0.001

t = 14.28

P(%) = 0.000

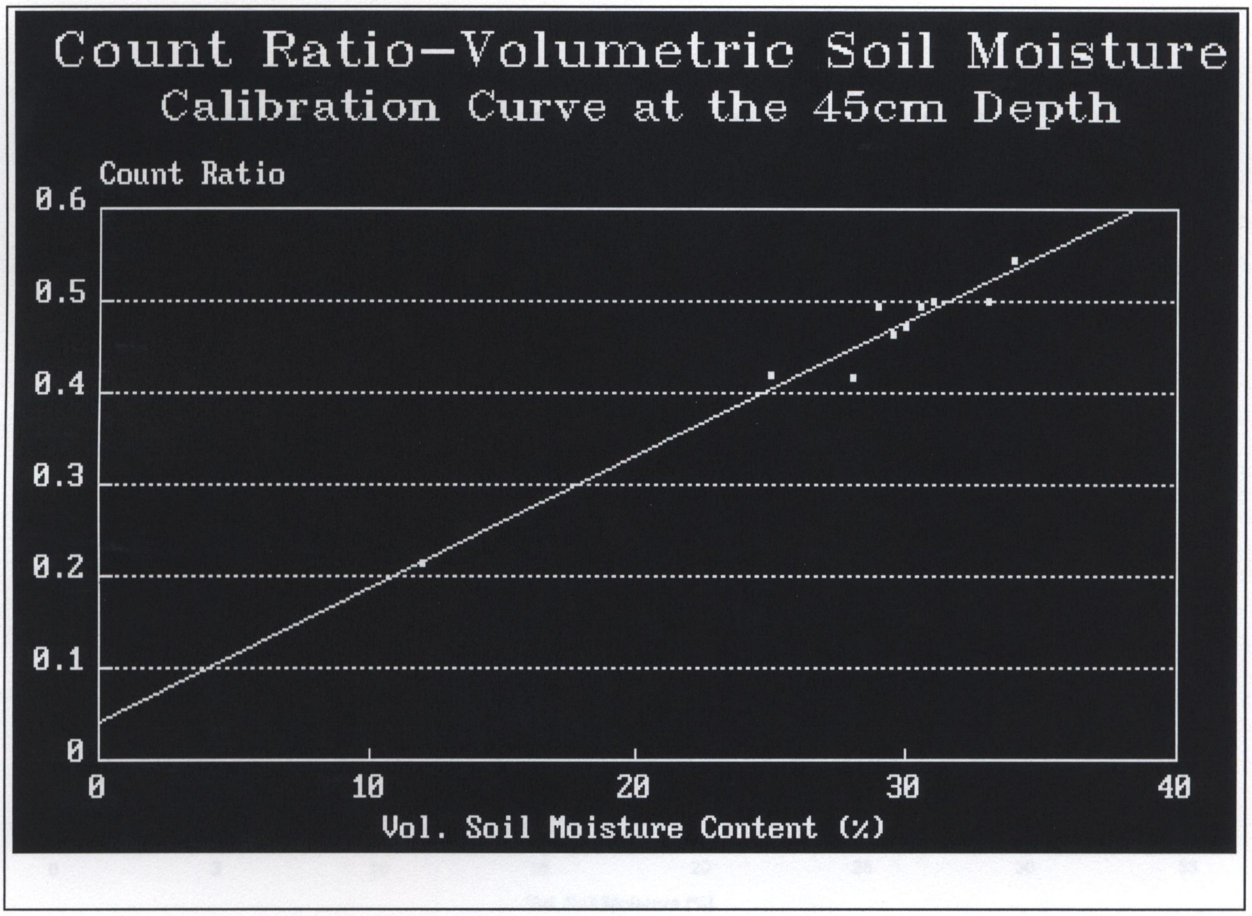

Figure 4

Y = 0.039 + 0.015 x

Regression Table

K = 13

X-bar = 28.41

Var. X = 28.73

Y-bar = 0.453

Var. Y = 0.007

r = 0.967

a = 0.039

b = 0.015

s = 0.001

t = 12.61

P(%) = 0.000

Count Ratio-Volumetric Soil Moisture Calibration Curve at the 60 cm depth

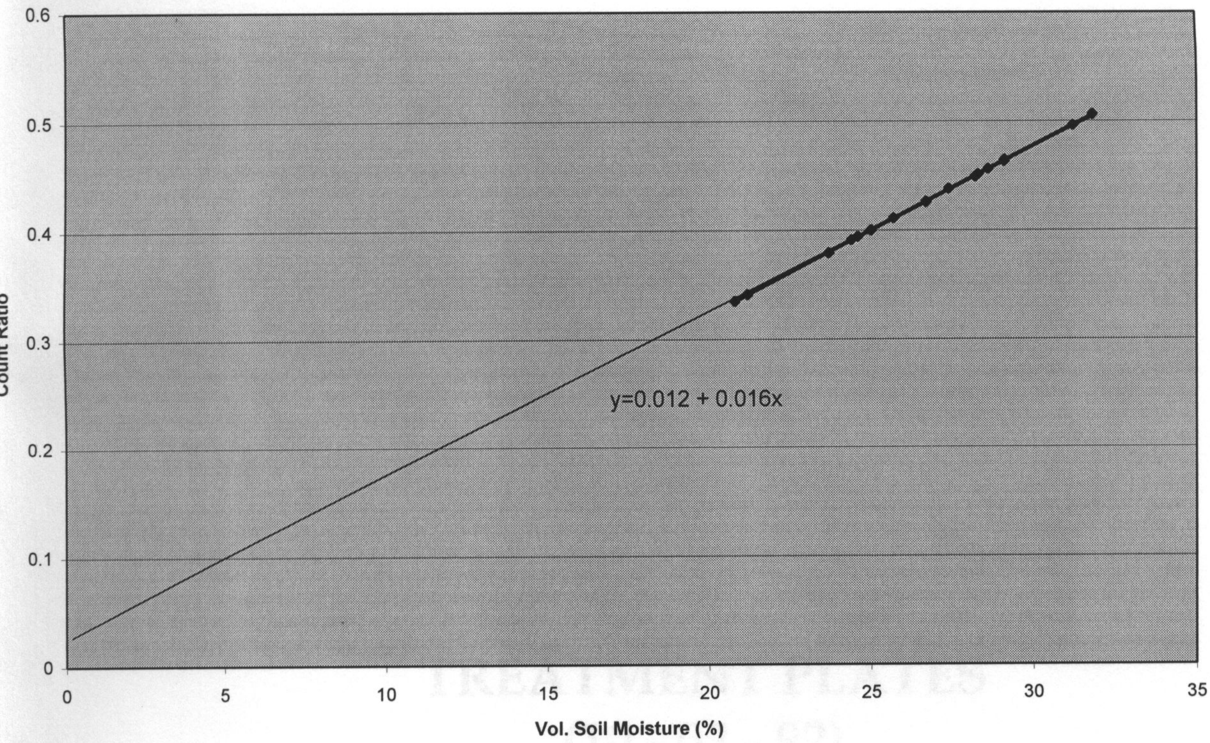

Figure 5

Y = 0.012 + 0.016 x

Regression Table

K = 13
X – bar = 26.61
Var. X = 10.28
Y – bar = 0.425
Var Y = 0.002
r = 0.999
a = 0.012
b = 0.016
s = 0.001
t = 11.11
P (%) = 0.000

TREATMENT PLATES
(10 - 02 - 92)

Plate 1: Unplanted Treatment

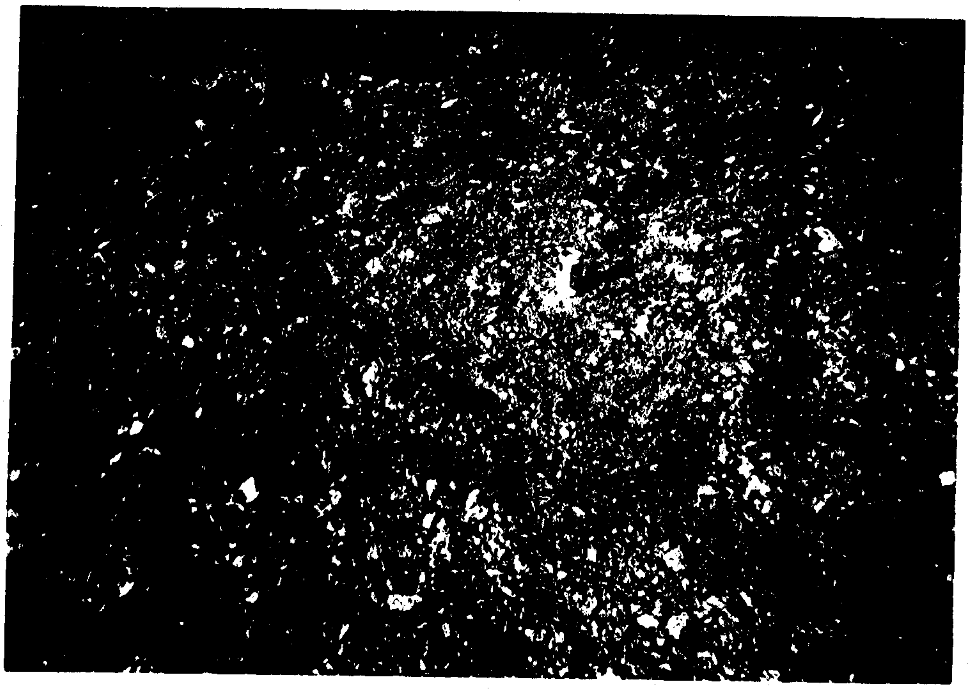

Plate 2: Maize Monocrop

Plate 3: Soyabean Monocrop

Plate 4: Maize-soyabean intercrop

Plate 5 Common bean Monocrop

Plate 6: Maize-Common bean Intercrop

late 7: Sunhemp Monocrop

late 8: Maize-Sunhemp Intercrop